Government of South Australia
Department of Primary Industries and Regions

Our ref: CORP F2025/000265
Receipt No: 22016010

CORPORATE SERVICES
Level 20
11 Waymouth Street
Adelaide SA 5000
GPO Box 1671
Adelaide SA 5001
DX 667
Tel 8429 0422
www.pir.sa.gov.au

3 October 2025

Removed from Disclosure Log

Dear Removed from Disclosure Log

Determination under the *Freedom of Information Act 1991*

I refer to your application made under the *Freedom of Information Act 1991* which was received by the Department of Primary Industries and Regions (PIRSA) on 21 August 2025, seeking access to the following:

> *"Documents in relation to a fine I received for transporting bananas into South Australia at the Dukes Highway roadblock near Bordertown in January 2025.*
>
> *Specifically, I seek access to documents, reports, scientific studies, guidelines, or risk assessments in the possession of PIRSA that form the basis of the enforcement measures which prohibit the carriage of fresh fruit and vegetables across the South Australian border, including:*
>
> *1. Scientific evidence and reports that demonstrate how the introduction of small quantities of fresh fruit or vegetables (e.g. bananas) into South Australia from Victoria presents a risk of introducing or spreading fruit fly or similar pests.*
>
> *2. Risk assessment documents that establish how fresh produce brought into the state by private individuals (in small personal quantities) has been shown to contribute to fruit fly infestations in South Australia.*
>
> *3. Policy or enforcement guidelines used by PIRSA or associated agencies that explain:*
>
> • *Why all quantities of fruit and vegetables (regardless of amount, e.g. 1–3 pieces intended for immediate personal consumption) are prohibited.*
>
> • *The scientific or epidemiological reasoning supporting a zero-tolerance approach.*
>
> *4. Internal or external briefing papers, reports, or reviews that explain how effective border fruit inspections and penalties are in preventing fruit fly infestations in South Australia."*

On 21 August 2025, PIRSA's Records Management and FOI Support Officer contacted you seeking payment of the application fee and confirmation of the timeframe of your request.

Payment was subsequently made when submitting your application through the on-line FOI application system on 21 August 2025.

On 25 August 2025, you clarified that the timeframe is from 1 January 2015 to the present. Following preliminary document searches, it was established that to deal with your application in its original form and with the stipulated timeframe would result in a substantial and unreasonable diversion of agency resources, pursuant to Section 18 of the Freedom of Information Act.

Following further negotiations, on 3 September 2025, the scope of your application was confirmed as being amended as follows:

> *"Documents that support import conditions relating to Fruit Fly host produce and the application of the zero-tolerance approach, specifically:*
>
> 1. *Scientific evidence and reports (including risk assessments and/or the scientific or epidemiological reasoning) that demonstrate how the introduction of small quantities of fresh fruit or vegetables (e.g. 1–3 pieces such as bananas) into South Australia from Victoria presents a risk of introducing or spreading fruit fly or similar pests.*
> 2. *Policy or enforcement guidelines used by PIRSA or associated agencies that explain why all quantities of fruit and vegetables (regardless of amount or intent for immediate consumption) are prohibited.*
> 3. *Internal or external briefing papers, reports, reviews, or evaluations that explain how effective border fruit inspections and infringement penalties are in preventing fruit fly infestations in South Australia."*
>
> Timeframe: 1/01/2017 to 25/8/2025

Subsequently, your application was confirmed as valid on 3 September 2025.

Accordingly, the following determination has been finalised.

I have located twenty-seven documents that are captured within the scope of your request.

Determination 1

I have determined that access to the following documents is **granted in full**:

Doc No.	Description of document	No. of Pages
1	International Standards for Phytosanitary Measures – ISPM 26 – Establishment of pest free areas for fruit flies (Tephritidae) - 2018	57

2	*Plant Health Act 2009* – South Australia – Version 14.12.2017	36
3	*Plant Health Regulations 2022* under the *Plant Health Act 2009* – South Australia – Version 1.8.2022	6
4	Fruit Fly Management for Vegetable Growers Guide – Horticulture Innovation Australia	32
5	International Standard for Phytosanitary Measures – ISPM 4 – Requirements for the Establishment of Pest Free Areas – 2024	12
6	National Fruit Fly Strategy Implementation Report 2021-22 – National Fruit Fly Council	34
7	National Fruit Fly Strategy Implementation Report 2022-23 – National Fruit Fly Council	28
8	PIRSA Plant Quarantine Standard South Australia Version 17.5	146
9	Australian Interstate Quarantine – A Travellers Guide dated September 2021	20
10	Research article - Revised Distribution of *Bactrocera tryoni* in Eastern Australia and Effect on Possible Incursions of Mediterranean Fruit Fly: Development of Australia's Eastern Trading Block – Horticultural Entomology – Bernard C. Dominiak and Richard Mapson – dated 11 October 2017	7
11	PIRSA South Australia's Biosecurity Policy 2024 – 2025	14
12	Victoria's Fruit Fly Strategy 2021 – 2025 – Agriculture Victoria	16
13	The South Australian Government Gazette – *Plant Health Act 2009* Section 7(2) – *Prohibition on Introducing Pest Affected Plants or Plant Related Products* – No. 42 p. 1513 dated 13/6/2024	3
14	Gazettal Notice - *Plant Health Act 2009* Section 4 *Declaration of Pests* dated 7/12/2023	2
15	Gazettal Notice - *Plant Health Act 2009* Section 8 *Declaration of Quarantine Areas*	4
16	Reproductive Capacity of Queensland Fruit Fly *Bactrocera tryoni* Froggatt in Different Host Fruit – A Field Assessment in Southern New South Wales – Bernard C. Dominiak, Brett Kerruish and Daryl Cooper – Vol. 48, 2020	4
17	Current Quarantine and Suspension Distances are Excessive for Incipient Populations of Queensland Fruit Fly (*Bactrocera tryoni* (Froggatt)) (Diptera: Tephritidae) in Southern New South Wales, Australia – Bernard C. Dominiak and Benjamin G. Fanson – *Crop Protection 138* – 4/8/2020	8
18	Predicting Point-Source Invasion Success in the Queensland Fruit Fly (*Bactrocera tryoni*): An Individual-based Modelling Approach – Bernard C. Dominiak and Benjamin G. Fanson – Crop Protection 164 – 22/10/2022	9
19	Research article - Host Reproduction Number as an Indicator of Reproductive Advantage in *Bactrocera dorsalis* over *Bactrocera tryoni* – Can the Concept Elucidate the Invasive Threat in Northern Australia? – Bernard Charles Dominiak – International Journal of Tropical Insect Science – No. 44, 19/2/2024	10

20	Review article - Sequential Invasions by Fruit Flies (Diptera: Tephritidae) in Pacific and Indian Ocean Islands: A Systematic Review – Pierre-Francois Duyck, Herve Jourdan and Christian Mille – Ecology and Evolution – 14/4/2022	10
21	Fruit Flies: Challenges and Opportunities to Stem the Tide of Global Invasions – Nikos T. Papadopoulos, Marc De Meyer, John S. Terblanche and Darren J. Kriticos – Annual Review of Entomology – 2024	19
22	Establishing Criteria for the Management of Tephritid Fruit Fly Outbreaks – Michael D. Ormsby – CABI Agriculture and Bioscience – 2021	22
23	Global Drivers of Historical True Fruit Fly (Diptera: Tephritidae) Invasions – Jiri Trombik, Samuel Ward, Allen L. Norrbom, Andrew M. Liebhold – 7/2/2022	38
24	National Fruit Fly Strategy 2020-25 – National Fruit Fly Council	28

Determination 2

I have determined that access to the following document is **granted in part**:

Doc No.	Description of document	No. of Pages
25	Minute from A/Chief Executive, PIRSA to Minister for Primary Industries and Regional Development dated 28/12/2018 re Zero tolerance approach to fruit fly quarantine restrictions	4

The information removed from the above document is pursuant to Clause 6(1) of Schedule 1 of the Freedom of Information Act which states:

> *"**6 - Documents affecting personal affairs***
> *(1) A document is an exempt document if it contains matter the disclosure of which would involve the unreasonable disclosure of information concerning the personal affairs of any person (living or dead)."*

The information removed consists of the mobile telephone numbers of Departmental officers.

As a mobile telephone number allows a person, including an officer of an agency, to be contacted outside of business hours and is information that is not ordinarily available to the public, the information is taken to concern the personal affairs of an individual. Accordingly, it is considered that disclosure of this information would be an unreasonable intrusion into the privacy rights of the individuals concerned.

Determination 3

I have determined that access to the following document is **refused**:

Doc No.	Description of document	No. of Pages
26	Australia's Fruit Fly Management System – Issues Arising from Detections and Outbreaks of Fruit Fly 2017/18 - Draft	16

Access to the above document is refused pursuant to Clause 5(1)(a)(i) and Clause 7(1)(c) of Schedule 1 of the Freedom of Information Act.

The document consists of a draft document regarding the management of fruit fly detections and outbreaks and was for discussion at a forthcoming meeting of representatives from the Commonwealth and state and territory governments.

Clause 5(1)(a)(i) states:

> ***"5—Documents affecting inter-governmental or local government relations***
> *(1) A document is an exempt document if it contains matter—*
> *(a) the disclosure of which -*
> *(i) could reasonably be expected to cause damage to intergovernmental relations; and*
> *(b) the disclosure of which would, on balance, be contrary to the public interest."*

In addressing the public interest test for the Clause 5(1)(a)(i) exemption, I have balanced the following factors:

In favour of the public interest:

- Meeting the objects of the Freedom of Information Act favouring access to documents.
- Ensuring optimal use of public resources.
- High level of interest in the accountability of public office holders.
- The importance of transparency and openness and the interest that the public has in the decision-making processes of Government.
- The knowledge that government agencies are working together in managing detections and outbreaks of fruit fly across Australia.

Contrary to the public interest:

- The report clearly indicates that it is to be treated confidentially and circulated responsibly as its contents may have adverse consequences for Australia's international relationships. It was not intended for distribution into the wider community.
- The need to preserve confidentiality of information being shared between government agencies on sensitive matters.
- The information is not of public knowledge.

- The release of this information could prejudice the future supply and flow of information between Commonwealth and state/territory government agencies as the information was being provided in good faith to jurisdictions and may not be as easily shared in the future if there is a concern that information will be divulged into the public domain.
- Release of this information would affect PIRSA's relations with the Department of Agriculture, Fisheries and Forestry (DAFF) as it would deter DAFF from providing similar information to the South Australian Government in the future
- Disclosure would impede DAFF's ability to promptly manage emergency responses with other states and territories.
- Protecting the interests of the horticulture industry.
- The release of this information would undermine the government's efforts in addressing biosecurity responses.
- It is expected that disclosure would harm inter-governmental relationships with the Commonwealth Government resulting in agencies reconsidering their position regarding their future interactions with the South Australian Government.
- To release this information prematurely would undermine the government's efforts in addressing the biosecurity risk and harm inter-governmental relationships with the Commonwealth Government resulting in agencies reconsidering their position regarding their future interactions with the South Australia Government.
- The release of this information would undermine the efforts of the Commonwealth Government and the States/Jurisdictions in managing fruit fly across Australia.

Having considered the various factors weighing for and against disclosure, I have determined that disclosure of this document would, on balance, be contrary to the public interest.

Clause 7(1)(c) states:

> *"**7 – Documents affecting business affairs***
> *(1) A document is an exempt document –*
> *(c) if it contains matter –*
> *(i) consisting of information (other than trade secrets or information referred to in paragraph (b)) concerning the business, professional, commercial or financial affairs of any agency or any other person; and*
> *(ii) the disclosure of which –*
> *(A) could reasonably be expected to have an adverse effect on those affairs or to prejudice the future supply of such information to the Government or to an agency; and*
> *(B) would, on balance, be contrary to the public interest"*

In addressing the public interest test requirement for this exemption, I have balanced the following factors:

In favour of the public interest:

- Meeting the objects of the Freedom of Information Act favouring access to documents.
- Ensuring optimal use of public resources.
- High level of interest in the accountability of public office holders.
- The importance of transparency and openness and the interest that the public has in the decision-making processes of Government.
- High level of community interest in managing fruit fly outbreaks.

Contrary to the public interest:

- The report clearly indicates that it is trade sensitive as its contents may have adverse consequences for Australia's international relationships.
- The release of this information has the potential to have a major impact on the capacity for South Australia and Australia to trade competitively in domestic and international agricultural markets. Such impacts on export markets would affect the State's agricultural industry and have a substantial adverse effect on the business and financial affairs of producers.
- The disclosure of such details could jeopardise domestic and international market access, including for fruit from South Australia's horticulture growing regions.
- Disclosure of this information could reasonably be expected to cause damage to relations with industry organisations and producers.
- The release of this information would undermine the Government's efforts in managing fruit fly detections and outbreaks.

Having considered the various factors weighing for and against disclosure, I have determined that disclosure of this document would, on balance, be contrary to the public interest.

Determination 4

I have determined that access to the following document is **refused**:

Doc No.	Description of document	No. of Pages
27	Operations Standard No. 1 – Pest Free Areas – NFFPD-POL-001 – Version 4.0	33

Access to the above document is refused pursuant to Clause 5(1)(a)(i) and Clause 7(1)(c) of Schedule 1 of the Freedom of Information Act.

The document consists of information that is confidential and is not intended for distribution.

In addressing the public interest test for the Clause 5(1)(a)(i) exemption, I have balanced the following factors:

In favour of the public interest:

- Meeting the objects of the Freedom of Information Act favouring access to documents.
- Ensuring optimal use of public resources.
- High level of interest in the accountability of public office holders.
- The importance of transparency and openness and the interest that the public has in the decision-making processes of Government.
- The knowledge that government agencies are working together in managing detections and outbreaks of fruit fly across Australia.

Contrary to the public interest:

- The report clearly indicates that it is to be treated confidentially and is not for distribution as its contents may have adverse consequences for Australia's international relationships. It was not intended for distribution into the wider community.
- The need to preserve confidentiality of information being shared between government agencies on sensitive matters.
- The information is not of public knowledge.
- The release of this information could prejudice the future supply and flow of information between Commonwealth and state/territory government agencies as the information was being provided in good faith to jurisdictions and may not be as easily shared in the future if there is a concern that information will be divulged into the public domain.
- Release of this information would affect PIRSA's relations with DAFF as it would deter DAFF from providing similar information to the South Australian Government in the future
- Disclosure would impede DAFF's ability to promptly manage emergency responses with other states and territories.
- Protecting the interests of the horticulture industry.
- The release of this information would undermine the government's efforts in addressing biosecurity responses.
- It is expected that disclosure would harm inter-governmental relationships with the Commonwealth Government resulting in agencies reconsidering their position regarding their future interactions with the South Australian Government.
- To release this information prematurely would undermine the government's efforts in addressing the biosecurity risk and harm inter-governmental relationships with the Commonwealth Government resulting in agencies reconsidering their position regarding their future interactions with the South Australia Government.
- The release of this information would undermine the efforts of the Commonwealth Government and the States/Jurisdictions in managing fruit fly across Australia.

Having considered the various factors weighing for and against disclosure, I have determined that disclosure of this document would, on balance, be contrary to the public interest.

In addressing the public interest test requirement for the Clause 7(1)(c) exemption, I have balanced the following factors:

In favour of the public interest:

- Meeting the objects of the Freedom of Information Act favouring access to documents.
- Ensuring optimal use of public resources.
- High level of interest in the accountability of public office holders.
- The importance of transparency and openness and the interest that the public has in the decision-making processes of Government.
- High level of community interest in managing fruit fly outbreaks.

Contrary to the public interest:

- The release of this information has the potential to have a major impact on the capacity for South Australia and Australia to trade competitively in domestic and international agricultural markets. Such impacts on export markets would affect the State's agricultural industry and have a substantial adverse effect on the business and financial affairs of producers.
- The disclosure of such details could jeopardise domestic and international market access, including for fruit from South Australia's horticulture growing regions.
- Disclosure of this information could reasonably be expected to cause damage to relations with industry organisations and producers.
- The release of this information would undermine the Government's efforts in managing fruit fly detections and outbreaks.

Having considered the various factors weighing for and against disclosure, I have determined that disclosure of this document would, on balance, be contrary to the public interest.

If you are dissatisfied with this determination, you are entitled to exercise your right of review and appeal as outlined in the attached documentation Making a Freedom of Information Application | State Records of South Australia (archives.sa.gov.au), by completing the "FOI Application Form for Internal Review of a Determination" and returning the completed form to:

Freedom of Information Principal Officer
Department of Primary Industries and Regions
GPO Box 1671
ADELAIDE SA 5001

or via email PIRSA.FOI@sa.gov.au

In accordance with the requirements of Premier and Cabinet Circular PC045, details of your application, and the documents to which you are given access, will be published in PIRSA's disclosure log. A copy of PC045 can be found at http://dpc.sa.gov.au/__data/assets/pdf_file/0019/20818/PC045-Disclosure-Log-Policy.pdf

If you disagree with publication, please advise the undersigned in writing within fourteen calendar days from the date of this determination.

Should you require further information or clarification with respect to this matter, please contact Ms Lisa Farley, Senior Freedom of Information Advisor on 8429 0422 or email PIRSA.FOI@sa.gov.au.

Yours sincerely

Michelle Griffiths
Accredited Freedom of Information Officer
DEPARTMENT OF PRIMARY INDUSTRIES AND REGIONS

INTERNATIONAL STANDARDS FOR
PHYTOSANITARY MEASURES

ISPM 26

Establishment of pest free areas for fruit flies (Tephritidae)

Produced by the Secretariat of the
International Plant Protection Convention
Adopted 2015; published 2018

© FAO 2015

FAO encourages the use, reproduction and dissemination of material in this information product. Except where otherwise indicated, material may be copied, downloaded and printed for private study, research and teaching purposes, or for use in non-commercial products or services, provided that appropriate acknowledgement of FAO as the source and copyright holder is given and that FAO's endorsement of users' views, products or services is not implied in any way.

When this ISPM is reproduced, it should be mentioned that current adopted versions of ISPMs are available for download on www.ippc.int.

All requests for translation and adaptation rights, and for resale and other commercial use rights should be made via www.fao.org/contact-us/licence-request or addressed to copyright@fao.org.

FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org.

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned. The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

Publication history

This is not an official part of the standard

2004-04 ICPM-6 added topic *Pest free areas and systems approached for fruit flies* (2004-027).

2004-09 TPFF developed the draft text.

2004-11 SC approved Specification 27 *Pest free areas for fruit flies.*

2005-04 SC revised draft and approved for member consultation.

2005-06 Member consultation.

2005-09 TPFF revised draft text.

2005-11 SC approved draft to be submitted for adoption.

2006-04 CPM-1 revised and adopted standard.

ISPM 26. 2006. *Establishment of pest free areas for fruit flies* (*Tephritidae*). Rome, IPPC, FAO.

2006-04 CPM-1 added topic *Trapping procedures for fruit flies* (2006-037).

2006-05 SC approved Specification 35 *Trapping procedures for fruit flies of the family Tephritidae.*

2007-12 TPFF developed draft text cooperated with IAEA.

2008-05 SC approved draft for member consultation.

2008-06 Member consultation.

2009-05 SC revised draft and proposed as Appendix to ISPM 26.

2009-05 SC-7 revised draft.

2009-11 SC revised draft.

2010-03 CPM-5 reviewed draft and returned to SC with guidance for modifications.

2010-04 SC reviewed draft and returned to TPFF.

2010-10 TPFF revised draft.

2010-11 SC approved draft to be submitted for adoption.

2011-03 CPM-6 revised and adopted Appendix 1.

2009-11 SC introduced topic *Establishment and maintenance of regulated areas upon outbreak detection in fruit fly free areas* (2009-007).

2010-03 CPM-5 added topic (2009-007).

2010-11 SC approved draft specification for member consultation.

2011-02 Member consultation

2011-05 SC revised and approved Specification 53.

2011-08 TPFF developed draft text.

2012-04 SC revised and approved draft for member consultation.

2012-06 Member consultation.

2013-03 TPG reviewed comments.

2013-05 SC-7 approved for Substantial concerns commenting period.

2013-10 Substantial concerns commenting period.

2013-11 SC approved draft to be submitted for adoption.

2014-04 CPM-9 adopted Annex 2.

2014-07 Secretariat corrected error in table of contents.

2005-11 SC recommended topic: *Suppression and eradication procedures for fruit flies* (2005-010) to be added to the work programme.

2006-04 CPM-1 (2006) added topic (2005-010).

2006-11 SC approved Specification 39.

2009-09 TPFF drafted text.

2011-01 TPFF recommended draft ISPM *Phytosanitary Procedures for Fruit Fly (Tephritidae) Management* (2005-010) to SC as an annex to ISPM 26.

2011-05 SC noted TPFF recommendation.

2012-04 SC reviewed draft ISPM and returned it to steward for redrafting.

2012-12 Steward revised draft in consultation with TPFF.

2013-05 SC revised in meeting and approved for MC.

2013-07 MC.

2014-02 Steward revised draft ISPM.

2014-05 SC-7 revised and approved for SCCP.

2014-07 SCCP.

2014-11 Steward revised draft after SCCP.

2014-11 SC revised and approved for CPM adoption.

2015-03 CPM adopted Annex 3.

2015-03 CPM-10 noted ink amendments in relation to “phytosanitary status”.

2015-04 IPPC Secretariat incorporated ink amendments and reformatted standards following revoking of standards procedure from CPM-10 (2015).

2018-04 CPM-13 noted ink amendments in relation to reorganization, harmonization and minor technical updates of the fruit flies ISPMs and revoked previous version of ISPM 26.

2018-09 IPPC Secretariat incorporated ink amendments and applied minor edits.

Publication history last updated: 2018-10.

CONTENTS

Adoption 7

INTRODUCTION 7

Scope 7

References 7

Definitions 7

Outline of Requirements 7

BACKGROUND 8

REQUIREMENTS 8

1. General Requirements 8
   1.1 Public awareness 9
   1.2 Documentation and record keeping 9
   1.3 Supervision activities 9
2. Specific Requirements 9
   2.1 Characterization of the FF-PFA 9
   2.2 Establishment of the FF-PFA 10
   2.2.1 Buffer zone 10
   2.2.2 Surveillance activities before establishment 10
   2.2.3 Controls on the movement of regulated articles 13
   2.2.4 Additional technical information for the establishment of an FF-PFA 13
   2.2.5 Domestic declaration of pest freedom 13
   2.3 Maintenance of the FF-PFA 13
   2.3.1 Surveillance for the maintenance of the FF-PFA 13
   2.3.2 Controls on the movement of regulated articles 14
   2.3.3 Corrective actions (including response to an outbreak) 14
   2.4 Suspension, reinstatement or revocation of an FF-PFA status 14
   2.4.1 Suspension 14
   2.4.2 Reinstatement 14
   2.4.3 Revocation 15

ANNEX 1: Corrective action plans 16

1. Actions to apply the corrective action plan 16

ANNEX 2: Control measures for an outbreak within a fruit fly pest free area (2014) 18

1. Establishment of an Eradication Area 18
2. Control Measures 19
   2.1 Production 19
   2.2 Movement of regulated articles 20
   2.3 Packing and packing facilities 20
   2.4 Storage and storage facilities 20
   2.5 Processing and processing facilities 20
   2.6 Treatment and treatment facilities 21

2.7 Sale inside the eradication area 21
3. Documentation and Record Keeping 21
4. Termination of Control Measures in the Eradication Area 21
ANNEX 3: Phytosanitary procedures for fruit fly management (2015) 22
1. Objectives of Fruit Fly Management Strategies 22
1.1 Suppression 22
1.2 Containment 22
1.3 Eradication 22
1.4 Exclusion 23
2. Requirements for the Application of the Phytosanitary Procedures 23
2.1 Fruit fly identification capabilities 23
2.2 Knowledge of fruit fly biology 23
2.3 Area delimitation 23
2.4 Stakeholder participation 23
2.5 Public awareness 23
2.6 Operational plans 23
3. Phytosanitary Procedures Used in Fruit Fly Management Strategies 23
3.1 Mechanical and cultural controls 24
3.2 Insecticide bait application technique 24
3.2.1 Ground application 24
3.2.2 Aerial application 25
3.3 Bait stations 25
3.4 Male annihilation technique 25
3.5 Mass trapping 25
3.6 Sterile insect technique 25
3.6.1 Sterile fruit fly release 26
3.6.2 Sterile fruit fly quality control 26
3.7 Biological control 26
3.8 Controls on the movement of regulated articles 27
4. Materials Used in the Phytosanitary Procedures 27
5. Verification and Documentation 27
6. References 27
APPENDIX 1: Fruit fly trapping (2011) 28
1. Pest Status and Survey Types 28
2. Trapping Scenarios 29
3. Trapping Materials 29
3.1 Attractants 29
3.1.1 Male-specific attractants 30
3.1.2 Female-biased attractants 30
3.2 Killing and preserving agents 37
3.3 Commonly used fruit fly traps 37

3.3.1 Cook and Cunningham trap....37
3.3.2 ChamP trap....38
3.3.3 Easy trap....38
3.3.4 Fluorescent yellow sticky “cloak” trap....39
3.3.5 Jackson trap or Delta trap....39
3.3.6 Lynfield trap....40
3.3.7 McPhail trap....40
3.3.8 Modified funnel trap....42
3.3.9 Multilure trap....42
3.3.10 Open bottom dry trap or Phase IV trap....43
3.3.11 Red sphere trap....43
3.3.12 Sensus trap....44
3.3.13 Steiner trap....44
3.3.14 Tephri trap....44
3.3.15 Yellow panel trap and Rebell trap....45
4. Trapping Procedures....46
4.1 Spatial distribution of traps....46
4.2 Trap deployment....46
4.3 Trap mapping....47
4.4 Trap servicing and inspection....47
4.5 Trapping records....48
4.6 Flies per trap per day....48
5. Trap Densities....49
6. Supervision Activities....53
7. Bibliography....54
APPENDIX 2: Fruit sampling....57

Adoption

This standard was adopted by the First Session of the Commission on Phytosanitary Measures in April 2006. Revision of Appendix 1 was adopted by the Sixth Session of the Commission on Phytosanitary Measures in March 2011. Annex 2 was adopted by the Ninth Session of the Commission on Phytosanitary Measures in April 2014. Annex 3 was adopted by the Tenth Session of the Commission on Phytosanitary Measures in March 2015.

INTRODUCTION

Scope

This standard provides guidance for the establishment of pest free areas for fruit flies (Tephritidae) of economic importance, and for the maintenance of their pest free status.

References

The present standard refers to ISPMs. ISPMs are available on the International Phytosanitary Portal (IPP) at https://www.ippc.int/core-activities/standards-setting/ispms.

IPPC. 1997. *International Plant Protection Convention*. Rome, IPPC, FAO.

Definitions

Definitions of phytosanitary terms used in this standard can be found in ISPM 5 (*Glossary of phytosanitary terms*).

Outline of Requirements

The general requirements for establishing a fruit fly pest free area (FF-PFA) include:

- the preparation of a public awareness programme
- the management elements of the system (documentation and review systems, recordkeeping)
- supervision activities.

The major elements of an FF-PFA are:

- the characterization of the FF-PFA
- the establishment and maintenance of the FF-PFA.

These elements include the surveillance activities of fruit fly trapping (described in Appendix 1) and fruit sampling (described in Appendix 2), and official control on the movement of regulated articles.

Additional elements include: corrective action planning, and suspension, reinstatement (if possible) and revocation of pest free status of the FF-PFA. Corrective action plans are described in Annex 1, control measures for an outbreak within a fruit fly pest free area in Annex 2 and phytosanitary procedures for fruit fly management in Annex 3.

BACKGROUND

Fruit flies are a very important group of pests for many countries because of their potential to cause damage in fruits and to their potential to restrict access to international markets for plant products that can host fruit flies. The high probability of introduction of fruit flies associated with a wide range of hosts results in restrictions imposed by many importing countries on accepting fruits from areas in which these pests are established. For these reasons, there is a need for an ISPM that provides specific guidance for the establishment and maintenance of pest free areas for fruit flies.

A pest free area is "an area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained" (ISPM 5). Areas initially free from fruit flies may remain naturally free from fruit flies as a result of the presence of barriers or climatic conditions, and/or may be maintained free through movement restrictions and related measures (though fruit flies have the potential to establish there) or may be made free by an eradication programme (ISPM 9 (*Guidelines for pest eradication programmes*)). ISPM 4 (*Requirements for the establishment of pest free areas*) describes different types of pest free areas and provides general guidance on the establishment of pest free areas. However, a need for additional guidance on the establishment and maintenance of pest free areas specifically for fruit flies was recognized. This standard describes additional requirements for the establishment and maintenance of FF-PFAs. The target pests for which this standard was developed include insects of the order Diptera, family Tephritidae, genera *Anastrepha*, *Bactrocera*, *Ceratitis*, *Dacus*, *Rhagoletis* and *Toxotrypana*.

The establishment and maintenance of an FF-PFA implies that no other phytosanitary measures specific for the target species are required for host commodities within the pest free area.

REQUIREMENTS

1. General Requirements

The concepts and provisions of ISPM 4 apply to the establishment and maintenance of pest free areas for all pests, including fruit flies, and therefore ISPM 4 should be referred to in conjunction with this standard.

Phytosanitary measures and specific procedures as further described in this standard may be required for the establishment and maintenance of an FF-PFA. The decision to establish an FF-PFA may be made based on the technical factors provided in this standard. They include components such as pest biology, size of the area, pest population levels and dispersal pathway, ecological conditions, geographical isolation and availability of methods for pest eradication.

FF-PFAs may be established in accordance with this ISPM under a variety of situations. Some of them require the application of the full range of elements provided by this standard; others require only the application of some of these elements.

In areas where the fruit flies concerned are not capable of establishment because of climatic, geographical or other reasons, there should be no records of presence and it may be reasonable to conclude that the pest is absent (ISPM 8 (*Determination of pest status in an area*)). If, however, the fruit flies are detected and can cause economic damage during a season (Article VII.3 of the IPPC), corrective actions should be applied in order to allow the maintenance of an FF-PFA.

In areas where the fruit flies are capable of establishment and known to be absent, general surveillance in accordance with ISPM 8 is normally sufficient for the purpose of delimiting and establishing a pest free area. Where appropriate, import requirements and/or domestic movement restrictions against the introduction of the relevant fruit fly species into the area may be required to maintain the area free from the pest.

1.1 Public awareness

A public awareness programme is most important in areas where the risk of introduction is higher. An important factor in the establishment and maintenance of FF-PFAs is the support and participation of the public (especially the local community) close to the FF-PFA and individuals who travel to or through the area, including parties with direct and indirect interests. The public and stakeholders should be informed through different media (written, radio, television) of the importance of establishing and maintaining the pest free status of the area, and of avoiding the introduction or reintroduction of potentially infested host material. This may contribute to and improve compliance with the phytosanitary measures for the FF-PFA. The public awareness and phytosanitary education programme should be ongoing and may include information on:

- permanent or random checkpoints
- posting signs at entry points and transit corridors
- disposal bins for host material
- leaflets or brochures with information on the pest and the pest free area
- publications (e.g. print, electronic)
- systems to regulate fruit movement
- non-commercial hosts
- security of the traps
- penalties for non-compliance, where applicable.

1.2 Documentation and record keeping

The phytosanitary measures used for the establishment and maintenance of an FF-PFA should be adequately documented as part of phytosanitary procedures. They should be reviewed and updated regularly, and include corrective actions, if required (see also ISPM 4).

The records of surveys, detections, occurrences or outbreaks and results of other operational procedures should be retained for at least 24 months. Such records should be made available to the national plant protection organization (NPPO) of the importing country on request.

1.3 Supervision activities

The FF-PFA programme, including regulatory control, surveillance procedures (e.g. trapping, fruit sampling – see details in Appendix 1 and Appendix 2, respectively) and corrective action planning should comply with officially approved procedures.

Such procedures should include delegation of responsibility assigned to key personnel, for example:

- a person with defined authority and responsibility to ensure that the procedures are implemented and maintained appropriately
- entomologist(s) with responsibility for the authoritative identification of fruit flies to species level.

The effectiveness of the programme should be monitored periodically by the NPPO of the exporting country, through review of documentation and procedures.

2. Specific Requirements

2.1 Characterization of the FF-PFA

The determining characteristics of the FF-PFA include:

- the target fruit fly species and its distribution within or adjacent to the area
- commercial and non-commercial host species

- delimitation of the area (detailed maps or global positioning system (GPS) coordinates showing the boundaries, natural barriers, entry points and host area locations, and, where necessary, buffer zones)
- climate, for example rainfall, relative humidity, temperature, prevailing wind speed and direction.

Further guidance on establishing and describing a pest free area is provided in ISPM 4.

2.2 Establishment of the FF-PFA

The following should be developed and implemented when establishing an FF-PFA:

- surveillance activities for the establishment of the FF-PFA
- delimitation of the FF-PFA
- phytosanitary measures related to movement of host material or regulated articles
- pest suppression and eradication techniques, as appropriate.

The establishment of buffer zones may also be necessary (as described in section 2.2.1) and it may be useful to collect additional technical information during the establishment of the FF-PFA.

2.2.1 Buffer zone

In areas where geographic isolation is not considered adequate to prevent introduction to or reinfestation of a pest free area or where there are no other means of preventing fruit fly movement to the pest free area, a buffer zone should be established. Factors that should be considered in the establishment and effectiveness of a buffer zone include:

- pest suppression techniques, which may be used to reduce the fruit fly population, including:
  - use of selective insecticide bait
  - spraying
  - sterile insect technique
  - male annihilation technique
  - biological control
  - mechanical control, etc.
- host availability, cropping systems, natural vegetation
- climatic conditions
- the geography of the area
- the capacity for natural spread through identified pathways
- the ability to implement a system to monitor the effectiveness of buffer zone establishment (e.g. trapping network).

2.2.2 Surveillance activities before establishment

A regular survey programme should be established and implemented. Trapping is the preferred option to determine fruit fly absence or presence in an area for lure or bait-responsive species. However, fruit sampling activities may sometimes be required to complement the trapping programme in cases where trapping is less effective, for example when species are less responsive to specific lures.

Before the establishment of an FF-PFA, surveillance should be undertaken for a period determined by the climatic characteristics of the area, and as technically appropriate, for at least 12 consecutive months in the FF-PFA in all relevant areas of commercial and non-commercial host plants to demonstrate that the pest is not present in the area. There should be no populations detected during the surveillance activities before establishment. A single adult detection, depending on its status (in accordance with ISPM 8), may not disqualify an area from subsequent designation as an FF-PFA. For qualifying the area as a pest free area, there should be no detection of an immature specimen, two or

more fertile adults, or an inseminated female of the target species during the survey period. There are different trapping and fruit sampling regimes for different fruit fly species. Surveys should be conducted following the guidance in Appendix 1 and Appendix 2. These appendices may be revised as trap, lure and fruit sampling efficiencies improve.

2.2.2.1 Trapping procedures

This section contains general information on trapping procedures for target fruit fly species. Trapping conditions may vary depending on, for example, the target fruit fly and environmental conditions. More information is provided in Appendix 1. When planning for trapping, the following should be considered.

Trap type and lures

Several types of traps and lures have been developed over decades to survey fruit fly populations. Fly catches differ depending on the types of lure used. The type of trap chosen for a survey depends on the target fruit fly species and the nature of the attractant. The most widely used traps include Jackson, McPhail, Steiner, open bottom dry trap, yellow panel traps, which may use specific attractants (parapheromone or pheromone lures that are male specific), or food or host odours (liquid protein or dry synthetic protein). Liquid protein is used to catch a wide range of different fruit fly species and to capture both females and males, with a slightly higher percentage of females captured. However, identification of the fruit flies can be difficult because of decomposition within the liquid bait. In traps such as McPhail, ethylene glycol may be added to delay decomposition. Dry synthetic protein baits are female biased, capture fewer non-target organisms and, when used in dry traps, may prevent premature decomposition of captured specimens.

Trap density

Trap density (number of traps per unit area) is a critical factor for effective fruit fly surveys and it should be designed based on target fruit fly species, trap efficiency, cultivation practices, and other biotic and abiotic factors. Density may change depending on the programme phase, with different densities required during the establishment of an FF-PFA and the maintenance phase. Trap density also depends on the risk associated with potential pathways for entry into the designated pest free area.

Trap deployment

In an FF-PFA programme, an extensive trapping network should be deployed over the entire area (i.e. determination of the specific location of the traps). The trapping network layout will depend on the characteristics of the area, host distribution and the biology of the fruit fly of concern. One of the most important features of trap placement is the selection of a proper location and trap site within the host plant. The application of GPS and geographic information systems (GIS) are useful tools for the management of a trapping network.

Trap location should take into consideration the presence of hosts (primary, secondary and occasional) of the target species. Because the pest is associated with maturing fruit, the location, including rotation, of traps should follow the sequence of fruit maturity in host plants. Consideration should be given to commercial management practices in the area where host trees are selected. For example, the regular application of insecticides (and/or other chemicals) to selected host trees may have a false-negative effect on the trapping programme.

Trap servicing

The frequency of trap servicing (maintaining and refreshing the traps) during the period of trapping should depend on the:

- longevity of baits (attractant persistency)
- retention capacity
- rate of catch
- season of fruit fly activity

- placement of the traps
- biology of the species
- environmental conditions.

Trap inspection

The frequency of inspection (checking the traps for fruit flies) during the period of trapping should depend on:

- expected fruit fly activity (biology of the species)
- the response of the target fruit fly in relation to host status (ISPM 37 (*Determination of host status of fruit to fruit flies (Tephritidae)*)) at different times of the year
- the relative number of target and non-target fruit flies expected to be caught in a trap
- type of trap used
- the physical condition of the flies in the trap (and whether they can be identified).

In certain traps, specimens may degrade quickly making identification difficult or impossible unless the traps are checked frequently.

Identification capability

NPPOs should have in place, or have ready access to, adequate infrastructure and trained personnel to identify fruit fly specimens of the target species in an expeditious manner, preferably within 48 hours. Continuous access to expertise may be necessary during the establishment phase or when implementing corrective actions.

2.2.2.2 Fruit sampling procedures

Fruit sampling may be used as a surveillance method in combination with trapping where trapping is less effective. It should be noted that fruit sampling is particularly effective in small-scale delimiting surveys in an outbreak area. However, it is labour-intensive, time consuming and expensive because of the destruction of fruit. It is important that fruit samples should be held in suitable conditions to maintain the viability of all immature stages of fruit flies in infested fruit for identification purposes. Further information is provided in Appendix 2.

Host preference

Fruit sampling should take into consideration the presence of primary, secondary and occasional hosts of the target species. Fruit sampling should also take into account the maturity of fruit, apparent signs of infestation in fruit, and commercial practices (e.g. application of insecticides) in the area.

High-risk areas

Fruit sampling should be targeted to areas likely to have presence of infested fruits such as:

- urban areas
- abandoned orchards
- rejected fruit at packing facilities
- fruit markets
- sites with a high concentration of primary hosts
- entrance points in to the FF-PFA, where appropriate.

The sequence of hosts that are likely to be infested by the target fruit fly species in the area should be used as fruit sampling areas.

Sample size and selection

Factors to be considered include:

- the required level of confidence

- the availability of primary host material in the field
- fruits with symptoms on trees, fallen or rejected fruit (e.g. at packing facilities), where appropriate.

Procedures for processing sampled fruit for inspection

Fruit samples collected in the field should be brought to a facility for holding, fruit dissection, and pest recovery and identification. Fruit should be labelled, transported and held in a secure manner to avoid mixing fruits from different samples.

Identification capability

NPPOs should have in place, or have ready access to, adequate infrastructure and trained personnel to identify fruit fly immature stages and emerged adults of the target species in an expeditious manner.

2.2.3 Controls on the movement of regulated articles

Controls on the movement of regulated articles should be implemented to prevent the entry of target pests into the FF-PFA. These controls depend on the assessed risks (after identification of likely pathways and regulated articles) and may include:

- listing of the target fruit fly species on a quarantine pest list
- regulation of the pathways and articles that require control to maintain the FF-PFA
- domestic restrictions to control the movement of regulated articles into the FF-PFA
- inspection of regulated articles, examination of relevant documentation as appropriate and, where necessary for cases of non-compliance, the application of appropriate phytosanitary measures (e.g. treatment, refusal or destruction).

2.2.4 Additional technical information for the establishment of an FF-PFA

Additional information that may be useful during the establishment phase of FF-PFAs includes:

- historical records of detection, biology and population dynamics of the target pest(s), and survey activities for the designated target pest(s) in the FF-PFA
- the results of phytosanitary measures taken as part of actions following detections of fruit flies in the FF-PFA
- records of the commercial production of host crops in the area, an estimate of non-commercial production and the presence of wild host material
- lists of the other fruit fly species of economic importance that may be present in the FF-PFA.

2.2.5 Domestic declaration of pest freedom

The NPPO should verify the fruit fly free status of the area (in accordance with ISPM 8) specifically by confirming compliance with the procedures established in accordance with this standard (surveillance and controls). The NPPO should declare and notify the establishment of the FF-PFA, as appropriate.

In order to be able to verify the fruit fly free status in the area and for the purpose of internal management, the continuing FF-PFA status should be checked after the FF-PFA has been established and any phytosanitary measures for the maintenance of the FF-PFA have been put in place.

2.3 Maintenance of the FF-PFA

In order to maintain the FF-PFA status, the NPPO should monitor the surveillance and control activities, continuously verifying the pest free status.

2.3.1 Surveillance for the maintenance of the FF-PFA

After verifying and declaring the FF-PFA, the surveillance programme should be continued at a level assessed as being necessary for the maintenance of the FF-PFA. Regular technical reports on the

survey activities should be generated (e.g. monthly). Requirements for this are essentially the same as for the establishment of the FF-PFA (see section 2.2) but with differences in trap density and trap deployment dependent upon the assessed level of risk of introduction of the target species.

2.3.2 Controls on the movement of regulated articles

These are the same as for the establishment of the FF-PFA (provided in section 2.2.3).

2.3.3 Corrective actions (including response to an outbreak)

The NPPO should have plans prepared for corrective actions that may be implemented if the target pest(s) is detected in the FF-PFA or in host material from that area (detailed guidance is provided in Annex 1, Annex 2 and Annex 3), or if faulty procedures are found. These plans should include components or systems to cover:

- outbreak declaration, according to criteria in ISPM 8, and notification
- delimiting surveillance (trapping and fruit sampling) to determine the infested area under corrective actions
- the implementation of control measures
- further surveillance
- criteria for the reinstatement of freedom of the area affected by the outbreak
- responses to interceptions.

A corrective action plan should be initiated as soon as possible and in any case within 72 hours of the detection (of an adult or immature stage of the target pest).

2.4 Suspension, reinstatement or revocation of an FF-PFA status

2.4.1 Suspension

The status of the FF-PFA or the affected part within the FF-PFA should be suspended when an outbreak of the target fruit fly occurs or based on one of the following triggers: detection of an immature specimen of the target fruit fly; detection of two or more fertile adults as demonstrated by scientific evidence; or detection of an inseminated female within a defined period and distance. Suspension may also be applied if procedures are found to be faulty (e.g. inadequate trapping, host movement controls or treatments).

If the criteria for an outbreak are met, this should result in the implementation of the corrective action plan as specified in this standard and immediate notification to interested importing countries' NPPOs (see ISPM 17 (*Pest reporting*)). The whole or part of the FF-PFA may be suspended or revoked. In most cases a suspension radius will delimit the affected part of the FF-PFA. The radius will depend on the biology and ecology of the target fruit fly. The same radius will generally apply for all FF-PFAs for a given target species unless scientific evidence supports any proposed deviation. Where a suspension is put in place, the criteria for lifting the suspension should be made clear. Interested importing countries' NPPOs should be informed of any change in FF-PFA status.

2.4.2 Reinstatement

Reinstatement should be based on requirements for establishment with the following conditions:

- no further detection of the target pest species for a period determined by the biology of the species and the prevailing environmental conditions[1], as confirmed by surveillance, or
- in the case of a fault in the procedures, only when the fault has been corrected.

[1] The period starts from the last detection. For some species, no further detection should occur for at least three life cycles; however, the required period should be based on scientific information, including that provided by the surveillance systems in place.

2.4.3 Revocation

If the control measures are not effective and the pest becomes established in the whole area (the area recognized as pest free), the status of the FF-PFA should be revoked. In order to achieve again the FF-PFA, the procedures of establishment and maintenance outlined in this standard should be followed.

This annex is a prescriptive part of the standard.

ANNEX 1: Corrective action plans

The detection of a single fruit fly (adult or immature stage) of the target species in the FF-PFA should trigger the enforcement of a corrective action plan.

In case of an outbreak, the objective of the corrective action plan is to ensure eradication of the pest to enable reinstatement of the affected area into the FF-PFA.

The corrective action plan should be prepared taking into account the biology of the target fruit fly species, the geography of the FF-PFA area, climatic conditions and host distribution within the area.

The elements required for implementation of a corrective action plan include:

- a legal framework under which the corrective action plan can be applied
- criteria for the declaration of an outbreak
- time scales for the initial response
- technical criteria for delimiting trapping, fruit sampling, application of the eradication actions and establishment of regulatory measures
- the availability of sufficient operational resources
- identification capability
- effective communication within the NPPO and with the NPPO(s) of the importing country(ies), including provision of contact details of all parties involved.

1. Actions to apply the corrective action plan

(1) *Determination of the pest status of the detection (actionable or non-actionable)*

(1.1) If the detection is a transient non-actionable occurrence (ISPM 8), no further action is required.

(1.2) If the detection of a target pest may be actionable, a delimiting survey, which includes additional traps, and usually fruit sampling as well as an increased trap inspection rate, should be implemented immediately after the detection to assess whether the detection represents an outbreak, which will determine necessary responsive actions. If a population is present, this action is also used to determine the size of the affected area.

(2) *Suspension of FF-PFA status*

If after detection it is determined that an outbreak has occurred or any of the triggers specified in section 2.4.1 of this standard is reached, the FF-PFA status in the affected area should be suspended. The affected area may be limited to parts of the FF-PFA or may be the whole FF-PFA.

(3) *Implementation of control measures in the affected area*

As per ISPM 9, specific corrective or eradication actions should be implemented immediately in the affected area and adequately communicated to the community. Eradication actions may include:

- selective insecticide bait treatments
- sterile fly release
- total harvest of fruit in the trees
- male annihilation technique
- destruction of infested fruit
- soil treatment (chemical or physical)
- insecticide application.

Phytosanitary measures should be immediately enforced for control of movement of regulated articles that can host fruit flies. These measures may include the cancellation of shipments of fruit commodities from the affected area and, as appropriate, fruit disinfestation and the operation of road

blocks to prevent the movement of infested fruit from the affected area to the rest of the pest free area. Other measures could be adopted if agreed by the importing country, for example, treatment, increased surveys or supplementary trapping.

(4) *Criteria for reinstatement of an FF-PFA after an outbreak and actions to be taken*

The criteria for determining that eradication has been successful are specified in section 2.4.2 of this standard and should be included in the corrective action plan for the target fruit fly. The time period will depend on the biology of the species and the prevailing environmental conditions. Once the criteria have been fulfilled the following actions should be taken:

- notification of NPPOs of importing countries
- reinstatement of normal surveillance levels
- reinstatement of the FF-PFA.

(5) *Notification of relevant agencies*

Relevant NPPOs and other agencies should be kept informed of any change in FF-PFA status, as appropriate, and IPPC pest reporting obligations observed (ISPM 17).

This annex is a prescriptive part of the standard.

ANNEX 2: Control measures for an outbreak within a fruit fly pest free area (2014)

A fruit fly (Tephritidae) outbreak detected in an FF-PFA may pose a risk for those importing countries where the fruit fly species is considered a quarantine pest. This annex describes control measures to be taken in a fruit fly eradication area established within an FF-PFA in the event of an outbreak.

Corrective actions and other phytosanitary measures that may be used in an eradication area within an FF-PFA are covered by this standard.

The eradication area and the related control measures are established with the intent to eradicate the target fruit fly species and restore FF-PFA status, to protect the surrounding FF-PFA, and to meet the phytosanitary import requirements of the importing country, where applicable. In particular, control measures are needed because movements of regulated articles from and through an eradication area pose a potential risk of spreading the target fruit fly species.

1. Establishment of an Eradication Area

The NPPO of the exporting country should declare an outbreak in accordance with this and other relevant ISPMs (e.g. ISPM 8, ISPM 9, ISPM 17). When a target fruit fly species outbreak is detected within an FF-PFA, an eradication area should be established based on a technical evaluation. The pest free status of the eradication area should be suspended. If control measures cannot be applied to establish an eradication area, then the status of the FF-PFA should be revoked in accordance with this standard.

The eradication area should cover the infested area. In addition, a buffer zone should be established in accordance with this standard, and as determined by delimiting surveys, taking into account the natural dispersal capability of the target fruit fly species, its relevant biological characteristics, and geographical and environmental factors.

A circle delimiting the minimum size of the eradication area should be drawn, centred on the actual target fruit fly species detection and with a radius large enough to comply with the above considerations, as determined by the NPPO of the exporting country. In the case of several pest detections, several (possibly overlapping) circles should be drawn accordingly, as illustrated in Figure 1.

If necessary for the practical implementation of the eradication area, the NPPO of the exporting country may decide to adjust the eradication area to correspond to administrative boundaries or topography, or to approximate the circle with a polygon.

A georeferencing device (e.g. GPS) or map with geographical coordinates may be used for delimiting and enabling recognition of the eradication area. Signposts may be placed along boundaries and on roads to alert the public, and notices may be published to facilitate public awareness.

The NPPO of the exporting country should inform the NPPO of the importing country when a fruit fly outbreak is confirmed and an eradication area is established within an FF-PFA.

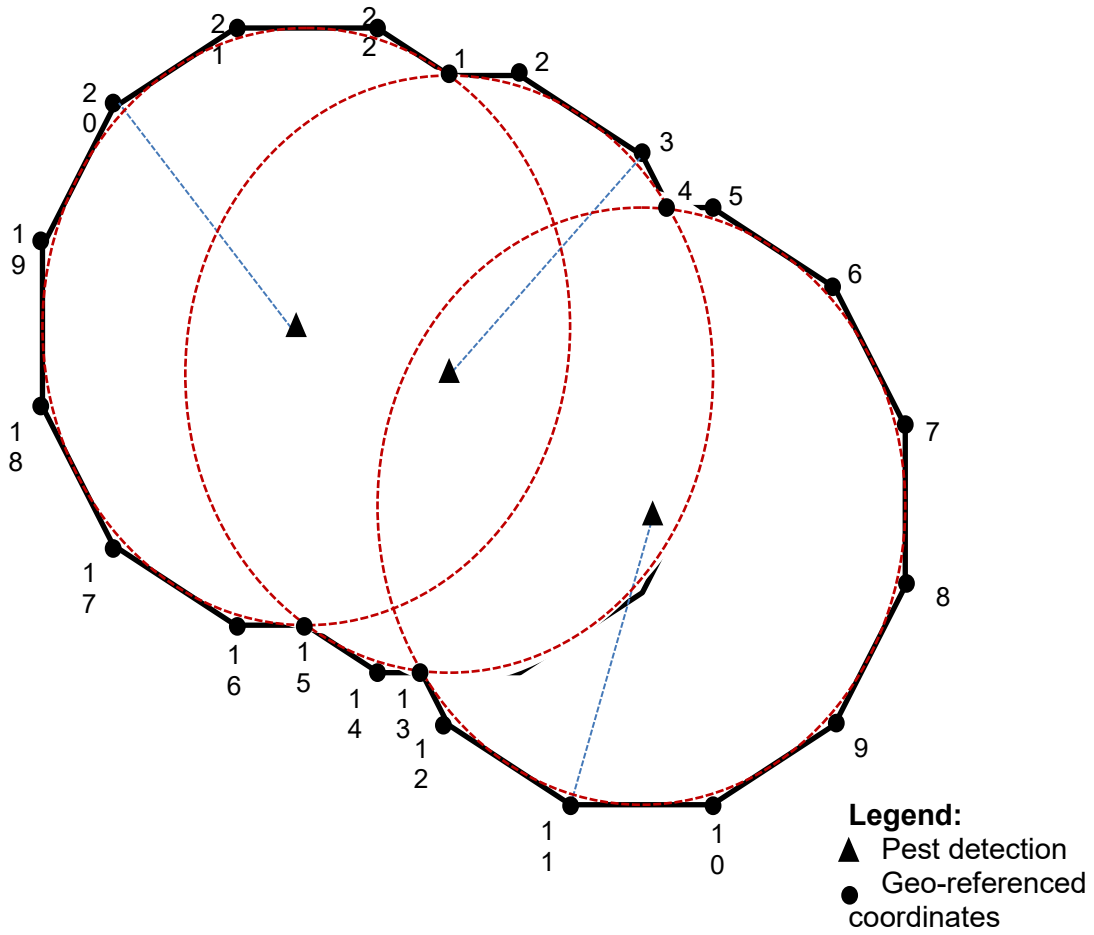


Figure 1. Example of delimiting circles and approximating polygons to determine the eradication area around three pest detections.

2. Control Measures

Each stage of the production chain (e.g. growing, sorting, packing, transporting, dispatching) may lead to spread of the target fruit fly species from the eradication area into the FF-PFA. This statement does not apply to any facilities located in the FF-PFA and handling only host fruit from the FF-PFA. Appropriate control measures should be applied to manage the pest risk for the surrounding FF-PFA and the importing country.

Control measures in use in other fruit fly-infested areas may be implemented in the eradication area.

Control measures may be audited by the NPPO of the importing country, in accordance with the NPPO of the exporting country's requirements.

Control measures applied at each stage of the production chain are described in the following sections.

2.1 Production

During the production period, within the eradication area, the NPPO of the exporting country may require control measures to avoid infestation, such as mechanical and cultural controls, insecticide bait application technique, bait stations, male annihilation technique, mass trapping, sterile insect technique and biological control (details on these control measures are provided in Annex 3 of this standard).

2.2 Movement of regulated articles

Movement of regulated articles (e.g. soil, host plants, host fruit) into, from, through or within the eradication area should comply with control measures to prevent the spread of the target fruit fly species and should be accompanied by the necessary documentation to indicate the articles' origin and destination. This also pertains to moving regulated articles for phytosanitary certification.

2.3 Packing and packing facilities

Fruit packing facilities may be located within or outside the eradication area and may pack host fruit grown in or outside the eradication area. Control measures preventing spread of the target fruit fly species should be taken into account in each case.

The NPPO of the exporting country should:

- register the facility
- require control measures to prevent the target fruit fly species from entering or escaping the facility, as appropriate
- require and approve methods of physical separation of different host fruit lots (e.g. by using insect-proof packaging) to avoid cross-contamination
- require appropriate measures to maintain segregation of host fruits originating from areas of different pest status (e.g. separate locations for reception, processing, storage and dispatch)
- require appropriate measures regarding the handling and movement of host fruit through the facility to prevent mixing of fruit from areas of different pest status (e.g. flowcharts, signs and staff training)
- require and approve methods of disposal of rejected host fruit from the eradication area
- monitor the target fruit fly species at the facility and, if relevant, in the adjacent FF-PFA
- verify the packing material is insect-proof and clean
- require appropriate control measures to eradicate target fruit fly species from the facility when they are detected
- audit the facility.

2.4 Storage and storage facilities

Fruit storage facilities may be located within or outside the eradication area. Such facilities should be registered with the NPPO of the exporting country and comply with the control measures to prevent the spread of the target fruit fly species; for example, they should:

- maintain distinction and separation between host fruit originating from the eradication area and from the FF-PFA
- use an approved method of disposal of host fruit from the eradication area that has been rejected as a result of inspection or quality control activities
- monitor for the target fruit fly species at the facility and if relevant, in the adjacent FF-PFA
- take appropriate control measures to eradicate the target fruit fly species from the facility when detected.

2.5 Processing and processing facilities

If the processing facility is located within the eradication area, host fruit destined for processing (such as juicing, canning and puréeing) does not pose an additional fruit fly risk to the area.

If the facility is located outside the eradication area, the NPPO of the exporting country should require measures within the facility to prevent the escape of the target fruit fly species, through insect-proof reception, storage and processing areas.

Monitoring for the target fruit fly species may be conducted at the facility and, if relevant, in the adjacent FF-PFA. Appropriate control measures should be taken to eradicate target fruit fly species from the facility when they are detected.

Approved disposal of rejected host fruit and plant waste from the eradication area should be required by the NPPO of the exporting country. Rejected host fruit should be disposed of in such a way that the target fruit fly species are rendered non-viable.

2.6 Treatment and treatment facilities

Treatment facilities should be registered by the NPPO of the exporting country.

Post-harvest treatment (e.g. cold treatment, heat treatment, fumigation, irradiation), or in some cases pre-harvest treatment (e.g. bait spray, fruit bagging), may be required for host fruit moving into an FF-PFA or being exported to countries where the target fruit fly species is regulated as a quarantine pest.

Control measures preventing the escape of the target fruit fly species may be required for treatment facilities located within the FF-PFA, if treating regulated articles from the eradication area. The NPPO of the exporting country may require physical isolation within the facility.
The NPPO of the exporting country should approve the method of disposal of rejected host fruit from the eradication area to reduce the risk of spread of the target fruit fly species. Disposal methods may include double bagging followed by deep burial or incineration.

2.7 Sale inside the eradication area

Host fruit sold within the eradication area may be at risk of infestation if exposed before being sold (e.g. placed on display in an open air market) and may therefore need to be physically protected, when feasible, to avoid spread of the target fruit fly species while on display and being stored.

3. Documentation and Record Keeping

The control measures, including corrective actions, used in the eradication area should be adequately documented, reviewed and updated (see also ISPM 4). Such documents should be made available to the NPPO of the importing country on request.

4. Termination of Control Measures in the Eradication Area

Eradication of the target fruit fly species in the eradication area should meet the requirements for reinstatement of an FF-PFA status after an outbreak, according to this standard. The declaration of eradication should be based on no further detections of the target fruit fly species for a period determined by its biology and prevailing environmental conditions, as confirmed by surveillance referred to in this standard.[2]

The control measures should remain in force until eradication is declared. If eradication is successful, the particular control measures in the eradication area may be terminated and the FF-PFA status should be reinstated. If eradication is unsuccessful, the FF-PFA delimitation should be modified accordingly. The NPPO of the importing country should be notified as appropriate.

[2] The period starts from the last detection. For some species, no further detection should occur for at least three life cycles; however, the required period should be based on scientific information, including that provided by the surveillance systems in place.

This annex is a prescriptive part of the standard.

ANNEX 3: Phytosanitary procedures for fruit fly management (2015)

This annex provides guidance for the application of phytosanitary procedures for fruit fly management.

Various phytosanitary procedures are used for fruit fly suppression, containment, eradication and exclusion. These procedures may be applied to establish and maintain FF-PFAs (this standard), and to develop a systems approach for fruit flies, which may include the establishment and maintenance of fruit fly areas of low pest prevalence (FF-ALPPs) (ISPM 35 (*Systems approach for pest risk management of fruit flies (Tephritidae)*)).

The phytosanitary procedures include mechanical and cultural controls, insecticide bait application technique (BAT), bait stations, male annihilation technique (MAT), mass trapping, sterile insect technique (SIT), biological control, and controls on the movement of regulated articles. Many of these procedures can be environmentally friendly alternatives to insecticide application for managing fruit flies.

1. Objectives of Fruit Fly Management Strategies

The four strategies used to manage target fruit fly populations are suppression, containment, eradication and exclusion. One or more of these strategies can be used depending on the circumstances and objectives. The corresponding phytosanitary procedures used for fruit fly management should take into account the phytosanitary import requirements of the importing country, fruit fly status in the target area, hosts, host phenology and host susceptibility, pest biology, and economic and technical feasibility of the available phytosanitary procedures, as relevant.

1.1 Suppression

Suppression strategies may be applied for purposes such as to:

- reduce a target fruit fly population to below an acceptable level
- establish an FF-ALPP (ISPM 22 (*Requirements for the establishment of areas of low pest prevalence*); ISPM 35)
- implement a corrective action in an FF-ALPP when the specified level of low pest prevalence has been exceeded (ISPM 22; ISPM 35)
- reduce a target fruit fly population in order to achieve a specified pest population level that can be used as part of a systems approach (ISPM 14 (*The use of integrated measures in a systems approach for pest risk management*); ISPM 35)
- precede, as part of a process, target fruit fly population eradication in order to establish an FF-PFA (ISPM 4).

1.2 Containment

Containment strategies may be applied for purposes such as to:

- prevent the spread of a target fruit fly from an infested area to an adjacent FF-PFA
- contain an incursion of a target fruit fly into non-infested areas
- protect, as a temporary measure, individual areas where target fruit flies have been eradicated as part of an ongoing eradication programme in a larger area.

1.3 Eradication

Eradication strategies may be applied for purposes such as to:

- eliminate a fruit fly population in order to establish an FF-PFA (ISPM 4)

- eliminate an incursion of a fruit fly species that is a quarantine pest before establishment can occur (this may be part of a corrective action plan in an FF-PFA if the target fruit fly species is detected).

1.4 Exclusion

Exclusion strategies may be applied to prevent the introduction of a fruit fly into an FF-PFA.

2. Requirements for the Application of the Phytosanitary Procedures

The following requirements should be considered when applying phytosanitary procedures for fruit fly management:

2.1 Fruit fly identification capabilities

Accurate identification of the target fruit fly species should be ensured so that the appropriate strategies and phytosanitary procedures can be selected and applied. NPPOs should have access to trained personnel to identify detected specimens of adult and, where possible, immature stages of the target fruit fly species in an expeditious manner (ISPM 6 (*Guidelines for surveillance*)).

2.2 Knowledge of fruit fly biology

The biology of the target fruit fly species should be known in order to determine the appropriate strategy to address its management and select the phytosanitary procedures that will be applied. Basic information on the target fruit fly species may include life cycle, hosts, host sequence, host distribution and abundance, dispersal capacity, geographical distribution and population dynamics. The climatic conditions may also affect the strategy adopted.

2.3 Area delimitation

The area in which the phytosanitary procedures will be applied should be delimited. Geographical characteristics and host distribution within this area should be known.

2.4 Stakeholder participation

Successful implementation of fruit fly phytosanitary procedures requires active and coordinated participation of interested and affected groups, including government, local communities and industry.

2.5 Public awareness

An ongoing public awareness programme should be put in place to inform interested and affected groups about the pest risk and phytosanitary procedures that will be implemented as part of the fruit fly management strategy. Such a programme is most important in areas where the risk of introduction of the target fruit fly species is high. For the success of the management programme it is important to have the support and participation of the public (especially the local community) within the management programme area and of individuals who travel to or through the area.

2.6 Operational plans

An official operational plan that specifies the required phytosanitary procedures should be developed. This operational plan may include specific requirements for the application of phytosanitary procedures and describe the roles and responsibilities of the interested and affected groups (ISPM 4; ISPM 22).

3. Phytosanitary Procedures Used in Fruit Fly Management Strategies

Fruit fly management strategies may involve the use of more than one phytosanitary procedure.

Phytosanitary procedures may be applied in an area, at a place of production or at a production site; during the pre- or post-harvest period; at the packing house; or during shipment or distribution of the commodity. Pest free areas, pest free places of production and pest free production sites may require

the establishment and maintenance of an appropriate buffer zone. Appropriate phytosanitary procedures may be applied in the buffer zone if necessary (this standard and ISPM 10 (*Requirements for the establishment of pest free places of production and pest free production sites*)).

3.1 Mechanical and cultural controls

Mechanical and cultural control procedures may be applied in order to reduce the level of fruit fly populations. These controls include phytosanitary procedures such as orchard and field sanitation, fruit stripping, pruning, host plant removal or netting, fruit bagging, host-free periods, use of resistant varieties, trap cropping, ploughing and ground swamping.

The effectiveness of field sanitation increases when the collection and disposal of fallen fruit are focused on the preferred hosts and are done continuously on an area-wide basis. For good results, collection and disposal should be done before, during and after harvest.

Fruit that remains on the host plants after harvest, fruit rejected because of poor quality during harvest and packing, and fruit on host plants present in the surrounding area should be collected and safely disposed of (e.g. by deep burial).

Elimination or maintaining a low level of vegetation at the place of production will facilitate collection of fallen fruit. In addition, when vegetation is kept low fallen fruit with larvae may be more exposed to direct sunlight and natural enemies, which will contribute to fruit fly larvae mortality.

Bagging of fruit and use of exclusion netting can prevent fruit fly infestation of the fruit. Where used, bagging or exclusion netting should be carried out before the fruit becomes susceptible to fruit fly infestation.

The pupae of many fruit flies can be targeted by disturbing the soil medium in which they pupate. This can be done by ground swamping (causing pupae anoxia) or ploughing (causing physical damage, desiccation to the pupae and exposing them to natural enemies).

3.2 Insecticide bait application technique

BAT uses an appropriate insecticide mixed together with a food bait. Commonly used food baits include attractants such as hydrolysed protein, high-fructose syrup and molasses, used alone or in combination. This technique is an effective control of adult fruit fly populations and reduces the negative impacts on non-target insects and the environment.

Insecticide bait applications should start in time to target maturing adults and to prevent the infestation of fruit. For fruit protection this may be up to three months before the beginning of the harvesting season for fruit intended for export or on detection of the first adult flies or larvae in the field or urban area. Maturing adults should be targeted as this is when protein demands are at their highest. The number of and intervals between applications will depend on the characteristics of the target fruit fly species (biology, abundance, behaviour, distribution, life cycle, etc.), host phenology and weather conditions.

Insecticide baits can be applied from the ground or from the air.

3.2.1 Ground application

Ground application of insecticide bait is usually used for relatively small production areas, such as individual orchards, or in urban areas.

The insecticide bait should generally be applied on or inside the middle to top part of the canopy of host and shelter plants, but specific application should relate to the height of the host plant. For low-growing host plants (e.g. cucurbits, tomatoes, peppers), the insecticide bait should be applied on taller plants surrounding the cultivated area that serve as shelter and a source of food. In FF-PFAs, as part of an emergency action plan to eliminate an outbreak, the insecticide bait can also be applied to non-host plants or other appropriate surfaces around the detection site.

3.2.2 Aerial application

Aerial application of insecticide bait may be used on large production areas and in areas where hosts are scattered in patches over large areas of land. Aerial spraying may be more cost-effective than ground spraying for large-scale programmes, and a more uniform coverage of bait in the target area may be achieved. In some countries, however, aerial spraying may be subject to restrictions due to environmental considerations.

Once the treatment area is selected, it may be defined using a georeferencing device and recorded in digitized maps using GIS software in order to ensure the efficient application of bait sprays and reduce the environmental impact.

To treat the target area, insecticide bait may not need to be applied as full coverage but only in some swathes, such as every second or third swathe. The altitude and speed of aerial application should be adjusted to conditions such as bait viscosity and nozzle specifications, wind velocity, temperature, cloud cover and topography of the terrain.

3.3 Bait stations

Lure and kill devices known as "bait stations" may be a more environmentally friendly control procedure for fruit fly suppression than BAT. Bait stations consist of an attractant and a killing agent that may be contained in a device or directly applied to an appropriate surface. Unlike traps, bait stations do not retain the attracted fruit flies.

Bait stations are suitable for use in, for example, commercial fruit production operations, area-wide fruit fly management programmes, public areas and, in many cases, organic groves. Bait stations may be used in FF-PFAs for population suppression of localized and well-isolated outbreaks. In infested areas known to be fruit fly reservoirs and sources of incursions into FF-ALPPs and FF-PFAs, bait stations should be deployed at high densities.

It is recommended that the attractant used in the bait station be female-biased, thereby directly reducing the overall fruit infestation.

3.4 Male annihilation technique

MAT involves the use of a high density of bait stations consisting of a male lure combined with an insecticide to reduce the male population of target fruit flies to such a low level that mating is unlikely to occur (FAO, 2017).

MAT may be used for the control of those fruit fly species of the genera *Bactrocera* and *Dacus* that are attracted to male lures (cuelure or methyl eugenol). Methyl eugenol is more effective than cuelure for male annihilation of species attracted to these lures.

3.5 Mass trapping

Mass trapping uses trapping systems at a high density to suppress fruit fly populations. In general, mass trapping procedures are the same as for trapping used for survey purposes (Appendix 1 of this standard). Traps should be deployed at the place of production early in the season when the first adult flies move into the field and populations are still at low levels and should be serviced appropriately.

Trap density should be based on such factors as fruit fly density, physiological stage of the fruit fly, efficacy of the attractant and killing agent, phenology of the host and host density. The timing, layout and deployment of traps should be based on the target fruit fly species and host ecological data.

3.6 Sterile insect technique

The SIT is a species-specific environmentally friendly technique that can provide effective control of target fruit fly populations (FAO, 2017).

SIT is effective only at low population levels of the target species and may be used for:

- suppression, where SIT may be a stand-alone phytosanitary procedure or combined with other phytosanitary procedures to achieve and maintain low population levels
- containment, where SIT may be particularly effective in areas that are largely pest free (such as buffer zones) but that are subjected to regular pest entries from adjacent infested areas
- eradication, where SIT may be applied when population levels are low to eradicate the remaining population
- exclusion, where SIT may be applied in endangered areas that are subject to high pest pressure from neighbouring areas.

3.6.1 Sterile fruit fly release

Sterile fruit flies may be released from the ground or from the air. Release intervals should be adjusted according to the longevity of the insect. Sterile fruit flies are generally released once or twice per week but the frequency of release may be influenced by circumstances such as pupae supply, staggered adult fly emergence and unfavourable weather. To establish sterile fruit fly release density, the quality of the sterile fruit flies, the level of the wild population and the desired sterile: wild fruit fly ratio should be considered.

After release of the sterile fruit flies, trapping and identification of the sterile and wild flies should be performed in order to evaluate the effectiveness of the release procedure and also to prevent unnecessary corrective actions. Released sterile flies should be recaptured in the same traps that are used for detection of the wild population as this provides feedback on whether the desired sterile fruit fly density and sterile: wild fly ratio were attained (FAO, 2017).

Ground release may be used when aerial release is neither cost-effective nor efficient (i.e. discontinuous distribution or relatively small area), or where additional releases are required to provide a higher density of fruit flies for a particular reason (e.g. in areas where a specified level of low pest prevalence is exceeded).

Aerial release is more cost-effective than ground release for large-scale programmes and it provides a more uniform sterile fruit fly distribution than ground release, which may clump sterile fruit flies in localized sites or along release routes. Once the release area is selected, it may be defined using a georeferencing device and recorded in digitized maps using GIS software: this will help ensure the efficient distribution of sterile flies. The most common methods for aerial release are chilled adult and paper bag systems (FAO, 2017).

To determine the release altitude, several factors should be considered, including wind velocity, temperature, cloud cover, topography of the terrain, vegetation cover, and whether the target area is urban or rural. Release altitudes range from 200 to 600 m above ground level. However, lower release altitudes should be preferred, especially in areas subjected to strong winds (to prevent excessive sterile fruit fly or bag drift) and in areas where predation by birds is high and frequent. Release in the early morning, when winds and temperature are moderate, is preferable.

3.6.2 Sterile fruit fly quality control

Routine and periodic quality control tests should be carried out to determine the effect of mass rearing, irradiation, handling, shipment duration, holding and release on the performance of the sterile fruit flies, according to desired quality parameters (FAO/IAEA/USDA, 2014).

3.7 Biological control

Classic biological control may be used to reduce fruit fly populations. For further suppression, inundative release may be used. During inundative release, large numbers of natural enemies, typically parasitoids, are mass reared and released during critical periods to reduce pest populations. The use of biological control by inundation is limited to those biological control agents for which mass-rearing technology is available. The mass-reared natural enemies should be of high quality so that suppression

of the target fruit fly population can be effectively achieved. The release of the biological control agents should be directed towards marginal and difficult to access areas that have high host density and that are known to be fruit fly reservoirs and sources of infestation for commercial fruit production or urban areas.

3.8 Controls on the movement of regulated articles

For FF-PFAs, and under certain circumstances for FF-ALPPs, controls on the movement of regulated articles should be implemented to prevent the entry or spread of target fruit fly species (see details in Annex 1 of this standard).

4. Materials Used in the Phytosanitary Procedures

The materials used in the phytosanitary procedures should perform effectively and reliably at an acceptable level for an appropriate period of time. The devices and equipment should maintain their integrity for the intended duration that they are deployed in the field. The attractants and chemicals should be certified or bio-assayed for an acceptable level of performance.

5. Verification and Documentation

The NPPO should verify the effectiveness of the chosen strategies (suppression, containment, eradication and exclusion) and relevant phytosanitary procedures. The main phytosanitary procedure used for verification is adult and larval surveillance, as described in ISPM 6.

NPPOs should ensure that records of information supporting all stages of the suppression, containment, eradication and exclusion strategies are kept for at least 24 months.

6. References

FAO/IAEA (International Atomic Energy Agency)**. 2017.** *Guideline for packing, shipping, holding and release of sterile flies in area-wide fruit fly control programmes*, Second edition, by Zavala-López J.L. and Enkerlin W.R. (eds.). Rome, Italy. 140 pp.

FAO/IAEA (International Atomic Energy Agency)/**USDA** (United States Department of Agriculture)**.** 2014. *Product quality control for sterile mass-reared and released tephritid fruit flies*. Version 6.0. Vienna, IAEA. 164 pp.

This appendix is for reference purposes only and is not a prescriptive part of the standard.

APPENDIX 1: Fruit fly trapping (2011)

This appendix provides detailed information for trapping procedures for fruit fly species (Tephritidae) of economic importance under different pest statuses. Specific traps, in combination with attractants and killing and preserving agents, should be used depending on the technical feasibility, the species of fruit fly and the pest status of the area, which can be an infested area, an FF-ALPP, or an FF-PFA. It describes the most widely used traps, including materials such as trapping devices and attractants, and trap densities, as well as procedures including evaluation, data recording and analysis.

Additional information about fruit fly trapping is available in the following publication of the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA) (in English only):

FAO/IAEA (International Atomic Energy Agency). 2018. *Trapping guidelines for area-wide fruit fly programmes*, 2nd edn, eds W.R. Enkerlin & J. Reyes-Flores. Rome, FAO. 65 pp. Available at https://www.iaea.org/about/insect-pest-control-section (last accessed 1 October 2018).

Diagnostic protocols adopted as annexes to ISPM 27 (*Diagnostic protocols for regulated pests*) may be useful tools to diagnose the adult fruit fly specimens.

1. Pest Status and Survey Types

There are five pest statuses where surveys may be applied:

A. Pest present without control. The pest is present but not subject to any control measures.

B. Pest present under suppression. The pest is present and subject to control measures. Includes FF-ALPP.

C. Pest present under eradication. The pest is present and subject to control measures. Includes FF-ALPP.

D. Pest absent and FF-PFA being maintained. The pest is absent (e.g. eradicated, no pest records, no longer present) and measures to maintain pest absence are being applied.

E. Pest transient. Pest under surveillance and actionable, under eradication.

The three types of surveys and corresponding objectives are:

- **monitoring surveys**, conducted to verify the characteristics of the pest population
- **delimiting surveys**, conducted to establish the boundaries of an area considered to be infested by or free from the pest
- **detection surveys**, conducted to determine if the pest is present in an area.

Monitoring surveys are necessary to verify the characteristics of the pest population before the initiation or during the application of suppression and eradication measures to verify the population levels and to evaluate the efficacy of the control measures. These surveys are necessary for situations A, B and C. Delimiting surveys are conducted to determine the boundaries of an area considered to be infested by or free from the pest such as boundaries of an established FF-ALPP (situation B) (Annex 1 of ISPM 35) and as part of a corrective action plan when the pest exceeds the established low pest prevalence level or in an FF-PFA (situation E) as part of a corrective action plan when a detection occurs. Detection surveys are conducted to determine if the pest is present in an area, that is, to demonstrate pest absence (situation D) and to detect a possible entry of the pest into the FF-PFA (pest transient, actionable) (ISPM 8 (*Determination of pest status in an area*)).

Additional information on how or when specific types of surveys should be applied can be found in other standards dealing with specific topics such as pest status, eradication, pest free areas or areas of low pest prevalence.

2. Trapping Scenarios

As the pest status may change over time, the type of survey needed may also change:

- Pest present. Starting from an established population with no control (situation A), phytosanitary measures may be applied, and potentially lead to an FF-ALPP (situation B and C) or an FF-PFA (situation D).
- Pest absent. Starting from an FF-PFA (situation D), either the pest status is maintained or a detection occurs (situation E), where measures aimed at restoring the FF-PFA would be applied.

3. Trapping Materials

The effective use of traps relies on the proper combination of trap, attractant and killing agent to attract, capture, kill and preserve the target fruit fly species for effective identification, counting and data analysis. Traps for fruit fly surveys use the following materials, as appropriate:

- a trapping device
- attractants (pheromones, male lures and food attractants)
- killing agents in wet and dry traps (with physical or chemical action)
- preservation agents (wet or dry traps).

3.1 Attractants

Some fruit fly species of economic importance and the attractants commonly used to capture them are presented in Table 1. The presence or absence of a species from this table does not indicate that pest risk analysis has been performed and in no way is presence or absence indicative of the regulatory status of a fruit fly species.

Table 1. A number of fruit fly species of economic importance and commonly used attractants

Species	Attractant
Anastrepha fraterculus (Wiedemann)[4]	Protein attractant (PA)
Anastrepha grandis (Macquart)	PA
Anastrepha ludens (Loew)	PA, 2C-1[1]
Anastrepha obliqua (Macquart)	PA, 2C-1[1]
Anastrepha serpentina (Wiedemann)	PA
Anastrepha striata (Schiner)	PA
Anastrepha suspensa (Loew)	PA, 2C-1[1]
Bactrocera carambolae (Drew & Hancock)	Methyl eugenol (ME)
Bactrocera caryeae (Kapoor)	ME
Bactrocera correcta (Bezzi)	ME
Bactrocera dorsalis (Hendel)[4]	ME, 3C[2]
Bactrocera kandiensis (Drew & Hancock)	ME
Bactrocera musae (Tryon)	ME
Bactrocera occipitalis (Bezzi)	ME
Bactrocera umbrosa (Fabricius)	ME
Bactrocera zonata (Saunders)	ME, 3C[2], ammonium acetate (AA)
Bactrocera cucurbitae (Coquillett)	Cuelure (CUE), 3C[2], AA
Bactrocera neohumeralis (Hardy)	CUE
Bactrocera tau (Walker)	CUE
Bactrocera tryoni (Froggatt)	CUE
Bactrocera minax (Enderlein)	PA
Bactrocera cucumis (French)	PA

Species	Attractant
Bactrocera jarvisi (Tryon)	PA, zingerone
Bactrocera latifrons (Hendel)	PA
Bactrocera oleae (Gmelin)	PA, ammonium bicarbonate (AC), spiroketal (SK)
Bactrocera tsuneonis (Miyake)	PA
Ceratitis capitata (Wiedemann)	Trimedlure (TML), Capilure (CE), PA, 3C[2], 2C-2[3]
Ceratitis cosyra (Walker)	PA, 3C[2], 2C-2[3]
Ceratitis rosa (Karsch)	TML, PA, 3C[2], 2C-2[3]
Dacus ciliatus (Loew)	PA, 3C[2], AA
Myiopardalis pardalina (Bigot)	PA
Rhagoletis cerasi (Linnaeus)	Ammonium salts (AS), AA, AC
Rhagoletis cingulata (Loew)	AS, AA, AC
Rhagoletis indifferens (Curran)	AA, AC
Rhagoletis pomonella (Walsh)	Butyl hexanoate, AS
Toxotrypana curvicauda (Gerstaecker)	2-Methyl-vinylpyrazine

[1] Two-component (2C-1) synthetic food attractant (ammonium acetate and putrescine), mainly for female captures.

[2] Three-component (3C) synthetic food attractant (ammonium acetate, putrescine, trimethylamine), mainly for female captures.

[3] Two-component (2C-2) synthetic food attractant (ammonium acetate and trimethylamine), mainly for female captures.

[4] Taxonomic status of some listed members of the *Bactrocera dorsalis* complex and of *Anastrepha fraterculus* is uncertain.

3.1.1 Male-specific attractants

The most widely used attractants are pheromones or male lures that are male-specific. The male lure trimedlure (TML) captures species of the genus *Ceratitis* (including *C. capitata* and *C. rosa*). The male lure methyl eugenol (ME) captures a large number of species of the genus *Bactrocera* (including *B. carambolae, B. dorsalis, B. musae,* and *B. zonata*). The pheromone spiroketal captures *B. oleae*. The male lure cuelure (CUE) captures a large number of other *Bactrocera* species, including *B. cucurbitae* and *B. tryoni*. Male lures are generally highly volatile and can be used with a variety of traps (examples are listed in Table 2a). Controlled-release formulations exist for TML, CUE and ME, providing a longer-lasting attractant for field use. It is important to be aware that some inherent environmental conditions may affect the longevity of pheromone and male lures.

3.1.2 Female-biased attractants

Female-specific pheromones are not usually commercially available (except, for example, 2-methyl-vinylpyrazine). Therefore, the female-biased attractants (natural, synthetic, liquid or dry) that are commonly used are based on food or host odours (Table 2b). Historically, liquid protein attractants (PAs) have been used to capture a wide range of fruit fly species. Liquid PAs capture both females and males. These liquid PAs are generally less sensitive than the male lures. In addition, liquid PAs capture high numbers of non-target insects and require more frequent servicing.

Several food-based synthetic attractants have been developed using ammonia and its derivatives. These may reduce the number of non-target insects captured. For example, for capturing *C. capitata* a synthetic food attractant consisting of three components (ammonium acetate, putrescine and trimethylamine) is used. For capturing *Anastrepha* species the trimethylamine component may be removed. A synthetic attractant lasts approximately four to ten weeks, depending on climatic conditions. It captures few non-target insects and significantly fewer male than female fruit flies, making this attractant suited for use in sterile fruit fly release programmes. New synthetic food attractant technologies are available, including the long-lasting three-component and two-component

mixtures contained in the same patch, as well as the three component mixture incorporated in a single cone-shaped plug.

Because food-foraging female and male fruit flies respond to synthetic food attractants at the sexually immature adult stage, these attractant types are capable of detecting female fruit flies earlier and at lower population levels than liquid PAs.

Table 2a. Attractants and traps for male fruit fly surveys

Fruit fly species	Attractant and trap																									
	TML/CE											ME								CUE							
	CC	CH	ET	JT	LT	MM	ST	SE	TP	YP	VARs+	CH	ET	JT	LT	MM	ST	TP	YP	CH	ET	JT	LT	MM	ST	TP	YP
Anastrepha fraterculus																											
Anastrepha ludens																											
Anastrepha obliqua																											
Anastrepha striata																											
Anastrepha suspensa																											
Bactrocera carambolae												x	x	x	x	x	x	x	x								
Bactrocera caryeae												x	x	x	x	x	x	x	x								
Bactrocera minax																											
Bactrocera correcta												x	x	x	x	x	x	x	x								
Bactrocera cucumis																											
Bactrocera cucurbitae																				x	x	x	x	x	x	x	x
Bactrocera dorsalis												x	x	x	x	x	x	x	x								
Bactrocera kandiensis												x	x	x	x	x	x	x	x								
Bactrocera latifrons																											
Bactrocera occipitalis												x	x	x	x	x	x	x	x								
Bactrocera oleae																											
Bactrocera tau																				x	x	x	x	x	x	x	x
Bactrocera tryoni																				x	x	x	x	x	x	x	x
Bactrocera tsuneonis																											
Bactrocera umbrosa												x	x	x	x	x	x	x	x								
Bactrocera zonata												x	x	x	x	x	x	x	x								
Ceratitis capitata		x	x	x	x	x	x	x	x	x	x																
Ceratitis cosyra																											
Ceratitis rosa		x	x	x	x	x	x	x	x	x	x																
Dacus ciliatus																											
Myiopardalis pardalina																											
Rhagoletis cerasi																											
Rhagoletis cingulata																											
Rhagoletis indifferens																											
Rhagoletis pomonella																											

Fruit fly species	Attractant and trap																								
	TML/CE											ME								CUE							
	CC	CH	ET	JT	LT	MM	ST	SE	TP	YP	VARs+	CH	ET	JT	LT	MM	ST	TP	YP	CH	ET	JT	LT	MM	ST	TP	YP
Toxotrypana curvicauda																											

Attractant abbreviations

CE	Capilure
CUE	Cuelure
ME	Methyl eugenol
TML	Trimedlure

Trap abbreviations

CC	Cook and Cunningham trap
CH	ChamP trap
ET	Easy trap
JT	Jackson trap
LT	Lynfield trap
MM	Maghreb-Med or Morocco trap
SE	Sensus trap
ST	Steiner trap
TP	Tephri trap
VARs+	Modified funnel trap
YP	Yellow panel trap

Table 2b. Attractants and traps for female-biased fruit fly surveys

Fruit fly species	**Attractant and trap** (see below for abbreviations)																								
	3C							**2C-2**					**2C-1**	**PA**			**SK+AC**		**AS (AA, AC)**				**BuH**			**MVP**
	ET	SE	MLT	OBDT	LT	MM	TP	ET	MLT	LT	MM	TP	MLT	ET	McP	MLT	CH	YP	RB	RS	YP	PALz	RS	YP	PALz	GS
Anastrepha fraterculus															x	x										
Anastrepha grandis															x	x										
Anastrepha ludens													x		x	x										
Anastrepha obliqua													x		x	x										
Anastrepha striata															x	x										
Anastrepha suspensa													x		x	x										
Bactrocera carambolae															x	x										
Bactrocera caryeae															x	x										
Bactrocera minax															x	x										
Bactrocera correcta															x	x										
Bactrocera cucumis															x	x										
Bactrocera cucurbitae			x												x	x										
Bactrocera dorsalis															x	x										
Bactrocera kandiensis															x	x										
Bactrocera latifrons															x	x										
Bactrocera occipitalis															x	x										
Bactrocera oleae														x	x	x	x	x			x	x				
Bactrocera tau															x	x										
Bactrocera tryoni															x	x										
Bactrocera tsuneonis															x	x										
Bactrocera umbrosa															x	x										
Bactrocera zonata			x												x	x										
Ceratitis capitata	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x										
Ceratitis cosyra			x						x						x	x										
Ceratitis rosa		x	x						x						x	x										
Dacus ciliatus			x												x	x										

Fruit fly species	**Attractant and trap** (see below for abbreviations)																								
	3C							**2C-2**					**2C-1**	**PA**			**SK+AC**		**AS (AA, AC)**				**BuH**			**MVP**
	ET	SE	MLT	OBDT	LT	MM	TP	ET	MLT	LT	MM	TP	MLT	ET	McP	MLT	CH	YP	RB	RS	YP	PALz	RS	YP	PALz	GS
Myiopardalis pardalina															x	x										
Rhagoletis cerasi																			x	x	x	x	x	x	x	
Rhagoletis cingulata																					x	x		x	x	
Rhagoletis indifferens																				x	x					
Rhagoletis pomonella																			x		x	x	x			
Toxotrypana curvicauda																										x

Attractant abbreviations

2C-1	(AA+Pt)	BuH	butyl hexanoate
2C-2	(AA+TMA)	MVP	papaya fruit fly pheromone (2-methyl vinylpyrazine)
3C	(AA+Pt+TMA)		
AA	ammonium acetate	PA	protein attractant
AC	ammonium (bi)carbonate	Pt	putrescine
AS	ammonium salts	SK	spiroketal
		TMA	trimethylamine

Trap abbreviations

CH	ChamP trap	MLT	Multilure trap	RS	Red sphere trap
ET	Easy trap	MM	Maghreb-Med or Morocco trap	SE	Sensus trap
GS	Green sphere trap	OBDT	Open bottom dry trap	TP	Tephri trap
LT	Lynfield trap	PALz	Fluorescent yellow sticky “cloak” trap	YP	Yellow panel trap
McP	McPhail trap	RB	Rebell trap		

Table 3. List of attractants and field longevity

Common name	Abbreviation	Formulation	Field longevity[1] (weeks)
Male lures			
Trimedlure	TML	Polymeric plug	4–10
		Laminate	3–6
		Liquid	1–4
		Polyethylene bag	4-5
Methyl eugenol	ME	Polymeric plug	4–10
		Liquid	4–8
Cuelure	CUE	Polymeric plug	4–10
		Liquid	4–8
Capilure (TML plus extenders)	CE	Liquid	12–36
Pheromones			
Papaya fruit fly (*Toxotrypana curvicauda*) (2-methyl-6-vinylpyrazine)	MVP	Patches	4–6
Olive fly (spiroketal)	SK	Polymer	4–6
Food-based attractants			
Torula yeast/borax	PA	Pellet	1–2
Protein derivatives	PA	Liquid	1–2
Ammonium acetate	AA	Patches	4–6
		Liquid	1
		Polymer	2–4
Ammonium (bi)carbonate	AC	Patches	4–6
		Liquid	1
		Polymer	1–4
Ammonium salts	AS	Salt	1
Putrescine	Pt	Patches	6–10
Trimethylamine	TMA	Patches	6–10
Butyl hexanoate	BuH	Vial	2
Ammonium acetate + Putrescine + Trimethylamine	3C (AA+Pt+TMA)	Cone/patches	6–10
Ammonium acetate + Putrescine + Trimethylamine	3C (AA+Pt+TMA)	Long-lasting patches	18–26
Ammonium acetate + Trimethylamine	2C-2 (AA+TMA)	Patches	6–10
Ammonium acetate + Putrescine	2C-1 (AA+Pt)	Patches	6–10
Ammonium acetate / Ammonium carbonate	AA/AC	Polyethylene bag with Aluminium foil cover	3–4

[1] Based on half-life. Attractant longevity is indicative only. Actual timing should be supported by field testing and validation.

3.2 Killing and preserving agents

Traps retain attracted fruit flies through the use of killing and preserving agents. In some dry traps, killing agents are a sticky material or a toxicant. Some organophosphates may act as a repellent at higher doses. The use of insecticides in traps is subject to the registration and approval of the product in the respective national legislation.

In other traps, liquid is the killing agent. When liquid PAs are used, borax to 3% concentration is mixed in to preserve the captured fruit flies. Some PAs are formulated with borax, and thus no additional borax is required. When water is used in hot climates, 10% propylene glycol is added to prevent evaporation of the attractant and to preserve captured flies.

3.3 Commonly used fruit fly traps

This section describes commonly used fruit fly traps. The list of traps is not comprehensive; other types of traps may achieve equivalent results and may be used for fruit fly trapping.

Based on the killing agent, there are three types of traps commonly used:

- **Dry traps.** The fly is caught on a sticky material board or killed by a chemical agent. Some of the most widely used dry traps are Cook and Cunningham (C&C) trap, ChamP (CH) trap, Jackson trap (JT) or Delta trap, Lynfield trap (LT), open bottom dry trap (OBDT) or Phase IV trap, red sphere (RS) trap, Steiner trap (ST), and yellow panel (YP) trap and Rebell (RB) trap.
- **Wet traps.** The fly is captured and drowns in the attractant solution or in water with surfactant. One of the most widely used wet traps is the McPhail (McP) trap. The Harris trap is also a wet trap with a more limited use.
- **Dry or wet traps.** These traps can be used either dry or wet. Some of the most widely used are easy trap (ET), Multilure trap (MLT) and Tephri (TP) trap.

3.3.1 Cook and Cunningham trap

Description

The C&C trap consists of three removable creamy white panels, spaced approximately 2.5 cm apart. The two outer panels are made of rectangular paperboard measuring 22.8 cm × 14.0 cm. One or both panels are coated with sticky material (Figure 1). The adhesive panel has one or more holes that allow air to circulate. The trap is used with a polymeric panel containing an olfactory attractant (usually TML), which is placed between the two outer panels. The polymeric panels come in two sizes – standard and half. The standard panel (15.2 cm × 15.2 cm) contains 20 g TML, while the half size panel (7.6 cm × 15.2 cm) contains 10 g. The entire unit is held together with clips and is suspended in the tree canopy with a wire hanger.

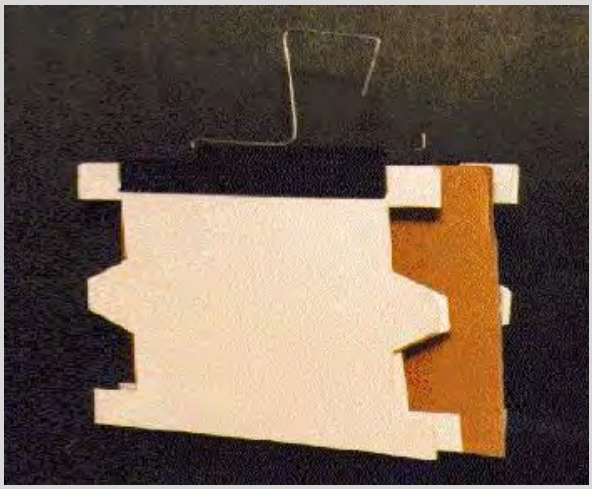


Figure 1. Cook and Cunningham (C&C) trap.

Use

As a result of the need for economical highly sensitive delimiting trapping of *C. capitata*, polymeric panels were developed for the controlled release of greater amounts of TML. These keep the release rate constant for a longer period of time, reducing hand labour and increasing sensitivity. The C&C trap with its multipanel construction has significant adhesive surface area for fly capture.

- For the species for which the trap and attractant is used, see Table 2a.
- For rebaiting (field longevity), see Table 3.

- For use under different scenarios and recommended densities, see Table 4d.

3.3.2 ChamP trap

Description

The CH trap is a hollow, YP-type trap with two perforated sticky side panels. When the two panels are folded, the trap is rectangular in shape (18 cm × 15 cm), and a central chamber is created to place the attractant (Figure 2). A wire hanger placed at the top of the trap is used to place it on branches.

Figure 2. ChamP trap.

Use

The CH trap can accommodate patches, polymeric panels, and plugs. It is equivalent to a YP trap and Rebell trap in sensitivity.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (b and c).

3.3.3 Easy trap

Description

The ET is a two-part rectangular plastic container with an inbuilt hanger. It is 14.5 cm high, 9.5 cm wide and 5 cm deep and can hold 400 ml of solution (Figure 3). The front part is transparent and the rear part is yellow. The transparent front of the trap contrasts with the yellow rear enhancing the trap's ability to catch fruit flies. It combines visual effects with male lure and food-based attractants.

Figure 3. Easy trap.

Use

The trap is multipurpose. It can be used dry baited with male lures (e.g. TML, CUE, ME) or synthetic food attractants (e.g. 3C and both combinations of 2C attractants) and a retention system such as dichlorvos. It can also be used wet baited with liquid PAs, holding up to 400 ml of mixture. When synthetic food attractants are used, one of the dispensers (the one containing putrescine) is attached inside the yellow part of the trap and the other dispensers are left free.

The ET is one of the most economical traps commercially available. It is easy to carry, handle and service, providing the opportunity to service a greater number of traps per person-hour than some other traps.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4d.

3.3.4 Fluorescent yellow sticky "cloak" trap

Description

The fluorescent yellow sticky "cloak" trap (PALz) trap is prepared from fluorescent yellow plastic sheets (36 cm × 23 cm). One side is covered with sticky material. When setting the trap up, the sticky sheet is placed around a vertical branch or a pole in a "cloak-like" manner (Figure 4), with the sticky side facing outward, and the back corners are fastened together with clips.

Figure 4. Fluorescent yellow sticky cloak trap.

Use

The trap uses the optimal combination of visual (fluorescent yellow) and chemical (cherry fruit fly synthetic bait) attractant cues. The trap is kept in place by a piece of wire, attached to the branch or pole. The bait dispenser is fastened to the front top edge of the trap, with the bait hanging in front of the sticky surface. The sticky surface of the trap has a capture capacity of about 500 to 600 fruit flies. Insects attracted by the combined action of these two stimuli are caught on the sticky surface.

- For the species for which the trap and attractant is used, see Table 2b.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4e.

3.3.5 Jackson trap or Delta trap

Description

The JT is hollow, delta-shaped and made of a white waxed cardboard. It is 8 cm high, 12.5 cm long and 9 cm wide (Figure 5). Additional parts include a white or yellow rectangular insert of waxed cardboard, which is covered with a thin layer of adhesive used to trap fruit flies once they land inside the trap body; a polymeric plug or cotton wick in a plastic basket or wire holder; and a wire hanger placed at the top of the trap body.

Use

This trap is mainly used with male lures to capture male fruit flies. The attractants used with JT or Delta traps are TML, ME and CUE. When ME and CUE are used a toxicant must be added.

Figure 5. Jackson trap or Delta trap.

For many years this trap has been used in exclusion, suppression or eradication programmes for multiple purposes, including population ecology studies (seasonal abundance, distribution, host sequence, etc.); detection and delimiting trapping; and surveying sterile fruit fly populations in areas subjected to sterile fly mass releases. JT or Delta traps may not be suitable for some environmental conditions (e.g. rain or dust).

The JT or Delta traps are some of the most economical traps commercially available. They are easy to carry, handle and service, providing the opportunity of servicing a greater number of traps per person-hour than some other traps.

- For the species for which the trap and attractant is used, see Table 2a.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (b and d).

3.3.6 Lynfield trap

Description

The conventional LT consists of a disposable, clear plastic, cylindrical container measuring 11.5 cm high with a 10 cm diameter base and 9 cm diameter screw-top lid. There are four entry holes evenly spaced around the wall of the trap (Figure 6). Another version of the LT is the Maghreb-Med trap, also known as the Morocco trap (Figure 7).

Figure 6. Lynfield trap.

Figure 7. Maghreb-Med trap or Morocco trap.

Use

The trap uses an attractant and insecticide system to attract and kill target fruit flies. The screw-top lid is usually colour-coded to the type of attractant being used (red, Capilure (CE)/TML; white, ME; yellow, CUE). To hold the attractant a 2.5 cm screw-tip cup hook (opening squeezed closed) screwed through the lid from above is used. The trap uses the male lures CUE, CE, TML and ME.

CUE and ME attractants, which are ingested by the male fruit fly, are mixed with malathion. However, because CE and TML are not ingested by either *C. capitata* or *C. rosa*, a dichlorvos-impregnated matrix is placed inside the trap to kill fruit flies that enter.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (b and d).

3.3.7 McPhail trap

Description

The conventional McP trap is a transparent glass or plastic pear-shaped invaginated container. The trap is 17.2 cm high and 16.5 cm wide at the base and holds up to 500 ml of solution (Figure 8). The trap parts include a rubber cork or plastic lid that seals the upper part of the trap and a wire hook to hang the trap on tree branches. A plastic version of the McP trap is 18 cm high and 16 cm wide at the base and holds up to 500 ml of solution (Figure 9). The top part is transparent and the base is yellow.

Figure 8. McPhail trap.

Use

For this trap to function properly it is essential that the body stays clean. Some designs have two parts in which the upper part and base of the trap can be separated, allowing for easy rebaiting and inspection of fruit fly captures.

This trap uses a liquid food attractant, based on hydrolysed protein or torula yeast/borax tablets. Torula tablets are more effective than hydrolysed protein over time because the pH is stable at 9.2. The level of pH in the mixture plays an important role in attracting fruit flies. Fewer fruit flies are attracted to the mixture as the pH becomes more acidic.

Figure 9. Plastic McPhail trap.

To bait with yeast tablets, mix three to five torula tablets in 500 ml of water or follow the manufacturer's recommendation. Stir to dissolve the tablets. To bait with protein hydrolysate, mix protein hydrolysate and borax (if not already added to the protein) in water to reach 5–9% hydrolysed protein concentration and 3% borax.

The nature of its attractant means this trap is more effective at catching females. Food attractants are generic by nature, and so McP traps tend to also catch a wide range of other non-target tephritid and non-tephritid fruit flies in addition to the target species.

McP traps are used in fruit fly management programmes in combination with other traps. In areas subjected to suppression and eradication actions, these traps are used mainly to monitor female populations. Female catches are crucial in assessing the amount of sterility induced to a wild population in a sterile insect technique (SIT) programme. In programmes releasing only sterile males or in a male annihilation technique programme, McP traps are used as a population detection tool by targeting feral females, whereas other traps (e.g. JT), used with male-specific attractants, catch the released sterile males, and their use should be limited to programmes with an SIT component. Furthermore, in fruit fly free areas, McP traps are an important part of the non-indigenous fruit fly trapping network because of their capacity to capture fruit fly species of quarantine importance for which no specific attractants exist.

McP traps with liquid PA are labour-intensive. Servicing and rebaiting take time, and the number of traps that can be serviced in a normal working day is half that of some of the other traps described in this appendix.

- For the species for which the trap and attractant is used, see Table 2b.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (a, b, d and e).

3.3.8 Modified funnel trap

Description

The modified funnel trap (VARs+) consists of a plastic funnel and a lower catch container (Figure 10). The top roof has a large (5 cm diameter) hole, over which an upper catch container (transparent plastic) is placed.

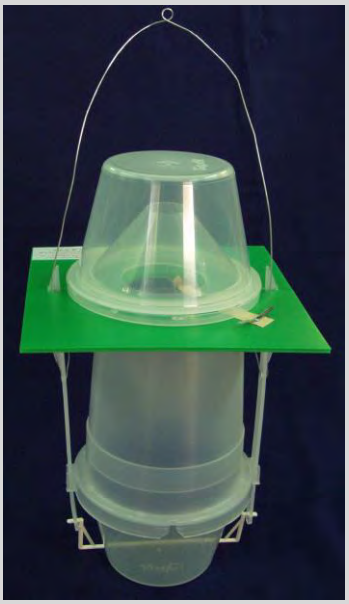


Figure 10. Modified funnel trap.

Use

As it is a non-sticky trap design, it has a virtually unlimited catch capacity and very long field life. The bait is attached to the roof, so that the bait dispenser is positioned in the middle of the large hole on the roof. A small piece of matrix impregnated with a killing agent is placed inside both the upper and the lower catch containers to kill fruit flies that enter.

- For the species for which the trap and attractant is used, see Table 2a.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4d.

3.3.9 Multilure trap

Description

The MLT is a version of the McP trap described previously. The trap is 18 cm high and 15 cm wide at the base and can hold up to 750 ml of solution (Figure 11). It consists of a two-piece plastic invaginated cylindrical container. The top part is transparent and the base is yellow. The upper part and base of the trap separate, allowing the trap to be serviced and rebaited. The transparent upper part of the trap contrasts with the yellow base enhancing the trap's ability to catch fruit flies. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Use

This trap follows the same principles as those of the McP trap. However, an MLT used with dry synthetic attractant is more efficient and selective than an MLT or McP trap used with liquid PA. Another important difference is that an MLT with a dry synthetic attractant allows for cleaner servicing and is much less labour-intensive than a McP trap. When synthetic food attractants are used, dispensers are attached to the inside walls of the upper cylindrical part of the trap or hung from a clip at the top. For this trap to function properly it is essential that the upper part stays transparent.

Figure 11. Multilure trap.

When the MLT is used as a wet trap a surfactant should be added to the water. In hot climates 10% propylene glycol can be used to decrease water evaporation and decomposition of captured fruit flies.

When the MLT is used as a dry trap, a suitable (non-repellent at the concentration used) insecticide such as dichlorvos or a deltamethrin (DM) strip is placed inside the trap to kill the fruit flies. DM is applied to a polyethylene strip placed on the upper plastic platform inside the trap. Alternatively, DM may be used in a circle of impregnated mosquito net and will retain its

killing effect for at least six months under field conditions. The net must be fixed on the ceiling inside the trap using adhesive material.

- For the species for which the trap and attractant is used, see Table 2b.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (a-d).

3.3.10 Open bottom dry trap or Phase IV trap

Description

The OBDT or Phase IV trap is an open-bottom cylindrical dry trap that can be made from opaque green plastic or wax-coated green cardboard. The cylinder is 15.2 cm high and 9 cm in diameter at the top and 10 cm in diameter at the bottom (Figure 12). It has a transparent top, three holes (each of 2.5 cm diameter) equally spaced around the wall of the cylinder midway between the ends, and an open bottom, and is used with a sticky insert. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Figure 12. Open bottom dry trap (Phase IV).

Use

A food-based synthetic chemical female-biased attractant can be used to capture *C. capitata*. However, it also serves to capture males. Synthetic attractants are attached to the inside walls of the cylinder. Servicing is easy because the sticky insert permits easy removal and replacement, similar to the inserts used in the JT. This trap is less expensive than the plastic or glass McP traps.

- For the species for which the trap and attractant is used, see Table 2b.
- For attractants used and rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4d.

3.3.11 Red sphere trap

Description

The RS trap is a red sphere 8 cm in diameter (Figure 13). The trap mimics the size and shape of a ripe apple. A green version of this trap is also used. The trap is covered with a sticky material and baited with the synthetic fruit odour butyl hexanoate, which has a fragrance like a ripe fruit. Attached to the top of the sphere is a wire hanger used to hang it from tree branches.

Figure 13. Red sphere trap.

Use

The red or green traps can be used unbaited, but they are much more efficient in capturing fruit flies when baited. Fruit flies that are sexually mature and ready to lay eggs are attracted to this trap.

Many types of insects will be caught by these traps. It will be necessary to positively identify the target fruit fly from the non-target insects likely to be present on the traps.

- For the species for which the trap and attractant is used, see Table 2b.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4e.

3.3.12 Sensus trap

Description

The Sensus (SE) trap consists of a vertical plastic bucket 12.5 cm high and 11.5 cm in diameter (Figure 14). It has a transparent body and a blue overhanging lid, which has a hole just underneath it. A wire hanger placed on top of the trap body is used to hang the trap from tree branches.

Figure 14. Sensus trap.

Use

The trap is dry and uses male lures or, for female-biased captures, dry synthetic food attractants. A dichlorvos block is placed in the comb on the lid to kill the flies.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4d.

3.3.13 Steiner trap

Description

The ST is a horizontal clear plastic cylinder with openings at each end. The conventional ST is 14.5 cm long and 11 cm in diameter (Figure 15). There are a number of versions of this trap. These include one that is 12 cm long and 10 cm in diameter (Figure 16) and one 14 cm long and 8.5 cm in diameter (Figure 17). A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Figure 15. Conventional Steiner trap.

Figure 16. Steiner trap version.

Figure 17. Steiner trap version.

Use

This trap uses the male lures TML, ME and CUE. The attractant is suspended from the centre of the inside of the trap. The attractant may be a cotton wick soaked in 2-3 ml of a mixture of male lure or a dispenser with the attractant and an insecticide (usually malathion, dibrom or DM) as a killing agent.

- For the species for which the trap and attractant is used, see Table 2a.
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Tables 4 (b and d).

3.3.14 Tephri trap

Description

The TP is similar to the McP trap. It is a vertical cylinder 15 cm high and 12 cm in diameter at the base and can hold up to 450 ml of solution (Figure 18). It has a yellow base and a clear top, which can be separated to facilitate servicing. There are entrance holes around the top of the periphery of the yellow base, and an invaginated opening in

the bottom. Inside the top is a platform to hold attractants. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Use

The trap is baited with hydrolysed protein at 9% concentration; however, it can also be used with other liquid PAs as described for the conventional glass McP trap or with the female dry synthetic food attractant and with TML in a plug or liquid as described for the JT or Delta trap and YP trap. If the trap is used with liquid PAs or with dry synthetic attractants combined with a liquid retention system and without the side holes, the insecticide will not be necessary. However, when used as a dry trap and with side holes, an insecticide solution (e.g. malathion) soaked into a cotton wick or other killing agent is needed to avoid escape of captured insects. Other suitable insecticides are dichlorvos or DM strips placed inside the trap to kill the fruit flies. DM is applied in a polyethylene strip, placed on the plastic platform inside the top of the trap. Alternatively, DM may be used in a circle of impregnated mosquito net and will retain its killing effect for at least six months under field conditions. The net must be fixed on the ceiling of the inside of the trap using adhesive material.

Figure 18. Tephri trap.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (b and d).

3.3.15 Yellow panel trap and Rebell trap

Description

The YP consists of a yellow rectangular cardboard plate (23 cm × 14 cm) coated with plastic (Figure 19). The rectangle is covered on both sides with a thin layer of sticky material. The RB trap is a three-dimensional YP-type trap with two crossed yellow rectangular plates (15 cm × 20 cm) made of plastic (polypropylene), making them extremely durable (Figure 20). The trap is also coated with a thin layer of sticky material on both sides of both plates. A wire hanger, placed on top of the trap body, is used to hang it from tree branches.

Figure 19. Yellow panel trap.

Use

Figure 20. Rebell trap.

These traps can be used as visual traps alone and baited with TML, spiroketal or ammonium salts (ammonium acetate). The attractants may be contained in controlled-release dispensers such as a polymeric plug. The attractants are attached to the face of the trap. The attractants can also be mixed into the cardboard's coating. The two-dimensional design and greater contact surface make these traps more efficient, in terms of fly captures, than the JT and McP trap. It is important to consider that these traps require special procedures for transportation, submission and fruit fly screening methods because they are so sticky that specimens can be destroyed in handling. Although these traps can be used in most types of control programme applications, their use is recommended for the post-eradication phase and for fruit fly free areas, where highly sensitive traps are required. These traps should not be used in areas subjected to mass release of sterile fruit flies because of the large number of released fruit flies that would be caught. It is important to note that their yellow colour and open design allow them to catch other non-target insects including natural enemies of fruit flies and pollinators.

- For the species for which the trap and attractant is used, see Table 2 (a and b).
- For rebaiting (field longevity), see Table 3.
- For use under different scenarios and recommended densities, see Table 4 (b-e).

4. Trapping Procedures

4.1 Spatial distribution of traps

The spatial distribution of traps will be guided by the purpose of the survey, the intrinsic characteristics of the area, the biological characteristics of the fruit fly and its interactions with its hosts, as well as the efficacy of the attractant and trap. In areas where continuous compact blocks of commercial orchards are present and in urban and suburban areas where hosts exist, traps are usually deployed in a grid system, which may have a uniform distribution.

In areas with scattered commercial orchards, in rural areas with hosts and in marginal areas where hosts exist, trap networks are normally distributed along roads that provide access to host material.

In suppression and eradication programmes, an extensive trapping network should be deployed over the entire area that is subject to surveillance and control actions.

Trapping networks are also placed as part of early detection programmes for target fruit fly species. In this case traps are placed in high-risk areas such as points of entry, fruit markets, urban areas and garbage dumps, as appropriate. Traps in these locations can be supplemented by traps placed along roadsides to form transects and in production areas close to or adjacent to land borders, ports of entry and national roads.

4.2 Trap deployment

Trap deployment involves the actual placement of the traps in the field. One of the most important factors of trap deployment is selecting an appropriate trap site. It is important to have a list of the primary, secondary and occasional fruit fly hosts, and their phenology, distribution and abundance. With this basic information, it is possible to properly place and distribute the traps in the field, and this information also allows for effective planning of a programme of trap relocation.

When possible, pheromone traps should be placed in mating areas. Fruit flies normally mate in the crown of host plants or close by, selecting semi-shaded spots usually on the upwind side of the crown. Other suitable trap sites are the eastern side of the tree, which gets the sunlight in the early hours of the

day, and resting and feeding areas in plants that provide shelter and protect fruit flies from strong winds and predators. In specific situations trap hangers may need to be coated with an appropriate insecticide to prevent ants from eating captured fruit flies.

PA traps should be deployed in shaded areas in host plants. In this case traps should be deployed in primary host plants during their fruit maturation period. In the absence of primary host plants, secondary host plants should be used. In areas with no host plants identified, traps should be deployed in plants that can provide shelter, protection and food to adult fruit flies.

Traps should be deployed in the middle to the top part of the host plant canopy, depending on the height of the host plant, and oriented towards the upwind side. Traps should not be exposed to direct sunlight, strong winds or dust. It is of vital importance to have the trap entrance clear from twigs, leaves and other obstructions such as spider webs to allow proper airflow and easy access for the fruit flies.

Placement of traps in the same tree baited with different attractants should be avoided because it may cause interference among attractants and a reduction of trap efficiency. For example, placing a *C. capitata* male-specific TML trap and a PA trap in the same tree will cause a reduction of female capture in the PA trap because TML acts as a female repellent.

Traps should be relocated following the maturation phenology of the fruit hosts present in the area and biology of the fruit fly species. By relocating the traps it is possible to follow the fruit fly population throughout the year and increase the number of sites being checked for fruit flies.

4.3 Trap mapping

Once traps are deployed at carefully selected sites at the correct density and distributed in an appropriate pattern, the location of the traps must be recorded. It is recommended that the location of traps should be geo-referenced with the use of GPS equipment, where available. A map or sketch of the trap location and the area around the traps should be prepared.

GPS and GIS have proven to be very powerful tools in the management of trapping networks. GPS allows each trap to be geo-referenced through geographical coordinates, which are then used as input information in a GIS.

In addition to GPS location data or in the event that GPS data are not available for trap location, reference for the trap location should include visible landmarks. In the case of traps placed in host plants located in suburban and urban areas, references should include the full address of the property where the traps were placed. Trap reference should be clear enough to allow control teams and supervisors who service the traps to find the trap easily.

A database or trapping book of all traps with their corresponding coordinates should be kept, together with the records of trap services, date of collection, collector, rebaiting, trap captures, and if possible notes on the collection site such as ecological characteristics. GIS provides high-resolution maps showing the exact location of each trap and other valuable information such as exact location of fruit fly detections, historical geographical distribution patterns of the fruit flies, relative size of the populations in given areas and spread of the fruit fly population in case of an outbreak. This information is extremely useful in planning control activities, ensuring that bait sprays and sterile fruit fly releases are accurately placed and cost-effective in their application.

4.4 Trap servicing and inspection

Trap servicing intervals are specific to each trapping system and are based on the half-life of the attractant, noting that actual timings should be supported by field testing and validation (see Table 3). Capturing fruit flies will depend, in part, on how well the trap is serviced. Trap servicing includes rebaiting and maintaining the trap in a clean and appropriate operating condition. Traps should be in a condition to consistently kill and retain in good condition any target flies that have been captured.

Attractants have to be used in the appropriate volumes and at the appropriate concentrations and replaced at the recommended intervals, as indicated by the manufacturer. The release rate of attractants varies considerably with environmental conditions. The release rate is generally high in hot and dry areas, and low in cool and humid areas. Thus, in cool climates traps may have to be rebaited less often than in hot conditions.

Inspection intervals (i.e. checking for fruit fly captures) should be adjusted according to the prevailing environmental conditions, pest situation and biology of fruit flies, on a case-by-case basis. The interval can range from one day up to 30 days, for example, seven days in areas where fruit fly populations are present and 14 days in fruit fly free areas. In the case of delimiting surveys inspection intervals may be more frequent, with two to three days being the most common interval.

It is recommended to avoid handling more than one lure type at a time if more than one lure type is being used at a single locality. Cross-contamination between traps of different attractant types (e.g. CUE and ME) reduces trap efficacy and makes laboratory identification unduly difficult. When changing attractants, it is important to avoid spillage or contamination of the external surface of the trap body or the ground. Attractant spillage or trap contamination would reduce the chance of fruit flies entering the trap. For traps that use a sticky insert to capture fruit flies, it is important to avoid contaminating areas in the trap that are not meant for capturing fruit flies with the sticky material. This also applies to leaves and twigs that surround the trap. Attractants, by their nature, are highly volatile and care should be taken when storing, packaging, handling and disposing of lures to avoid compromising the attractant efficacy and operator safety.

The number of traps serviced per day per person will vary depending on the type of trap, trap density, environmental and topographic conditions and experience of the operators. Where a large trap network is in place, it may need to be serviced over a number of days. In this case, the network may be serviced through a number of “routes” or “runs” that systematically ensure all traps within the network are inspected and serviced and none is missed.

4.5 Trapping records

The following information should be included in proper trapping records that provide confidence in the survey results: trap location, plant where the trap is placed, trap and attractant type, servicing and inspection dates, and target fruit fly capture. Any other information considered necessary can be added to the trapping records. Retaining results over a number of seasons can provide useful information on spatial changes in fruit fly populations.

4.6 Flies per trap per day

Flies per trap per day (FTD) is a population index that indicates the average number of flies of the target species captured per trap per day during a specified period in which the trap was exposed in the field (see also Annex 2 of ISPM 35).

The function of this population index is to have a comparative measure of the size of the adult pest population in a given space and time.

It is used as baseline information to compare the size of the population before, during and after the application of a fruit fly control programme. FTD should be used in all reports of trapping.

FTD is comparable within a programme; however, for meaningful comparisons between programmes, it should be based on the same fruit fly species, trapping system and trap density.

In areas where sterile fruit fly release programmes are in operation FTD is used to measure the relative abundance of the sterile and wild fruit flies.

FTD is the result of dividing the total number of fruit flies captured (F) by the product obtained from multiplying the total number of inspected traps (T) by the average number of days between trap inspections (D). The formula is as follows:

$$FTD = \frac{F}{T \times D}$$

5. Trap Densities

Establishing a trapping density appropriate to the purpose of the survey is critical and underpins confidence in the survey results. Trap density needs to be adjusted based on many factors including type of survey, trap efficiency, location (type and presence of host, climate and topography), pest situation and lure type. In terms of type and presence of host, as well as the risk involved, the following types of location may be of concern:

- production areas
- marginal areas
- urban areas
- points of entry (and other high-risk areas such as fruit markets).

Trap density may also vary as a gradient from production areas to marginal areas, urban areas and points of entry. For example, in a pest free area, a higher density of traps is required at high-risk points of entry and a lower density in commercial orchards. Or, in an area where suppression is applied, such as in an ALPP or an area under a systems approach where the target species is present, the reverse occurs, and trap density for that pest should be higher in the place of production and decrease towards points of entry. Other situations such as high-risk urban areas should be taken into consideration when assessing trapping density.

Table 4 (a–f) shows suggested trap densities for various fruit fly species based on common practice. These densities have been determined taking into consideration research results, feasibility and cost-effectiveness. Trap densities are dependent on associated surveillance activities, such as the type and intensity of fruit sampling to detect immature stages of fruit flies. In cases where trapping surveillance programmes are complemented with fruit sampling activities, trap densities could be lower than the suggested densities shown in Table 4 (a–f).

The suggested trap densities presented in Table 4 (a–f) take into account the following technical factors:

- various survey objectives and pest status
- target fruit fly species (Table 1)
- pest risk associated with working areas (production and other areas).

Within the delimited area, the suggested trap density should be applied in areas with a significant likelihood of capturing fruit flies such as areas with primary hosts and possible pathways (e.g. production areas versus industrial areas).

Table 4a. Trap densities suggested for *Anastrepha* spp.

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control	McP/MLT	2C-1/PA	0.25–1.00	0.25–0.50	0.25–0.50	0.25–0.50
Monitoring survey for suppression	McP/MLT	2C-1/PA	2–4	1–2	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	McP/MLT	2C-1/PA	3–5	3–5	3–5	3–5
Monitoring survey for eradication	McP/MLT	2C-1/PA	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion	McP/MLT	2C-1/PA	1–2	2–3	3–5	5–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[4]	McP/MLT	2C-1/PA	20–50	20–50	20–50	20–50

1 Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

3 Also other high-risk sites.

4 This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones.

Trap type		Attractant	
McP	McPhail trap	2C-1	AA+Pt
MLT	Multilure trap	AA	Ammonium acetate
		PA	Protein attractant
		Pt	Putrescine

Table 4b. Trap densities suggested for *Bactrocera* spp. responding to cuelure, methyl eugenol and food attractants

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control	ET/JT/LT/McP/MLT/ MM/ST/TP	CUE/ME/PA	0.25–1.00	0.2–0.5	0.2–0.5	0.2–0.5
Monitoring survey for suppression	ET/JT/LT/McP/MLT/ MM/ST/TP	CUE/ME/PA	2–4	1–2	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	ET/JT/LT/McP/MLT/ MM/ST/TP/YP	CUE/ME/PA	3–5	3–5	3–5	3–5
Monitoring survey for eradication	ET/JT/LT/McP/MLT/ MM/ST/TP	CUE/ME/PA	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion	CH/ET/JT/LT/McP/ MLT/MM/ST/TP/YP	CUE/ME/PA	1	1	1–5	3–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[4]	ET/JT/LT/McP/MLT/ MM/ST/TP/YP	CUE/ME/PA	20–50	20–50	20–50	20–50

1 Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

3 Also other high-risk sites.

4 This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones.

Trap type		Attractant	
CH	ChamP trap	CUE	Cuelure
ET	Easy trap	ME	Methyl eugenol
JT	Jackson trap	PA	Protein attractant
LT	Lynfield trap		
McP	McPhail trap		
MLT	Multilure trap		
MM	Maghreb-Med or Morocco trap		
ST	Steiner trap		
TP	Tephri trap		
YP	Yellow panel trap		

Table 4c. Trap densities suggested for *Bactrocera oleae*

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control	CH/ET/McP/MLT/YP	AC+SK/PA	0.5–1.0	0.25–0.50	0.25–0.50	0.25–0.50
Monitoring survey for suppression	CH/ET/McP/MLT/YP	AC+SK/PA	2–4	1–2	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	CH/ET/McP/MLT/YP	AC+SK/PA	3–5	3–5	3–5	3–5
Monitoring survey for eradication	CH/ET/McP/MLT/YP	AC+SK/PA	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion	CH/ET/McP/MLT/YP	AC+SK/PA	1	1	2–5	3–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[4]	CH/ET/McP/MLT/YP	AC+SK/PA	20–50	20–50	20–50	20–50

1 Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

3 Also other high-risk sites.

4 This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones.

Trap type		Attractant	
CH	ChamP trap	AC	Ammonium bicarbonate
ET	Easy trap	PA	Protein attractant
McP	McPhail trap	SK	Spiroketal
MLT	Multilure trap		
YP	Yellow panel trap		

Table 4d. Trap densities suggested for *Ceratitis* spp.

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control[4]	CH/ET/JT/LT/McP/MLT/OBDT/SE/ST/TP/VARs+	2C-2/3C/CE/PA/TML	0.5–1.0	0.25–0.50	0.25–0.50	0.25–0.50
Monitoring survey for suppression	CH/ET/JT/LT/McP/MLT/MM/OBDT/SE/ST/TP/VARs+	2C-2/3C/CE/PA/TML	2–4	1–2	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	CH/ET/JT/LT/McP/MLT/MM/OBDT/ST/TP/VARs+/YP	3C/CE/PA/TML	3–5	3–5	3–5	3–5
Monitoring survey for eradication[5]	CH/ET/JT/LT/McP/MLT/MM/OBDT/ST/TP/VARs+	2C-2/3C/CE/PA/TML	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion[5]	CC/CH/ET/JT/LT/McP/MLT/MM/ST/VARs+	3C/CE/PA/TML	1	1–2	1–5	3–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[6]	CH/ET/JT/LT/McP/MLT/MM/OBDT/ST/TP/VARs+/YP	3C/CE/PA/TML	20–50	20–50	20–50	20–50

1 Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

3 Also other high-risk sites.

4 1:1 ratio (one female trap per male trap).

[5] 3:1 ratio (three female traps per male trap).

[6] This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones (ratio 5:1; five female traps per male trap).

Trap type		Attractant	
CC	Cook and Cunningham trap (with TML for male capture)	2C-2	(AA+TMA)
CH	ChamP trap	3C	(AA+Pt+TMA)
ET	Easy trap (with 2C and 3C attractants for female-biased captures)	AA	Ammonium acetate
JT	Jackson trap (with TML for male capture)	CE	Capilure
LT	Lynfield trap (with TML for male capture)	PA	Protein attractant
McP	McPhail trap	Pt	Putrescine
MLT	Multilure trap (with 2C and 3C attractants for female-biased captures)	TMA	Trimethylamine
MM	Maghreb-Med or Morocco trap	TML	Trimedlure
OBDT	Open bottom dry trap (with 2C and 3C attractants for female-biased captures)		
SE	Sensus trap (with CE for male captures and with 3C for female-biased captures)		
ST	Steiner trap (with TML for male capture)		
TP	Tephri trap (with 2C and 3C attractants for female-biased captures)		
VARs+	Modified funnel trap		
YP	Yellow panel trap		

Table 4e. Trap densities suggested for *Rhagoletis* spp.

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control	PALz/RB/RS/YP	AS/BuH	0.5–1.0	0.25–0.50	0.25–0.50	0.25–0.50
Monitoring survey for suppression	PALz/RB/RS/YP	AS/BuH	2–4	1–2	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	PALz/RB/RS/YP	AS/BuH	3–5	3–5	3–5	3–5
Monitoring survey for eradication	PALz/RB/RS/YP	AS/BuH	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion	PALz/RB/RS/YP	AS/BuH	1	0.4–3.0	3–5	4–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[4]	PALz/RB/RS/YP	AS/BuH	20–50	20–50	20–50	20–50

[1] Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

[3] Also other high-risk sites.

[4] This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones.

Trap type		Attractant	
RB	Rebell trap	AS	Ammonium salt
RS	Red sphere trap	BuH	Butyl hexanoate
PALz	Fluorescent yellow sticky “cloak” trap		
YP	Yellow panel trap		

Table 4f. Trap densities suggested for *Toxotrypana curvicauda*

Trapping	Trap type[1]	Attractant	Trap density/km² (2)			
			Production area	Marginal	Urban	Points of entry[3]
Monitoring survey, no control	GS	MVP	0.25–0.50	0.25–0.50	0.25–0.50	0.25–0.50
Monitoring survey for suppression	GS	MVP	2–4	1	0.25–0.50	0.25–0.50
Delimiting survey in an FF-ALPP after an unexpected increase in population	GS	MVP	3–5	3–5	3–5	3–5
Monitoring survey for eradication	GS	MVP	3–5	3–5	3–5	3–5
Detection survey in an FF-PFA to verify pest absence and for exclusion	GS	MVP	2	2–3	3–6	5–12
Delimiting survey in an FF-PFA after a detection in addition to detection survey[4]	GS	MVP	20–50	20–50	20–50	20–50

1 Different traps can be combined to reach the total number.

(2) Refers to the total number of traps.

3 Also other high-risk sites.

4 This range includes high-density trapping in the immediate area of the detection (core area). However, it may decrease towards the surrounding trapping zones.

Trap type		Attractant	
GS	Green sphere trap	MVP	Papaya fruit fly pheromone (2-methyl-vinylpyrazine)

6. Supervision Activities

Supervision of trapping activities includes assessing the quality of the materials used and reviewing the effectiveness of the use of these materials and trapping procedures.

The materials used should perform effectively and reliably at an acceptable level for a prescribed period of time. The traps themselves should maintain their integrity for the entire duration that they are anticipated to remain in the field. The attractants should be certified or bio-assayed by the manufacturer for an acceptable level of performance based on their anticipated use.

The effectiveness of trapping should be officially reviewed periodically by individuals not directly involved in conducting trapping activities. The timing of review will vary by programme, but it is recommended to occur at least twice a year in programmes that run for six months or longer. The review should address all aspects related to the ability of trapping to detect targeted fruit flies within the time frame required to meet programme outcomes, for example, early detection of a fruit fly entry. Aspects of a review include quality of trapping materials, record-keeping, layout of the trapping network, trap mapping, trap placement, trap condition, trap servicing, trap inspection frequency, and capability for fruit fly identification.

The trap deployment should be evaluated to ensure that the prescribed types and densities of traps are in place. Field confirmation is achieved through inspection of individual routes.

Trap placement should be evaluated for appropriate host selection, trap relocation schedule, height, light penetration, fruit fly access to trap, and proximity to other traps. Host selection, trap relocation and trap proximity to other traps can be evaluated from the records for each trap route. Host selection, trap relocation and trap proximity to other traps can be further evaluated by field examination.

Traps should be evaluated for their overall condition, correct attractant, appropriate trap servicing and inspection intervals, correct identifying markings (such as trap identification and date placed), evidence of contamination and proper warning labels. Evaluation is performed in the field at each site where a trap is placed.

Evaluation of identification capability can occur via target fruit flies that have been marked in some manner in order to distinguish them from wild trapped fruit flies. These marked fruit flies are placed in

traps in order to evaluate the operator's diligence in servicing the traps, competence in recognizing the targeted fruit fly species, and knowledge of the proper reporting procedures once a fruit fly is found. Commonly used marking systems are fluorescent dyes or wing clipping.

In some programmes that survey for eradication or to maintain FF-PFAs, the fruit flies may also be marked by using sterile irradiated fruit flies in order to further reduce the chance of the marked fruit flies being falsely identified as wild fruit flies resulting in unnecessary actions being taken by the programme. A slightly different method is necessary under a sterile fruit fly release programme in order to evaluate personnel on their ability to accurately distinguish target wild fruit flies from the released sterile fruit flies. The marked fruit flies used are sterile and lack fluorescent dye, but are marked physically by wing clipping or some other method. These fruit flies are placed into the trap samples after they have been collected in the field but before they are inspected by the operators.

The review should be summarized in a report detailing how many inspected traps on each route were found to be in compliance with the accepted standards in categories such as trap mapping, placement, condition, and servicing and inspection intervals. Specific recommendations should be made to correct aspects found to be deficient.

Proper record keeping is crucial to the appropriate functioning of trapping. The records for each trap route should be inspected to ensure that they are complete and up to date. Field confirmation can then be used to validate the accuracy of the records. Maintenance of voucher specimens of collected species of regulated fruit fly species is recommended.

7. Bibliography

Baker, R., Herbert, R., Howse, P.E. & Jones, O.T. 1980. Identification and synthesis of the major sex pheromone of the olive fly (*Dacus oleae*). *Journal of the Chemical Society, Chemical Communications*, 1: 52–53.

Calkins, C.O., Schroeder, W.J. & Chambers, D.L. 1984. The probability of detecting the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae) with various densities of McPhail traps. *Journal of Economic Entomology*, 77: 198–201.

Campaña Nacional Contra Moscas de la Fruta (DGSV/CONASAG/SAGAR). 1999. *Apéndice Técnico para el Control de Calidad del Trampeo para Moscas de la Fruta del Género* Anastrepha *spp*. México D.F. 15 pp.

Conway, H.E. & Forrester, O.T. 2007. Comparison of Mexican fruit fly (Diptera: Tephritidae) capture between McPhail traps with Torula and Multilure traps with Biolures in South Texas. *Florida Entomologist*, 90(3): 579–580.

Cowley, J.M., Page, F.D., Nimmo, P.R. & Cowley, D.R. 1990. Comparison of the effectiveness of two traps for *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) and implications for quarantine surveillance systems. *Australian Journal of Entomology*, 29: 171–176.

Drew, R.A.I. 1982. Taxonomy. *In* R.A.I. Drew, G.H.S. Hooper & M.A. Bateman, eds. *Economic fruit flies of the South Pacific region,* 2nd edn, pp. 1–97. Brisbane, Australia, Queensland Department of Primary Industries. 150 pp.

Drew, R.A.I. & Hooper, G.H.S. 1981. The response of fruit fly species (Diptera; Tephritidae) in Australia to male attractants. *Australian Journal of Entomology*, 20: 201–205.

Epsky, N.D., Hendrichs, J., Katsoyannos, B.I., Vasquez, L.A., Ros, J.P., Zümreoglu, A., Pereira, R., Bakri, A., Seewooruthun, S.I. & Heath, R.R. 1999. Field evaluation of female-targeted trapping systems for *Ceratitis capitata* (Diptera: Tephritidae) in seven countries. *Journal of Economic Entomology*, 92(1): 156–164.

FAO/IAEA (International Atomic Energy Agency). 2018. *Trapping guidelines for area-wide fruit fly programmes*, 2nd edn, eds W.R. Enkerlin & J. Reyes-Flores. Rome, FAO. 65 pp. Available at https://www.iaea.org/about/insect-pest-control-section (last accessed 1 October 2018).

Fay, H.A.C. 2012. A highly effective and selective male lure for *Bactrocera jarvisi* (Tryon) (Diptera: Tephritidae). *Australian Journal of Entomology,* 51: 189–187.

Heath, R.R., Epsky, N.D., Guzman, A., Dueben, B.D., Manukian, A. & Meyer, W.L. 1995. Development of a dry plastic insect trap with food-based synthetic attractant for the Mediterranean and the Mexican fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology*, 88: 1307–1315.

Heath, R.H., Epsky, N., Midgarden, D. & Katsoyannos, B.I. 2004. Efficacy of 1,4-diaminobutane (putrescine) in a food-based synthetic attractant for capture of Mediterranean and Mexican fruit flies (Diptera: Tephritidae). *Journal of Economic Entomology*, 97(3): 1126–1131.

Hill, A.R. 1987. Comparison between trimedlure and Capilure® – Attractants for male *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). *Australian Journal of Entomology*, 26: 35–36.

Holler, T., Sivinski, J., Jenkins, C. & Fraser, S. 2006. A comparison of yeast hydrolysate and synthetic food attractants for capture of *Anastrepha suspensa* (Diptera: Tephritidae). *Florida Entomologist*, 89(3): 419–420.

IAEA (International Atomic Energy Agency). 1996. *Standardization of medfly trapping for use in sterile insect technique programmes*. Final report of Coordinated Research Programme 1986–1992. IAEA-TECDOC-883. Vienna, IAEA.

—— 1998. *Development of female medfly attractant systems for trapping and sterility assessment*. Final report of Coordinated Research Programme 1995–1998. IAEA-TECDOC-1099. Vienna, IAEA. 228 pp.

—— 2007. *Development of improved attractants and their integration into fruit fly SIT management programmes*. Final report of Coordinated Research Programme 2000–2005. IAEA-TECDOC-1574. Vienna, IAEA. 230 pp.

Jang, E.B., Holler, T.C., Moses, A.L., Salvato, M.H. & Fraser, S. 2007. Evaluation of a single-matrix food attractant Tephritid fruit fly bait dispenser for use in feral trap detection programs. *Proceedings of the Hawaiian Entomological Society*, 39: 1–8.

Katsoyannos, B.I. 1983. Captures of *Ceratitis capitata* and *Dacus oleae* flies (Diptera, Tephritidae) by McPhail and Rebell color traps suspended on citrus, fig and olive trees on Chios, Greece. *In* R. Cavalloro, ed. *Fruit flies of economic importance*. Proceedings of the CEC/IOBC International Symposium, Athens, November 1982, pp. 451–456.

—— 1989. Response to shape, size and color. *In* A.S. Robinson & G. Hooper, eds. *World crop pests*, Vol. 3A, *Fruit flies, their biology, natural enemies and control*, pp. 307–324. Amsterdam, Elsevier Science Publishers.

Lance, D.R. & Gates, D.B. 1994. Sensitivity of detection trapping systems for Mediterranean fruit flies (Diptera: Tephritidae) in southern California. *Journal of Economic Entomology*, 87: 1377.

Leonhardt, B.A., Cunningham, R.T., Chambers, D.L., Avery, J.W. & Harte, E.M. 1994. Controlled-release panel traps for the Mediterranean fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology*, 87: 1217–1223.

Martinez, A.J., Salinas, E. J. & Rendón, P. 2007. Capture of *Anastrepha* species (Diptera: Tephritidae) with Multilure traps and Biolure attractants in Guatemala. *Florida Entomologist*, 90(1): 258–263.

Prokopy, R.J. 1972. Response of apple maggot flies to rectangles of different colors and shades. *Environmental Entomology*, 1: 720–726.

Robacker, D.C. & Czokajlo, D. 2006. Effect of propylene glycol antifreeze on captures of Mexican fruit flies (Diptera: Tephritidae) in traps baited with BioLures and AFF lures. *Florida Entomologist*, 89(2): 286–287.

Robacker, D.C. & Warfield, W.C. 1993. Attraction of both sexes of Mexican fruit fly, *Anastrepha ludens*, to a mixture of ammonia, methylamine, and putrescine. *Journal of Chemical Ecology*, 19: 2999–3016.

Schutze, M.K., Aketarawong, N., Amornsak, W., Armstrong, K.F., Augustinos, A.A., Barr, N., Bo, W., Bourtzis, K., Boykin, L.M., Cáceres, C., Cameron, S.L., Chapman, T.A., Chinvinijkul, S., Chomič, A., De Meyer, M., Drosopoulou, E., Englezou, A., Ekesi, S., Gariou-Papalexiou, A., Geib, S.M., Hailstones, D., Hasanuzzaman, M., Haymer, D., Hee, A.K.W., Hendrichs, J., Jessup, A., Ji, Q., Khamis, F.M., Krosch, M.N., Leblanc, L., Mahmood, K., Malacrida, A.R., Mavragani-Tsipidou, P., Mwatawala, M., Nishida, R., Ono, H., Reyes, J., Rubinoff, D., San Jose, M., Shelly, T.E., Srikachar, S., Tan, K.H., Thanaphum, S., Ul-Haq, I., Vijaysegaran, S., Wee, S.L., Yesmin, F., Zacharopoulou, A. & Clarke, A.R. 2014. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): Taxonomic changes based on 20 years of integrative morphological, molecular, cytogenetic, behavioral, and chemoecological data. *Systematic Entomology,* 40: 456–471.

Tan, K.H. 1982. Effect of permethrin and cypermethrin against *Dacus dorsalis* in relation to temperature. *Malaysian Applied Biology*, 11: 41–45.

Tan, K.H., Nishida, R., Jang, E.B. & Shelly, T.E. 2014. Pheromones, male lures, and trapping of tephritid fruit flies. *In* T. Shelly, N. Epsky, E. Jang, J. Reyes-Flores & R. Vargas, eds. *Trapping and the detection, control, and regulation of tephritid fruit flies: Lures, area-wide programs, and trade implications,* pp. 15–74. Dordrecht, Springer. 638 pp.

Thomas, D.B. 2003. Nontarget insects captured in fruit fly (Diptera: Tephritridae) surveillance traps. *Journal of Economic Entomology*, 96(6): 1732–1737.

Tóth, M., Szarukán, I., Voigt, E. & Kozár, F. 2004. Hatékony cseresznyelégy- (*Rhagoletis cerasi* L., Diptera, Tephritidae) csapda kifejlesztése vizuális és kémiai ingerek figyelembevételével. [Importance of visual and chemical stimuli in the development of an efficient trap for the European cherry fruit fly (*Rhagoletis cerasi* L.) (Diptera, Tephritidae).] *Növényvédelem*, 40: 229–236.

Tóth, M., Tabilio, R., Mandatori, R., Quaranta, M. & Carbone, G. 2007. Comparative performance of traps for the Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) baited with female-targeted or male-targeted lures. *International Journal of Horticultural Science*, 13: 11–14.

Tóth, M., Tabilio, R. & Nobili, P. 2004. Különféle csapdatípusok hatékonyságának összehasonlitása a földközi-tengeri gyümölcslégy (*Ceratitis capitata* Wiedemann) hímek fogására. [Comparison of efficiency of different trap types for capturing males of the Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Diptera: Tephritidae).] *Növényvédelem*, 40: 179–183.

—— 2006. Le trappole per la cattura dei maschi della Mosca mediterranea della frutta. *Frutticoltura*, 68(1): 70–73.

Voigt, E. & Tóth, M. 2008. Az amerikai keleti cseresznyelegyet és az európai cseresznyelegyet egyaránt fogó csapdatípusok. [Trap types catcing both *Rhagoletis cingulata* and *R. cerasi* equally well.] *Agrofórum*, 19: 70–71.

Wall, C. 1989. Monitoring and spray timing. *In* A.R. Jutsum & R.F.S. Gordon, eds. *Insect pheromones in plant protection*, pp. 39–66. New York, NY, Wiley. 369 pp.

White, I.M. & Elson-Harris, M.M. 1994. *Fruit flies of economic significance: Their identification and bionomics*. CABI & Australian Centre for International Agricultural Research (ACIAR), 601 pp.

Wijesuriya, S.R. & De Lima, C.P.F. 1995. Comparison of two types of traps and lure dispensers for *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). *Australian Journal of Entomology*, 34: 273–275.

This appendix is for reference purposes only and is not a prescriptive part of the standard.

APPENDIX 2: Fruit sampling

Information about fruit sampling is available in *Fruit sampling guidelines for area-wide fruit fly programmes*, published in 2017 by FAO and the International Atomic Energy Agency (IAEA) (in English only) and available at: https://www.iaea.org/about/insect-pest-control-section.

IPPC Diagnostic protocols adopted as annexes to ISPM 27 (*Diagnostic protocols for regulated pests*) may be useful tools to diagnose the larvae of fruit fly specimens.

Version: 14.12.2017

South Australia

Plant Health Act 2009

An Act to provide for the protection of plants from pests, the regulation of the movement of plants into, within and out of the State, and the control, destruction and suppression of pests; to repeal the *Fruit and Plant Protection Act 1992* and the *Noxious Insects Act 1934*; and for other purposes.

Contents

Part 1—Preliminary

1 Short title
3 Interpretation
4 Pests and plant related products
5 Quarantine stations

Part 2—Protection of plant health

Division 1—Reporting of pest affected plants and plant related products and noxious insects

6 Reporting of pest affected plants and plant related products and noxious insects

Division 2—Control and prevention

7 Prohibition on introducing pest affected plants or plant related products
8 Quarantine areas
9 Orders relating to pest affected plants or plant related products
10 Action in emergency situations
11 Prohibition on sale of pest affected plants or plant related products

Part 3—Packaging, identifying and transporting plants and plant related products

Division 1—Packaging and labelling of fruits, vegetables and nuts

12 Packaging and labelling of fruit, vegetables and nuts for sale
13 Identification of plants sold for propagation

Division 2—Manifests

14 Manifests

Part 4—Accreditation and registration schemes

Division 1—Accreditation of production areas

15 Accreditation of production areas

Division 2—Accreditation of persons

16 Application for accreditation
17 Grant of accreditation
18 Authority conferred by accreditation
19 Assurance certificates and evidence of verification
20 Conditions of accreditation
21 Periodic fees and returns
22 Variation of accreditation
23 Surrender of accreditation
24 Suspension or cancellation of accreditation
25 Offences

Division 3—Registration of importers

26 Application for registration
27 Grant of registration
28 Conditions of registration
29 Periodic fees and returns
30 Variation of registration
31 Surrender of registration
32 Suspension or cancellation of registration
33 Offence

Division 4—Register

34 Register

Division 5—Reviews

35 Review by Minister
36 Review by Tribunal

Part 5—Enforcement

Division 1—Approved auditors

37 Approved auditors
38 Duty of auditor to report certain matters
39 Offence to hinder or obstruct auditor

Division 2—Inspectors

Subdivision 1—Appointment and identification

40 Appointment of Chief Inspector and deputy
41 Appointment of inspectors
42 Identification of inspectors

Subdivision 2—Powers

43 General powers
44 Power to investigate
45 Power to issue plant health certificates

Subdivision 3—Miscellaneous

47 Warrant procedures
48 Offence to hinder etc inspectors

Part 6—Miscellaneous

49 Delegation
50 Compensation
51 False or misleading statements
52 Self-incrimination
53 Service of notices and orders
54 Vicarious liability
55 Evidence
56 Commencement of prosecution of offences
57 Continuing offences
58 General defence
59 Incorporation of codes and standards
60 Regulations

Schedule 1—Repeal and transitional provisions

Part 2—Repeal

5 Repeal

Part 3—Transitional provisions

6 Transitional provisions
7 Regulations

Legislative history

The Parliament of South Australia enacts as follows:

Part 1—Preliminary

1—Short title

This Act may be cited as the *Plant Health Act 2009*.

3—Interpretation

(1) In this Act, unless the contrary intention appears—

accreditation conditions—see section 20;

accredited person means a person accredited under Part 4 Division 2;

approved auditor means a person approved to be an auditor under Part 5 Division 1;

assurance certificate means—

(a) an assurance certificate issued by an accredited person under Part 4 Division 2; or

(b) a certificate corresponding to an assurance certificate issued under a corresponding law;

Chief Inspector means the Chief Inspector appointed under Part 5 Division 2;

corresponding law means a law of another State declared by the regulations to be a law that corresponds to this Act;

disease means a bacterium, fungus, protozoa, phytoplasma, virus or any other organism or pathogen;

importer means a person who brings or introduces plants or plant related products into the State for the purposes of sale or any other commercial purpose;

inspector means an inspector appointed under Part 5 Division 2;

label includes a ticket, manifest, cartnote, stamp, tag or sticker;

noxious insect means any species of migratory or gregarious grasshopper;

packaging includes the whole or any part of a package, container, crate, covering, packing or material of any description that is being or has been used to cover or contain a plant or plant related product;

pest—see section 4;

place includes any land, road or premises;

plant means—

(a) the whole or any part of a tree, vine, flower, shrub, vegetable or other vegetation; and

(b) the whole or any part of the fruit or nut of a tree, vine or shrub; and

(c) any material used for the propagation of a tree, vine, flower, shrub, vegetable or other vegetation,

whether alive or dead (including timber that has been sawn or dressed);

plant health certificate means—

(a) a plant health certificate issued by an inspector under Part 5 Division 2; or

(b) a certificate corresponding to a plant health certificate issued under a corresponding law;

plant related product means—

(a) soil, potting mix, packaging, agricultural machinery or equipment; and

(b) any other material or item declared by the Minister under section 4 to be a plant related product;

premises means any land, building or structure (including a moveable building or structure);

quarantine station means a place declared by the Minister under section 5 to be a quarantine station;

registered importer means an importer registered under Part 4 Division 3;

sell includes possess, offer, display or consign for sale;

soil does not include clean sand;

State includes a Territory;

vehicle includes an aircraft, a train or a vessel.

(2) For the purposes of this Act—

(a) soil or potting mix will be taken to be affected by a pest if a plant affected by a pest has been growing in the soil or potting mix;

(b) a plant related product (other than soil or potting mix) will be taken to be affected by a pest if the product has been used to contain or cover, or has been in contact with, a plant, soil or potting mix affected by a pest.

4—Pests and plant related products

(1) The Minister may, by notice in the Gazette, declare—

(a) a disease; or

(b) an insect, a mite or other arthropod, a snail, slug or nematode; or

(c) any other organism; or

(d) any other condition,

that affects or may affect a plant or plant related product to be a pest for the purposes of this Act.

(2) The Minister may, by notice in the Gazette, declare material or an item to be a plant related product for the purposes of this Act.

(3) The Minister may, by notice in the Gazette, vary or revoke a notice under this section.

5—Quarantine stations

(1) The Minister may, by notice in the Gazette, declare a place to be a quarantine station in which a plant or plant related product may, subject to this Act, be held, examined, disinfected, treated, destroyed or otherwise disposed of.

(2) The Minister may, by notice in the Gazette, vary or revoke a notice under this section.

Part 2—Protection of plant health

Division 1—Reporting of pest affected plants and plant related products and noxious insects

6—Reporting of pest affected plants and plant related products and noxious insects

(1) A person who knows or has reason to suspect that a plant or plant related product is affected by a pest must—

(a) immediately report the matter to an inspector by the quickest practicable means; and

(b) provide the inspector with such further information as the inspector may reasonably require; and

(c) take all reasonable measures to prevent the spread of the pest.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(2) A person who knows or has reason to suspect that noxious insects have appeared on premises (whether or not occupied by the person) must immediately report the matter to an inspector by the quickest practicable means.

Maximum penalty: $1 250.

Expiation fee: $160.

(3) A report is not required under this section with respect to a particular matter if the person knows or reasonably believes that the matter has already been reported to an inspector.

(4) A person who grows, propagates or processes plants or plant related products for profit or gain will, if the plants or plant related products are affected by a pest, be taken to know or have reason to suspect that the plants or plant related products are so affected in the absence of proof to the contrary.

Division 2—Control and prevention

7—Prohibition on introducing pest affected plants or plant related products

(1) Subject to this section, a person must not bring or introduce into the State a pest or a plant, or plant related product, affected by a pest.

(2) The Minister may, for the purpose of preventing the introduction into, or spread within, the State of a pest, prohibit, by notice in the Gazette, the bringing or introduction into the State of a specified class of plant or plant related product (either absolutely or subject to conditions).

(3) The Minister may, by notice in the Gazette, vary or revoke a notice under subsection (2).

(4) The Minister may, for the purposes of furthering agricultural interests, scientific research or the biological control of a pest, by notice in writing, exempt a person from complying with this section subject to conditions set out in the notice.

(5) The Minister must consult widely with, and take into account the advice of, members of the agricultural and scientific communities before taking action under subsection (4).

(6) The Minister may, by further notice in writing, vary or revoke a notice under subsection (4).

(7) A person—

(a) who contravenes or fails to comply with this section or a notice under this section; or

(b) who purchases or takes delivery of anything brought or introduced into the State in contravention of this section or a notice under this section,

is guilty of an offence.

Maximum penalty:

(a) in the case of a minor offence—$5 000;

(b) in any other case—

(i) in the case of a body corporate—$100 000;

(ii) in the case of a natural person—$20 000.

Expiation fee: In the case of a minor offence—$315.

(8) In this section—

minor offence means an offence that consists of a person bringing or introducing anything into the State, or purchasing or taking delivery of anything brought or introduced into the State, for domestic use, consumption or enjoyment (and not for the purposes of sale or any other commercial purpose).

8—Quarantine areas

(1) The Minister may, by notice in the Gazette, declare the whole of the State, or a portion of the State specified in the notice, to be a quarantine area—

(a) in respect of all pests; or

(b) in respect of those pests specified in the notice.

(2) A notice under this section may do 1 or more of the following:

(a) prohibit the removal from a quarantine area of—

(i) a plant of a species or kind specified in the notice that might, in the opinion of the Minister, transmit a pest; and

(ii) a plant related product of a kind specified in the notice that might, in the opinion of the Minister, transmit a pest;

(b) require the owners or occupiers of premises within the quarantine area to take measures (including the destruction of plants and plant related products), specified in the notice, that are, in the opinion of the Minister, necessary for the control or eradication of a pest;

(c) require the owners or occupiers of premises within specified portions of the quarantine area to take more stringent measures (including the destruction of plants and plant related products), specified in the notice, than the owners or occupiers of other premises within the quarantine area;

(d) prohibit absolutely or subject to exceptions and conditions specified in the notice persons, vehicles, machinery or equipment entering or departing from the quarantine area or a specified portion of the quarantine area;

(e) prohibit absolutely or subject to exceptions and conditions specified in the notice the bringing or introducing into the quarantine area of—

(i) a plant of a species or kind specified in the notice; and

(ii) any plant related product of a kind specified in the notice;

(f) prohibit the planting, propagation or harvesting of plants, or plants of a specified species or kind, within the quarantine area during a period specified in the notice.

(3) The Minister may, by notice in the Gazette, vary or revoke a notice under this section.

(4) A person—

(a) who contravenes or fails to comply with a notice under this section; or

(b) who purchases or takes delivery of anything brought or introduced into a quarantine area in contravention of a notice under this section,

is guilty of an offence.

Maximum penalty:

(a) in the case of a minor offence—$5 000;

(b) in any other case—

(i) in the case of a body corporate—$100 000;

(ii) in the case of a natural person—$20 000.

Expiation fee: In the case of a minor offence—$315.

(5) In this section—

minor offence means an offence that consists of—

(a) a person bringing or introducing anything into, or removing anything from, a quarantine area for domestic use, consumption or enjoyment (and not for the purposes of sale or any other commercial purpose); or

(b) a person purchasing or taking delivery of anything brought or introduced into, or removed from, a quarantine area for domestic use, consumption or enjoyment (and not for the purposes of sale or any other commercial purpose).

9—Orders relating to pest affected plants or plant related products

(1) If the Chief Inspector knows or reasonably suspects that a plant or plant related product is or might become affected by a pest, he or she may, with the approval of the Minister, issue such orders under this section as may be reasonably necessary to prevent or minimise the outbreak or spread of the pest to any of the following persons:

(a) a person who owns or has possession or control of the plant or plant related product;

(b) a person who sold or supplied the plant or plant related product;

(c) an owner or occupier of premises in the area specified in the order.

(2) The Chief Inspector may issue 1 or more of the following orders in relation to any plant or plant related product that is or might become affected by a pest:

(a) an order requiring that it be kept at a specified place for a specified period or otherwise restricting or prohibiting its movement;

(b) an order requiring that it be subjected to specified treatment;

(c) an order requiring that it be subjected to examinations or tests at specified intervals or that other specified action be taken for the purposes of determining the presence of a pest;

(d) an order restricting or prohibiting its sale or supply or restricting the purposes for which it may be used;

(e) if it has been sold or supplied—an order requiring that it be recalled;

(f) an order requiring that it be destroyed or disposed of in a specified manner;

(g) an order prohibiting the planting, propagation or harvesting of plants, or plants of a specified species or kind, on specified land during a specified period;

(h) an order requiring any other action be taken as may be reasonably necessary in the circumstances.

(3) An order issued under this section may be subject to such conditions as the Chief Inspector specifies in the order.

(4) If the Chief Inspector cannot, after reasonable inquiry, locate a person of whom the Chief Inspector intended to make any requirement for action by an order, the Chief Inspector may—

(a) cause the action to be taken by an inspector or other person; and

(b) recover costs and expenses reasonably incurred under this subsection by action in a court of competent jurisdiction as a debt owed by the owner of the plant or plant related product in respect of which action was taken by the inspector or other person.

(5) An order under this section—

(a) must be in writing; and

(b) may be of general or limited application; and

(c) may, by further order of the Chief Inspector, be varied or revoked.

(6) An order that is of a continuing nature has effect for such period as is specified in the order (and, if an order of such a nature is issued on the basis of a suspicion, the Chief Inspector must, as soon as practicable, take reasonable steps to determine whether that suspicion is correct).

(7) If a person refuses or fails to comply with an order, the Chief Inspector may cause an inspector or other person to take any necessary action to give effect to the order.

(8) The Chief Inspector may recover costs and expenses reasonably incurred under subsection (7) by action in a court of competent jurisdiction as a debt owed by the person to whom the order was issued.

(9) A person to whom an order has been issued under this section who contravenes or fails to comply with the order is guilty of an offence.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

10—Action in emergency situations

(1) If an inspector considers on reasonable grounds that urgent action is required for the purposes of controlling, preventing the spread of, or eradicating, a pest, the inspector may, after giving such notice (if any) as may be reasonable in the circumstances, take any action that could be required to be taken by notice or order under this Part, or cause such action to be taken.

(2) Action may be taken or caused to be taken under this section whether or not an order or notice has been issued in relation to the pest under this Part.

11—Prohibition on sale of pest affected plants or plant related products

(1) A person must not, without the approval of the Chief Inspector, sell or supply—

(a) a plant or plant related product affected by a pest; or

(b) a plant or plant related product subject to an order under this Part.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(2) The owner of premises in relation to which an order is in force under this Part must notify the Chief Inspector of any intended sale of the premises or part of the premises at least 28 days before the date of settlement.

Maximum penalty: $5 000.

Expiation fee: $315.

(3) If a person is guilty of an offence against this section, a court may (in addition to any other penalty that may be imposed) order the person to pay to the person to whom the plant or plant related product was sold or supplied such compensation as the court thinks fit.

Part 3—Packaging, identifying and transporting plants and plant related products

Division 1—Packaging and labelling of fruits, vegetables and nuts

12—Packaging and labelling of fruit, vegetables and nuts for sale

(1) A person must not pack for sale or sell any fruit, vegetables or nuts in packaging unless the packaging—

(a) is in good repair; and

(b) is clean and free of extraneous visible matter; and

(c) is free of any objectionable odour; and

(d) is labelled in accordance with the regulations.

Maximum penalty: $5 000.

Expiation fee: $315.

(2) A person must not pack for sale or sell any fruit, vegetables or nuts in used packaging except in accordance with the regulations (which may prohibit the use of certain used packaging absolutely or subject to conditions).

Maximum penalty: $5 000.

Expiation fee: $315.

13—Identification of plants sold for propagation

A person must not sell any prescribed plant for propagation unless it is accompanied by a label or other notice in writing containing the information prescribed by the regulations.

Maximum penalty: $5 000.

Expiation fee: $315.

Division 2—Manifests

14—Manifests

(1) A person must not bring or introduce into the State plants or plant related products for sale or any other commercial purpose unless, before so doing, a manifest that conforms to the requirements of the Minister about its form, contents and the manner in which it is made has been lodged with the Chief Inspector.

Maximum penalty: $5 000.

Expiation fee: $315.

(2) A person must not tranship, or transport through the State, plants or plant related products for sale in another State unless, before so doing, a manifest that conforms to the requirements of the Minister about its form, contents and the manner in which it is made has been lodged with the Chief Inspector.

Maximum penalty: $5 000.

Expiation fee: $315.

(3) A person referred to in subsection (1) or (2) must, at a quarantine station or on the request of an inspector, produce a copy of the manifest.

Maximum penalty: $5 000.

Expiation fee: $315.

Part 4—Accreditation and registration schemes

Division 1—Accreditation of production areas

15—Accreditation of production areas

(1) If the Minister is satisfied that, through the exercise of good management by the producers and processors of plants or plant related products in a specified area, the area is free of a specified pest or specified pests, the Minister may, by notice in the Gazette, declare that area to be free of the pest or pests specified in the notice and authorise the use of specified statements in respect of plants or plant related products produced or processed in that area when advertising, packaging or selling those plants or plant related products.

(2) The Minister may, by notice in the Gazette, vary or revoke a notice under this section.

(3) A person must only use a statement specified in a notice under this section in respect of plants or plant related products produced or processed in the area specified in the notice.

Maximum penalty: $20 000.

Expiation fee: $500.

Division 2—Accreditation of persons

16—Application for accreditation

(1) An application for accreditation for the purposes of this Division must be made to the Minister and must—

(a) be in the manner and form, and contain the information, required by the Minister; and

(b) be accompanied by the fee fixed by the regulations.

(2) The Minister may, by written notice, require the applicant—

(a) to provide the Minister with further information, documents or records relevant to the application; or

(b) to allow an inspector or an approved auditor to inspect premises, facilities, vehicles, plant or equipment, or any other thing, proposed to be used by the applicant in connection with the issuing of certificates under the proposed accreditation.

(3) The Minister may refuse the application if the applicant does not comply with such a request.

(4) The applicant may, with the approval of the Minister or at the request of the Minister, amend the application before the Minister has finished considering it.

17—Grant of accreditation

(1) On application for accreditation, the Minister must grant the accreditation sought by the applicant or another accreditation if satisfied—

(a) that the applicant is a suitable person to hold such accreditation; and

(b) if the applicant is a body corporate—that each director of the body corporate is a suitable person to be the director of a body corporate that holds such accreditation; and

(c) that the applicant satisfies any requirements for accreditation relating to protocols, operational procedures or other matters prescribed by the regulations.

(2) For the purposes of determining the suitability of a person under subsection (1), the Minister may, without limitation, take into account—

(a) any offence committed by the person against—

(i) this Act or an Act repealed by this Act; or

(ii) a corresponding law; or

(iii) a prescribed Act; or

(b) any offence of dishonesty committed by the person.

(3) Accreditation may be granted in the form the Minister considers appropriate.

18—Authority conferred by accreditation

Accreditation authorises the person named in the accreditation to do either or both of the following:

(a) to issue assurance certificates in relation to the movement of a plant or plant related product within the State, into or out of the State, or for another purpose;

(b) to verify assurance certificates or other documents, or the packaging or labelling of plants and plant related products,

in accordance with the terms and conditions of the accreditation.

19—Assurance certificates and evidence of verification

(1) An assurance certificate may be issued in a form approved by the Minister.

(2) An assurance certificate issued in respect of a plant or plant related product—

(a) grown, produced, processed, packed, used, treated or tested in the State; or

(b) to be brought or introduced into the State,

may certify that the plant or plant related product complies with specified requirements of this Act or a corresponding law in relation to the control or prevention of the spread of pests.

(3) Without limiting the generality of subsection (2), an assurance certificate issued in respect of a plant or plant related product may certify as to any of the following matters:

(a) that it is free of any or a specified pest;

(b) that it is free of any or a specified pest, disease, pest infestation, infection or condition within the meaning of a corresponding law;

(c) that it is in a specified condition;

(d) that it is from a specified area;

(e) that it has been treated in a specified way or with specified treatments;

(f) that it has been transported in a specified manner or via a specified route;

(g) that it meets specified requirements;

(h) as to any other matter specified in the certificate.

(4) Verification of assurance certificates or other documents, or the packaging or labelling of plants and plant related products, may be evidenced in a manner and form approved by the Minister.

20—Conditions of accreditation

(1) The Minister may impose conditions on a person's accreditation (***accreditation conditions***).

(2) Without limiting the conditions that may be imposed under subsection (1), the conditions may include the following:

(a) a condition restricting the class or type of certificate that may be issued;

(b) a condition restricting the activities in respect of which a certificate may be issued;

(c) a condition restricting the class or type of assurance certificate or other document that may be verified;

(d) a condition restricting the use of the accreditation in some other way;

(e) a condition as to the records to be kept by the accredited person;

(f) a condition requiring compliance with prescribed protocols and operational procedures;

(g) a condition requiring compliance with applicable codes or rules made under this Act as in force from time to time;

(h) a condition relating to the audit from time to time of all or part of the operations authorised by the accreditation (including the payment of all or part of the costs of the audit) and the reporting of the results of the audit to the Minister;

(i) a condition requiring the accredited person to provide, in the manner and form determined by the Minister, such other information as the Minister may from time to time require;

(j) any other condition that the Minister thinks fit.

(3) An accredited person must not contravene a condition of the person's accreditation.

Maximum penalty:

(a) in the case of a contravention of a prescribed condition—$5 000;

(b) in any other case—

(i) in the case of a body corporate—$100 000;

(ii) in the case of a natural person—$20 000.

Expiation fee: In the case of a contravention of a prescribed condition—$315.

21—Periodic fees and returns

(1) An accredited person must, in each year, on or before the first day of the month following the anniversary of the date on which the person was granted accreditation—

(a) pay to the Minister the fee fixed by regulation; and

(b) lodge with the Minister a return that conforms to the requirements of the Minister about its form, contents and the manner in which it is made.

(2) If an accredited person fails to lodge the return or pay the accreditation fee in accordance with this section, the Minister may, by written notice, require the accredited person to make good the default and, in addition, to pay to the Minister the amount prescribed as a penalty for default.

(3) If an accredited person—

(a) fails to comply with a notice under subsection (2) within 14 days after the giving of the notice—the accreditation is suspended until the notice is complied with; and

(b) fails to comply with any such notice within 3 months after the giving of the notice—the accreditation is cancelled.

(4) The Minister must cause written notice of the suspension or cancellation to be given to the person.

22—Variation of accreditation

(1) The Minister may vary the terms or conditions of a person's accreditation by written notice to the person as the Minister considers appropriate.

(2) The Minister's power under this section may be exercised on the Minister's own initiative or on the application of the accredited person and payment of the prescribed fee.

23—Surrender of accreditation

(1) An accredited person may surrender the person's accreditation to the Minister.

(2) At the time accreditation to issue assurance certificates is surrendered, the person must also surrender any unissued assurance certificates to the Minister.

Maximum penalty: $1 250.

Expiation fee: $160.

24—Suspension or cancellation of accreditation

(1) The Minister may suspend or cancel the accreditation of an accredited person if—

(a) the accredited person obtained the accreditation improperly; or

(b) an accredited person—

(i) has ceased to undertake the activity authorised by the accreditation; or

(ii) has not paid fees or charges payable to the Minister or an approved auditor within the required time; or

(iii) has been guilty of a contravention of a condition of the accreditation; or

(iv) has committed an offence against this Act; or

(v) has been convicted of an indictable offence.

(2) A suspension under this section may be for a specified period, or until the fulfilment of specified conditions, or until further order of the Minister.

(3) A suspension under this section may—

(a) be effective immediately; or

(b) be expressed to have effect at a specified future time; or

(c) be expressed to have effect at a specified future time unless a specified condition is fulfilled.

(4) The Minister must—

(a) notify the accredited person in writing of the action taken or proposed to be taken specifying the reasons for the action; and

(b) allow the accredited person at least 14 days within which to make submissions to the Minister in relation to the action or proposed action (as the case may be).

(5) If the Minister suspends or cancels an accreditation, the person must, within 14 days of the suspension or cancellation, return the accreditation (and, if relevant, any unissued assurance certificates) to the Minister.

Maximum penalty: $1 250.

Expiation fee: $160.

(6) In this section—

accredited person includes a person whose accreditation has been suspended.

25—Offences

(1) A person must not verify that—

(a) an assurance certificate or other document relating to a plant or plant related product required under this Act or a corresponding law; or

(b) the packaging or labelling of plants or plant related products,

complies with the requirements of this Act or a corresponding law (as the case may be) except as authorised by accreditation granted under this Division.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(2) A person must not issue an assurance certificate in relation to a plant or plant related product except as authorised by accreditation granted under this Division.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(3) A person must not issue anything that purports to be an assurance certificate unless the person is accredited under this Division to do so.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(4) A person must not alter or permit to be altered any information or statement in an assurance certificate unless—

(a) the alteration is authorised in writing by the accredited person who issued the certificate; or

(b) the alteration—

(i) relates to the splitting of a consignment to which the certificate relates; and

(ii) is made by an inspector or a person authorised by accreditation granted under this Division to split consignments.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

Division 3—Registration of importers

26—Application for registration

(1) An application for registration as an importer under this Division must be made to the Minister and must—

(a) be in the manner and form, and contain the information, required by the Minister; and

(b) be accompanied by the fee fixed by the regulations.

(2) The Minister may, by written notice, require the applicant to provide the Minister with further information, documents or records relevant to the application.

(3) The Minister may refuse an application if the applicant does not comply with such a request.

(4) The applicant may, with the approval of the Minister or at the request of the Minister, amend the application before the Minister has finished considering it.

27—Grant of registration

(1) The Minister must grant an application for registration as an importer if satisfied—

(a) that the applicant is a suitable person to be so registered; and

(b) if the applicant is a body corporate—that each director of the body corporate is a suitable person to be the director of a body corporate that is so registered; and

(c) that the applicant satisfies any requirements for registration relating to protocols, operational procedures or other matters prescribed by the regulations.

(2) For the purposes of determining the suitability of a person under subsection (1), the Minister may, without limitation, take into account—

(a) any offence committed by the person against—

(i) this Act or an Act repealed by this Act; or

(ii) a corresponding law; or

(iii) a prescribed Act; or

(b) any offence of dishonesty committed by the person.

(3) Registration may be granted in the form the Minister considers appropriate.

28—Conditions of registration

(1) The Minister may impose conditions on a person's registration as an importer.

(2) Without limiting the conditions that may be imposed under subsection (1), the conditions may include—

(a) a condition restricting the type of plant or plant related product that the person may bring or introduce into the State; and

(b) a condition as to the records to be kept by the registered importer; and

(c) a condition requiring compliance with prescribed protocols and operational procedures; and

(d) a condition requiring compliance with applicable codes or rules made under this Act as in force from time to time; and

(e) a condition requiring the registered importer to provide, in the manner and form determined by the Minister, such information as the Minister may from time to time require; and

(f) any other condition that the Minister thinks fit.

(3) A registered importer must not contravene a condition of the importer's registration.

Maximum penalty:

(a) in the case of a body corporate—$20 000;

(b) in the case of a natural person—$5 000.

Expiation fee:

(a) in the case of a body corporate—$500;

(b) in the case of a natural person—$315.

29—Periodic fees and returns

(1) A registered importer must, in each year, on or before the first day of the month following the anniversary of the date on which the person was granted registration—

(a) pay to the Minister the fee fixed by regulation; and

(b) lodge with the Minister a return that conforms to the requirements of the Minister about its form, contents and the manner in which it is made.

(2) If a registered importer fails to lodge the return or pay the registration fee in accordance with this section, the Minister may, by written notice, require the registered importer to make good the default and, in addition, to pay to the Minister the amount prescribed as a penalty for default.

(3) If a registered importer—

(a) fails to comply with a notice under subsection (2) within 14 days after the giving of the notice—the registration is suspended until the notice is complied with; and

(b) fails to comply with any such notice within 3 months after the giving of the notice—the registration is cancelled.

(4) The Minister must cause written notice of the suspension or cancellation to be given to the importer.

30—Variation of registration

(1) The Minister may vary the terms or conditions of an importer's registration by written notice to the importer as the Minister considers appropriate.

(2) The Minister's power under this section may be exercised on the Minister's own initiative or on the application of the registered importer and payment of the prescribed fee.

31—Surrender of registration

A registered importer may surrender the registration to the Minister.

32—Suspension or cancellation of registration

(1) The Minister may suspend or cancel the registration of an importer if—

(a) the registration was obtained improperly; or

(b) the registered importer—

(i) has ceased to undertake the activity authorised by the registration; or

(ii) has not paid fees or charges payable to the Minister within the required time; or

(iii) has been guilty of a contravention of a condition of the registration; or

(iv) has committed an offence against this Act; or

(v) has been convicted of an indictable offence.

(2) A suspension under this section may be for a specified period, or until the fulfilment of specified conditions, or until further order of the Minister.

(3) A suspension under this section may—

(a) be effective immediately; or

(b) be expressed to have effect at a specified future time; or

(c) be expressed to have effect at a specified future time unless a specified condition is fulfilled.

(4) The Minister must—

(a) notify the registered importer in writing of the action taken or proposed to be taken specifying the reasons for the action; and

(b) allow the registered importer at least 14 days within which to make submissions to the Minister in relation to the action or proposed action (as the case may be).

(5) If the Minister suspends or cancels a registration, the holder of the registration must, within 14 days of the suspension or cancellation, return the registration to the Minister.

Maximum penalty: $1 250.

Expiation fee: $160.

(6) In this section—

registered importer includes an importer whose registration has been suspended.

33—Offence

A person must not bring or introduce into the State plants or plant related products for sale or any other commercial purpose except as authorised by registration granted under this Division.

Maximum penalty:

(a) in the case of a body corporate—$20 000;

(b) in the case of a natural person—$5 000.

Expiation fee:

(a) in the case of a body corporate—$500;

(b) in the case of a natural person—$315.

Division 4—Register

34—Register

(1) The Minister must maintain a register of—

(a) production areas accredited under Division 1; and

(b) persons accredited under Division 2; and

(c) importers registered under Division 3.

(2) The register may contain the information and be kept in the form that the Minister considers appropriate.

Division 5—Reviews

35—Review by Minister

(1) A person may apply to the Minister for review of a decision of the Minister—

(a) refusing an application for the grant of accreditation under Division 2; or

(b) refusing an application for the grant of registration under Division 3; or

(c) imposing or varying conditions of any such accreditation or registration; or

(d) suspending or cancelling any such accreditation or registration.

(2) An application for review of a decision of the Minister must be made within 28 days after the day on which the person is given written notice of the decision.

(3) The Minister may determine an application for review as the Minister thinks fit.

(4) A review must be determined within 28 days of the application being lodged with the Minister.

(5) If a review is not determined within that period, the Minister is to be taken to have confirmed the decision.

36—Review by Tribunal

(1) An applicant for a review by the Minister who is not satisfied with the decision of the Minister on the review may apply to the Tribunal under section 34 of the *South Australian Civil and Administrative Tribunal Act 2013* for a review of the Minister's decision.

(2) Subject to subsection (4), an application must be made within 28 days of the making of the Minister's decision.

(3) The Minister must, if required by the applicant for the review, state in writing the reasons for the decision.

(4) If the reasons of the Minister are not given to the applicant for the review in writing at the time of making the decision and that person (within 28 days of the making of the decision) requires the Minister to state the reasons in writing, the time for commencing proceedings before the Tribunal runs from the time at which that person receives the written statement of those reasons.

(5) In this section—

Tribunal means the South Australian Civil and Administrative Tribunal established under the *South Australian Civil and Administrative Tribunal Act 2013*.

Part 5—Enforcement

Division 1—Approved auditors

37—Approved auditors

(1) The Minister may approve a person as an auditor for the purposes of this Act if the Minister is satisfied that the person can provide satisfactory and efficient audit services for the purposes of this Act and that the services will be provided by suitably qualified persons.

(2) An approval is subject to conditions imposed by the Minister.

(3) Without limiting subsection (2), the conditions may include the following:

(a) a condition requiring the person to enter into an agreement (an ***audit agreement***) with the Minister;

(b) a condition limiting the functions or powers of the person;

(c) a condition limiting the area of the State in which those functions or powers may be exercised;

(d) a condition fixing fees to be paid to the Minister.

(4) An audit agreement—

(a) must regulate the provision of audit services for the purposes of this Act; and

(b) must provide that the agreement terminates if the approval is withdrawn by the Minister; and

(c) must set out the requirements relating to audit reports including the content of the reports; and

(d) may regulate the charges to be made by the auditor for audit services under this Act (by fixing specific charges or maximum and minimum charges or by setting out a method of calculating charges); and

(e) may regulate the withdrawal of audit services for non-payment of charges; and

(f) may provide for the suspension of obligations under the agreement in specified circumstances; and

(g) may contain any other provision agreed between the Minister and the person.

(5) The Minister and an approved auditor may, by agreement, vary or terminate an audit agreement.

(6) The Minister may, by written notice to the approved auditor—

(a) impose a further condition of approval; or

(b) vary or revoke a condition of approval; or

(c) cancel the approval if satisfied that the auditor is in breach of a condition of the approval or a term of the audit agreement between the auditor and the Minister.

(7) An approval or audit agreement under this section does not derogate from the right of an inspector to exercise a power under this Act.

38—Duty of auditor to report certain matters

If, in the course of conducting an audit in respect of an accredited person, an approved auditor forms a reasonable belief that the accredited person—

(a) has engaged or is engaging in conduct that constitutes a breach of a prescribed accreditation condition; or

(b) has engaged or is engaging in conduct of a prescribed kind,

the auditor must, as soon as reasonably practicable, inform the Minister of the name and address of the accredited person and the details about the facts and circumstances giving rise to the belief.

Maximum penalty: $5 000.

39—Offence to hinder or obstruct auditor

A person who hinders or obstructs a person performing an audit under this Division is guilty of an offence.

Maximum penalty: $5 000.

Division 2—Inspectors

Subdivision 1—Appointment and identification

40—Appointment of Chief Inspector and deputy

(1) The Minister may, by instrument in writing, appoint a person to be the Chief Inspector for the purposes of this Act.

(2) The Minister may, by instrument in writing, appoint a person to be the deputy of the Chief Inspector, and a person so appointed has, while acting in the absence of the Chief Inspector, all the powers and functions of the Chief Inspector under this or any other Act.

41—Appointment of inspectors

(1) The Minister may, by instrument in writing, appoint persons to be inspectors for the purposes of this Act.

(2) An appointment under subsection (1) may be conditional.

42—Identification of inspectors

(1) An inspector must be issued with an identity card in a form approved by the Minister—

(a) containing a photograph of the person and the person's name or a unique identification code; and

(b) stating that the person is an inspector under this Act.

(2) An inspector must, at the request of a person in relation to whom the inspector intends to exercise any powers under this Act or any other Act, produce his or her identity card for inspection by the person.

(3) If a person in possession of an identity card issued to the person under this section ceases to be an inspector, the person must immediately return the identity card to the Minister.

Maximum penalty: $1 250.

Subdivision 2—Powers

43—General powers

(1) An inspector may—

(a) enter and search and, if necessary, use reasonable force to break into or open—

(i) any premises or vehicle; or

(ii) part of, or anything in or on, any premises or vehicle; and

(b) enter premises to carry out an investigation under section 44; and

(c) enter premises to—

(i) apply, instal, inspect or retrieve a bait, lure, trap or other equipment for the purpose of monitoring, controlling or eradicating a pest; or

(ii) carry out any other work or operation as may be necessary for the identification, destruction or suppression of a pest; and

(d) give directions with respect to the stopping or movement of a vehicle; and

(e) require a person to produce a document, including a written record that reproduces in an understandable form information stored by computer, microfilm or other process; and

(f) examine, copy or take extracts from a document or information so produced or require a person to provide a copy of any such document or information; and

(g) verify that a certificate or other document relating to a plant or plant related product complies with the requirements of this Act or a corresponding law; and

(h) verify that the packaging or labelling of plants or plant related products complies with the requirements of this Act or a corresponding law; and

(i) take photographs, films or audio, video or other recordings; and

(j) seize and retain any insect or other pest, or plant or plant related product, that the inspector reasonably suspects has been used in, or may constitute evidence of, a contravention of this Act; and

(k) seize any plant or plant related product brought into a place, removed from a place, or moved from 1 place to another, in contravention of this Act; and

(l) require a person holding or required to hold an accreditation or registration under this Act to produce it for inspection; and

(m) require the owner of any plant, plant related product or other thing to deliver it to a quarantine station; and

(n) identify, by marking, tagging or otherwise, any premises, plant, plant related product or other thing in respect of which powers have been exercised under this Act; and

(o) erect signs at, on or near any place or area in respect of which powers have been exercised under this Act; and

(p) require a person who the inspector reasonably suspects has committed, is committing, or is about to commit, a contravention of this Act to state the person's full name and usual place of residence and to produce evidence of the person's identity; and

(q) require a person who the inspector reasonably suspects has knowledge of matters in respect of which information is required for the administration or enforcement of this Act to answer questions in relation to those matters; and

(r) give a direction required in connection with the exercise of a power conferred by this Act or otherwise in connection with the administration or enforcement of this Act.

(2) An inspector—

(a) may only exercise the powers conferred by subsection (1) as reasonably required for the administration and enforcement of this Act; and

(b) may only exercise the power to use force under subsection (1)(a) on the authority of a warrant issued by a magistrate or in circumstances in which the inspector reasonably believes that urgent action is required in order to prevent or mitigate the spread of a pest; and

(c) may only exercise the power conferred by subsection (1)(c) if the occupier of the premises—

(i) has been given 24 hours notice in writing; or

(ii) has consented to the entry.

(3) Despite subsection (2)(c), this section does not authorise an inspector to enter a part of premises occupied as a residence except—

(a) with the consent of the occupier; or

(b) on the authority of a warrant issued by a magistrate.

(4) If an inspector seizes any plant or plant related product under subsection (1)(k), the inspector may do 1 or more of the following in relation to the plant or plant related product:

(a) retain it;

(b) cleanse, disinfect or otherwise treat it or subject it to treatment;

(c) submit it for scientific testing and analysis for the purposes of determining whether it is affected by a pest or a chemical residue;

(d) return it to its owner subject to any specified conditions (including conditions requiring payment of costs and expenses reasonably incurred in taking action in relation to it under this section);

(e) destroy or otherwise dispose of it.

(5) An inspector may be assisted in the exercise of powers under this Act by such persons as the inspector considers necessary in the circumstances.

(6) An inspector may require an occupier of premises or a person apparently in charge of a vehicle or other thing to give to the inspector or a person assisting the inspector such assistance as is reasonably required by the inspector for the effective exercise of powers under this Act.

44—Power to investigate

(1) An inspector may carry out an investigation as reasonably necessary for the purposes of—

(a) determining whether a plant or plant related product is affected by a pest; or

(b) determining the presence of noxious insects or other pests; or

(c) identifying or tracing any cause or source or potential cause or source of a pest.

(2) An inspector may, for the purposes of an investigation under this section, examine, take samples from or test any insect or other pest, plant or plant related product.

45—Power to issue plant health certificates

(1) An inspector may issue a plant health certificate in a form approved by the Minister in relation to plants or plant related products—

(a) grown, produced, processed, packed, used, treated or tested in the State; or

(b) to be brought or introduced into the State.

(2) Without limiting the generality of subsection (1), a plant health certificate issued in relation to a plant or plant related product may certify as to any of the following matters:

(a) that it is free of any or a specified pest;

(b) that it is free of any or a specified pest, disease, pest infestation, infection or condition within the meaning of a corresponding law;

(c) that it is in a specified condition;

(d) that it is from a specified area;

(e) that it has been treated in a specified way or with specified treatments;

(f) that it has been transported in a specified manner or via a specified route;

(g) that it complies with specified accreditation conditions;

(h) that it meets specified requirements;

(i) as to any other matter specified in the certificate.

(3) Before issuing a plant health certificate in relation to a plant or plant related product, the inspector may do 1 or more of the following:

(a) inspect the plant or plant related product;

(b) take samples of or from the plant or plant related product;

(c) supervise the treatment or grading of the plant or plant related product;

(d) inspect or test materials, chemicals or equipment used to treat or grade the plant or plant related product;

(e) do any other thing the inspector reasonably considers necessary in the circumstances.

(4) A plant health certificate may be issued in relation to the movement of a plant or plant related product within the State, into or out of the State, or for another purpose.

(5) A person who is not an inspector must not issue a plant health certificate.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

(6) A person must not alter, or permit to be altered, any information or statement in a plant health certificate unless—

(a) the alteration is authorised in writing by an inspector; or

(b) the alteration—

(i) relates to the splitting of a consignment to which the certificate relates; and

(ii) is made by a person authorised by accreditation granted under Part 4 Division 2 to split consignments.

Maximum penalty:

(a) in the case of a body corporate—$100 000;

(b) in the case of a natural person—$20 000.

Subdivision 3—Miscellaneous

47—Warrant procedures

(1) A magistrate must not issue a warrant for the purposes of this Part unless satisfied that the warrant is reasonably required in the circumstances.

(2) An application for a warrant may be made personally or, if, in the opinion of the applicant, the warrant is urgently required and there is not enough time to lodge a written application and appear before a magistrate, by fax transmission or telephone.

(3) The grounds of an application for a warrant must be verified by affidavit.

(4) If an application for the issue of a warrant is made by fax transmission, the following provisions apply:

(a) the application must be in a form approved by the Chief Magistrate;

(b) the application must be accompanied (through fax transmission) by an affidavit made by the applicant verifying the facts referred to in the application;

(c) the applicant must be available to speak to the magistrate by telephone;

(d) the magistrate is entitled to assume, without further inquiry, that a person who identifies himself or herself as the applicant acting in the capacity of an inspector during a telephone conversation with the magistrate is indeed the applicant acting in that capacity;

(e) the magistrate may, on being satisfied as to the circumstances of urgency and the grounds for the issue of a warrant, make out and sign a warrant;

(f) the warrant is to be taken to have been issued, and comes into force, when signed by the magistrate;

(g) the magistrate must forward the warrant to the applicant by fax transmission.

(5) If an application for a warrant is made by telephone, the following provisions apply:

(a) the applicant must inform the magistrate of the applicant's name and identify himself or herself as an inspector and the magistrate, on receiving that information, is entitled to assume its accuracy without further inquiry;

(b) the applicant must inform the magistrate of the purpose for which the warrant is required, the grounds on which it is sought and the circumstances giving rise to the urgency of the application;

(c) the magistrate may, on being satisfied as to the circumstances of urgency and the grounds for the issue of the warrant, inform the applicant of the facts on which the magistrate relies as grounds for the issue of the warrant, and must not proceed to issue the warrant unless the applicant undertakes to make an affidavit verifying those facts;

(d) if the applicant gives such an undertaking, the magistrate may then make out and sign a warrant;

(e) the warrant is to be taken to have been issued, and comes into force, when signed by the magistrate;

(f) the magistrate must inform the applicant of the terms of the warrant;

(g) the applicant must fill out and sign a warrant form (the ***duplicate warrant***) that—

(i) sets out the name of the magistrate who issued the original and the terms of the warrant; and

(ii) complies with any other prescribed requirements;

(h) the applicant must, as soon as practicable after the issue of the warrant, forward to the magistrate an affidavit verifying the facts referred to in paragraph (c) and a copy of the duplicate warrant.

(6) A warrant, if not executed at the expiration of 1 month from the date of its issue, then expires.

48—Offence to hinder etc inspectors

A person who—

(a) hinders or obstructs an inspector, a person assisting an inspector, or an animal accompanying an inspector, in the exercise of powers under this Act; or

(b) refuses or fails to comply with a requirement or direction of an inspector under this Act; or

(c) removes, damages or interferes with any notice, sign, identification mark, label, tape, seal, lock or other device used for the purposes of this Act; or

(d) when required by an inspector under this Act to answer a question, refuses or fails to answer the question to the best of the person's knowledge, information and belief; or

(e) falsely represents, by words or conduct, that he or she is an inspector,

is guilty of an offence.

Maximum penalty: $5 000.

Part 6—Miscellaneous

49—Delegation

(1) The Minister may delegate to a body or person (including a person for the time being performing particular duties or holding or acting in a particular position) a function or power of the Minister under this Act.

(2) The Chief Inspector may delegate to a person (including an inspector) a function or power of the Chief Inspector under this Act.

(3) A delegation under this section—

(a) must be by instrument in writing; and

(b) may be absolute or conditional; and

(c) does not derogate from the power of the delegator to act in any matter; and

(d) is revocable at will.

(4) A function or power delegated by the Minister under this section may, if the instrument of delegation so provides, be further delegated.

50—Compensation

(1) The Minister may pay compensation to any person who has suffered loss or damage as a direct consequence of a notice or an order made under Part 2.

(2) An application for compensation under this section—

(a) must be in writing; and

(b) must be made in a manner and form determined by the Minister; and

(c) must be supported by such evidence as the Minister may require.

(3) No action lies against the Minister to compel the Minister to make a payment of compensation under this section.

51—False or misleading statements

A person must not make a statement that is false or misleading in a material particular (whether by reason of the inclusion or omission of a particular) in an application made, information provided, or a certificate issued, under this Act.

Maximum penalty:

(a) if the person made the statement knowing that it was false or misleading—$10 000;

(b) in any other case—$5 000.

52—Self-incrimination

If a person is required to answer a question or to produce, or provide a copy of, a document or information under this Act and the answer or document or information would tend to incriminate the person or make the person liable to a penalty, the person must nevertheless answer or produce, or provide a copy of, the document or information, but the answer or document or information will not be admissible in evidence against the person in proceedings for an offence or for the imposition of a penalty other than proceedings in respect of the making of a false or misleading statement or declaration.

53—Service of notices and orders

(1) A notice or order required or authorised by this Act to be given or issued to a person may be given or issued—

(a) by delivering it personally to the person or an agent of the person; or

(b) by leaving it for the person at the person's place of residence or business with someone apparently over the age of 16 years; or

(c) by posting it to the person or agent of the person at the person's or agent's last known place of residence or business.

(2) Without limiting subsection (1), a notice or order required or authorised to be given to a person under this Act may be given or issued—

(a) by posting it to the person at the address last provided to the Minister by the person for that purpose; or

(b) by transmitting it to the person by fax transmission or email to the fax number or email address last provided to the Minister by the person for that purpose; or

(c) in the case of a company or registered body within the meaning of the *Corporations Act 2001* of the Commonwealth—in accordance with that Act.

54—Vicarious liability

(1) For the purposes of this Act, an act or omission of an employee or agent will be taken to be the act or omission of the employer or principal unless it is proved that the act or omission did not occur in the course of the employment or agency.

(2) If a body corporate is guilty of a prescribed offence, each member of the governing body of the body corporate is guilty of an offence and liable to the same penalty as is prescribed for the principal offence when committed by a natural person unless the member proves that he or she could not by the exercise of due diligence have prevented the commission of the offence.

(3) If a body corporate is guilty of any other offence against this Act (other than an offence against the regulations), each member of the governing body of the body corporate is guilty of an offence and liable to the same penalty as is prescribed for the principal offence when committed by a natural person if the prosecution proves that—

(a) the member knew, or ought reasonably to have known, that there was a significant risk that such an offence would be committed; and

(b) the member was in a position to influence the conduct of the body corporate in relation to the commission of such an offence; and

(c) the member failed to exercise due diligence to prevent the commission of the offence.

(4) Subsection (3) does not apply if the principal offence is—

(a) an offence against section 6(2), 11(2), 12, 13, 14, 15, 23, 24, 32, 33, 38, 39, 42, 45, 48 or 51; or

(b) an offence against section 7 that is a minor offence within the meaning of that section; or

(c) an offence against section 8 that is a minor offence within the meaning of that section; or

(d) an offence against section 20(3) consisting of a contravention of a prescribed condition of accreditation.

(5) The regulations may make provision in relation to the criminal liability of a member of the governing body of a body corporate that is guilty of an offence against the regulations.

(6) In this section—

prescribed offence means—

(a) an offence against section 6(1), 9, 11(1) or 28; or

(b) an offence against section 7 other than a minor offence within the meaning of that section; or

(c) an offence against section 8 other than a minor offence within the meaning of that section; or

(d) an offence against section 20(3) other than a contravention of a prescribed condition.

55—Evidence

(1) In proceedings, a certificate apparently executed by the Minister certifying as to a matter relating to—

(a) the accreditation of a place; or

(b) the accreditation of a person; or

(c) the registration of an importer; or

(d) the appointment of an inspector; or

(e) the approval of an auditor; or

(f) an order or approval of the Chief Inspector or any other inspector; or

(g) a delegation; or

(h) an exemption; or

(i) a notice; or

(j) an application; or

(k) the receipt or non-receipt of information; or

(l) the amount of costs and expenses incurred in taking specified action,

under this Act constitutes proof, in the absence of proof to the contrary, of the matters so certified.

(2) An allegation in a complaint—

(a) that a specified person is or was the owner or occupier of specified property; or

(b) that specified plants or plant related products were within a specified area; or

(c) that specified plants or plant related products are or were affected by a pest; or

(d) that something done was done without the approval of the Chief Inspector,

constitutes proof, in the absence of proof to the contrary, of the matters so alleged.

56—Commencement of prosecution of offences

Proceedings for an offence under this Act may be commenced at any time within 3 years of the day on which the offence is alleged to have been committed.

57—Continuing offences

(1) If an offence against a provision of this Act is committed by a person by reason of a continuing act or omission—

(a) the person is liable, in addition to the penalty otherwise applicable to the offence, to a penalty for each day during which the act or omission continues of not more than an amount equal to one-fifth of the maximum penalty prescribed for that offence; and

(b) if the act or omission continues after the person is convicted of the offence, the person is guilty of a further offence against that provision and liable, in addition to the penalty otherwise applicable to the further offence, to a penalty for each day during which the act or omission continues after that conviction, of not more than an amount equal to one-fifth of the maximum penalty prescribed for that offence.

(2) For the purposes of this section, an obligation to do something is to be regarded as continuing until the act is done despite the fact that any period within which, or time before which, the act is required to be done has expired or passed.

58—General defence

It is a defence to a charge of an offence against this Act if the defendant proves that the offence did not result from any failure on the part of the defendant to take reasonable care to avoid the commission of the offence.

59—Incorporation of codes and standards

(1) A notice given by the Minister, or a regulation made, under this Act may—

(a) be of general or limited application; and

(b) apply, adopt or incorporate, with or without modification, any code, standard or other document prepared or approved by a body or authority referred to in the notice or regulation as in force from time to time or as in force at a specified time.

(2) If a code, standard or other document is applied, adopted or incorporated in a notice or regulation—

(a) a copy of the code, standard or other document must be kept available for inspection by members of the public, without charge and during normal office hours, at the office of the Chief Inspector; and

(b) in any legal proceedings, evidence of the contents of the code, standard or other document may be given by production of a document apparently certified by or on behalf of the Minister as a true copy of the code, standard or other document.

60—Regulations

(1) The Governor may make such regulations as are contemplated by, or as are necessary or expedient for the purposes of, this Act.

(2) Without limiting subsection (1), the regulations may—

(a) fix fees to be paid in respect of a matter under this Act and regulate, or provide for the Minister to regulate, the payment, recovery, waiver or reduction of such fees; and

(b) exempt, or provide for the Minister to exempt, a class of persons, plants, plant related products or activities from the application of this Act or a specified provision of this Act unconditionally or subject to specified conditions; and

(c) impose fines, not exceeding $5 000, for offences against the regulations; and

(d) fix expiation fees, not exceeding $315, for alleged offences against the regulations.

(3) Regulations under this Act may—

(a) be of general application or limited application; and

(b) make different provision according to the matters or circumstances to which they are expressed to apply; and

(c) provide that a matter or thing in respect of which regulations may be made is to be determined according to the discretion of the Minister or the Chief Inspector; and

(d) include evidentiary provisions to facilitate proof of contraventions of the regulations for the purposes of proceedings for offences.

(4) Regulations under this Act may provide for fees that vary or are determined by the Minister according to factors specified in the regulations.

Schedule 1—Repeal and transitional provisions

Part 2—Repeal

5—Repeal

(1) The *Fruit and Plant Protection Act 1992* is repealed.

(2) The *Noxious Insects Act 1934* is repealed.

Part 3—Transitional provisions

6—Transitional provisions

(1) The person holding appointment as the Chief Inspector, deputy of the Chief Inspector, or inspector, under the repealed Act immediately before the commencement of this Schedule will become, on the commencement of this clause, a person holding the corresponding appointment under this Act.

(2) The notice signed by the Minister on 6 February 2006 (see Gazette 16 February 2006 p552) as varied from time to time and in force immediately before the commencement of this Schedule continues in force and will be taken to be a notice in force under this Act (and the *Plant Quarantine Standard South Australia* adopted under clause 7.1 of that notice will be taken to be adopted in the notice under section 59 of this Act).

(3) A declaration under section 4 of the repealed Act in operation immediately before the commencement of this Schedule that a condition of fruit or plants is a disease will be taken to be a declaration of a pest under section 4 of this Act.

(4) A declaration under section 5 of the repealed Act in operation immediately before the commencement of this Schedule that a place is a quarantine station will be taken to be a declaration that a place is a quarantine station under section 5 of this Act.

(5) A notice under section 13 of the repealed Act in force immediately before the commencement of this Schedule prohibiting the introduction or importation into the State of any specified class of fruit, plant, soil, packaging or other thing will be taken to be a notice prohibiting the bringing or introduction into the State of a specified class of plant or plant related product under section 7 of this Act.

(6) A declaration under section 14 of the repealed Act in operation immediately before the commencement of this Schedule that a place is a quarantine area will be taken to be a declaration that a place is a quarantine area under section 8 of this Act.

(7) A declaration under section 18 of the repealed Act in operation immediately before the commencement of this Schedule will be taken to be a declaration under section 15 of this Act.

(8) A notice incorporating a code, standard or other document under section 29 of the repealed Act in force immediately before the commencement of this Schedule will be taken to be a notice in force under this Act incorporating a code, standard or other document under section 59 of this Act.

(9) In this clause—

repealed Act means the *Fruit and Plant Protection Act 1992* repealed under Part 2 of this Schedule.

7—Regulations

(1) The Governor may, by regulation, make additional provisions of a saving or transitional nature consequent on the enactment of this Act.

(2) A provision of a regulation made under subclause (1) may, if the regulation so provides, take effect from the commencement of this Act or from a later day.

(3) To the extent to which a provision takes effect under subclause (2) from a day earlier than the day of the regulation's publication in the Gazette, the provision does not operate to the disadvantage of a person by—

(a) decreasing the person's rights; or

(b) imposing liabilities on the person.

(4) The *Acts Interpretation Act 1915* will, except to the extent of any inconsistency with the provisions of this Schedule, apply to any amendment or repeal effected by this Schedule.

Legislative history

Notes

- Please note—References in the legislation to other legislation or instruments or to titles of bodies or offices are not automatically updated as part of the program for the revision and publication of legislation and therefore may be obsolete.
- Earlier versions of this Act (historical versions) are listed at the end of the legislative history.
- For further information relating to the Act and subordinate legislation made under the Act see the Index of South Australian Statutes or www.legislation.sa.gov.au.

Legislation amended by principal Act

The *Plant Health Act 2009* amended the following:

Citrus Industry Act 2005

Phylloxera and Grape Industry Act 1995

Principal Act and amendments

New entries appear in bold.

Year	No	Title	Assent	Commencement
2009	2	*Plant Health Act 2009*	12.2.2009	1.8.2009 (*Gazette 30.7.2009 p3437*)
2009	84	*Statutes Amendment (Public Sector Consequential Amendments) Act 2009*	10.12.2009	Pt 115 (ss 268 & 269)—1.2.2010 (*Gazette 28.1.2010 p320*)
2013	16	*Statutes Amendment (Directors' Liability) Act 2013*	23.5.2013	Pt 40 (s 86)—17.6.2013 (*Gazette 6.6.2013 p2498*)
2017	7	*Statutes Amendment and Repeal (Simplify) Act 2017*	15.3.2017	Pt 24 (ss 95 & 96)—15.3.2017: s 2(1)
2017	**51**	***Statutes Amendment (SACAT No 2) Act 2017***	**28.11.2017**	**Pt 36 (ss 199 to 201)—14.12.2017 (*Gazette 12.12.2017 p4960*)**

Provisions amended

New entries appear in bold.

Entries that relate to provisions that have been deleted appear in italics.

Provision	How varied	Commencement
Long title	amended under *Legislation Revision and Publication Act 2002*	1.2.2010
Pt 1		
s 2	*omitted under Legislation Revision and Publication Act 2002*	*1.2.2010*
Pt 4		
s 21		
s 21(1)	amended by 7/2017 s 95	15.3.2017

s 29		
s 29(1)	amended by 7/2017 s 96	15.3.2017
Pt 4 Div 5		
heading	**substituted by 51/2017 s 199**	**14.12.2017**
s 36	**substituted by 51/2017 s 200**	**14.12.2017**
Pt 5		
s 54		
s 54(2)	substituted by 16/2013 s 86	17.6.2013
s 54(3)—(6)	inserted by 16/2013 s 86	17.6.2013
s 46	*deleted by 84/2009 s 268*	*1.2.2010*
Pt 6		
s 49		
s 49(1)	amended by 84/2009 s 269	1.2.2010
Sch 1		
Pt 1	*omitted under Legislation Revision and Publication Act 2002*	*1.2.2010*

Transitional etc provisions associated with Act or amendments

Statutes Amendment (SACAT No 2) Act 2017

201—Transitional provisions

(1) A right of appeal under section 36 of the principal Act in existence before the relevant day (but not exercised before that day) will be exercised as if this Part had been in operation before that right arose, so that the relevant proceedings may be commenced before the Tribunal rather than the District Court.

(2) Nothing in this section affects any proceedings before the District Court commenced before the relevant day.

(3) In this section—

principal Act means the *Plant Health Act 2009*;

relevant day means the day on which this Part comes into operation;

Tribunal means the South Australian Civil and Administrative Tribunal established under the *South Australian Civil and Administrative Tribunal Act 2013*.

Historical versions

1.2.2010

17.6.2013

15.3.2017

Version: 1.8.2022

South Australia

Plant Health Regulations 2022

under the *Plant Health Act 2009*

Contents

1 Short title
2 Commencement
3 Interpretation
4 Declaration of corresponding laws
5 Packaging and labelling of fruit, vegetables and nuts for sale
6 Identification and labelling of plants sold for propagation
7 Accreditation of persons
8 Registration of importers
9 Exemptions
10 Fees

Schedule 1—Prescribed plants for propagation

Schedule 2—Repeal of *Plant Health Regulations 2009*

Legislative history

1—Short title

These regulations may be cited as the *Plant Health Regulations 2022*.

2—Commencement

These regulations come into operation on 1 August 2022.

3—Interpretation

(1) In these regulations, unless the contrary intention appears—

Act means the *Plant Health Act 2009*;

ICA means the scheme for Interstate Certification Assurance relating to plant quarantine requirements developed by the States in accordance with the Memorandum of Understanding agreed on 6 August 1999 at the sixteenth meeting of the Agriculture and Resource Management Council of Australia and New Zealand;

IP number means the unique identifier (comprising a combination of letters and numbers) assigned to an accredited person;

operational procedure means an operational procedure agreed under the ICA included in the list of operational procedures as published from time to time on the website maintained by the Domestic Quarantine Market Access Working Group, a subcommittee of the national Plant Health Committee.

(2) In these regulations, a reference to the ***Plant Quarantine Standard*** is—

(a) a reference to the *Plant Quarantine Standard South Australia* adopted by the notice under the *Fruit and Plant Protection Act 1992* signed by the Minister on 6 February 2006 (see *Gazette 16.2.2006 p552*) as in force immediately before the commencement of clause 6(2) of Schedule 1 of the Act; or

(b) if the Minister, by notice under the Act, adopts some other plant quarantine standard—a reference to that other standard.

4—Declaration of corresponding laws

For the purposes of the definition of ***corresponding law*** in section 3(1) of the Act, the following Acts are declared to be corresponding laws:

(a) the *Pest Plants and Animals Act 2005* of the Australian Capital Territory;

(b) the *Biosecurity and Agriculture Management Act 2007* of Western Australia;

(c) the *Biosecurity Act 2015* of New South Wales;

(d) the *Plant Health Act 2008* of the Northern Territory;

(e) the *Plant Biosecurity Act 2010* of Victoria;

(f) the *Biosecurity Act 2014* of Queensland;

(g) the *Plant Quarantine Act 1997* of Tasmania.

5—Packaging and labelling of fruit, vegetables and nuts for sale

(1) For the purposes of section 12(1)(d) of the Act, a person who packs for sale any fruit, vegetables or nuts must label the packaging as follows:

(a) the label must—

(i) be legibly written in English in permanent ink in letters at least 5 mm in height; and

(ii) be clearly visible on the outside of the packaging;

(b) if the person doing the packing is an accredited person—the label must include—

(i) the date (or date code) on which the produce was packed; and

(ii) a brief description of the contents of the package; and

(iii) the IP number of the accredited person; and

(iv) either—

(A) a code approved by the Chief Inspector for the purposes of this subparagraph indicating where the produce was grown; or

(B) the postcode of the town nearest to the place of production; and

(v) the words "meets ICA" followed by the number that identifies the particular ICA operational procedures that have been followed and met in respect of the produce;

(c) in any other case—

(i) the date (or date code) on which the produce was packed; and

(ii) a brief description of the contents of the package; and

(iii) the district of production; and

(iv) either—

(A) the name, address and postcode of both the grower and packer of the produce; or

(B) the codes approved for the purpose by the Chief Inspector for the purposes of this subparagraph identifying both the packer and grower.

Maximum penalty: $5 000.

Expiation fee: $315.

(2) A person must not pack for sale or sell any fruit, vegetables or nuts in used packaging unless the packaging—

(a) is in good repair; and

(b) is clean and free of extraneous visible matter; and

(c) is free of any objectionable odour; and

(d) is labelled in accordance with subregulation (1).

Maximum penalty: $5 000.

Expiation fee: $315.

(3) This regulation does not apply to a person who has been approved by the Chief Inspector to receive bulk loads of produce for processing.

(4) In this regulation—

date code means a code approved by the Chief Inspector for the purposes of this regulation indicating the date on which produce is packed.

6—Identification and labelling of plants sold for propagation

(1) For the purposes of section 13 of the Act, the plants listed in Schedule 1 are prescribed (a ***prescribed plant***).

(2) A person must not sell for propagation a prescribed plant that has been brought or introduced into the State unless it is accompanied by—

(a) an assurance certificate or a plant health certificate issued in respect of the prescribed plant; and

(b) any other document issued in respect of the prescribed plant as required by the Minister and set out in the Plant Quarantine Standard.

Maximum penalty: $5 000.

Expiation fee: $315.

7—Accreditation of persons

(1) For the purposes of sections 17(1)(c) and 20(2)(f) of the Act, the prescribed protocols and operational procedures are the protocols and operational procedures specified by the Minister in respect of the particular authority conferred by the accreditation granted to a particular applicant.

(2) For the purposes of section 20(3) of the Act, the following conditions are prescribed:

(a) a condition imposed under section 20(2)(e);

(b) a condition imposed under section 20(2)(i).

8—Registration of importers

For the purposes of sections 27(1)(c) and 28(2)(c) of the Act, the prescribed protocols and operational procedures are the protocols and operational procedures specified by the Minister in respect of the particular authority conferred by the registration granted to a particular applicant.

9—Exemptions

The Minister may, in the Minister's discretion, by notice in the Gazette, exempt conditionally or unconditionally a class of persons, plants, plant related products or activities specified in the notice from the application of the Act or a specified provision of the Act, as determined by the Minister.

10—Fees

(1) The Minister may, on application or on the Minister's own initiative, in the Minister's discretion, waive payment of the whole or a part of a prescribed fee.

(2) In addition, the following are exempt from the relevant fees prescribed for the purposes of the Act:

(a) an application for registration as an importer where the applicant is—

(i) an accredited person; or

(ii) an agency or instrumentality of the Crown;

(b) an application for variation of registration as an importer where the applicant is—

(i) an accredited person; or

(ii) an agency or instrumentality of the Crown;

(c) an annual fee payable by a registered importer where the importer is—

(i) an accredited person; or

(ii) an agency or instrumentality of the Crown.

Schedule 1—Prescribed plants for propagation

Common name	Scientific name
Citrus	*Citrus* spp
Date palm offshoots	*Phoenix dactylifera*

Common name	Scientific name
Grapevines	*Vitis* spp
Pinus plants	*Pinus* spp
Tomato plants	*Solanum lycopersicum (syn. Lycopersicon esculentum)*

Schedule 2—Repeal of *Plant Health Regulations 2009*

The *Plant Health Regulations 2009* are repealed.

Legislative history

Notes

- For further information relating to the Act and subordinate legislation made under the Act see the Index of South Australian Statutes or www.legislation.sa.gov.au.

Principal regulations

Year	No	Reference	Commencement
2022	53	*Gazette 7.7.2022 p2135*	1.8.2022: r 2

Fruit Fly Management for Vegetable Growers

Horticulture Innovation Australia

contents

03. Introduction

04. Fruit fly species

06. The life of fruit flies

14. Monitoring

18. Protein baits

22. Male annihilation

24. Female biased traps

26. Physical protection

30. Hygiene

Guide by Dr Jenny Ekman
Applied Horticultural Research
jenny.ekman@ahr.com.au

All photographs and diagrams by AHR unless otherwise indicated

Copyright Horticulture Innovation Australia Ltd.

Acknowledgment: Fruit Fly Management for Vegetable Growers has been produced as part of project VG13042 New in-field treatment solutions to control fruit fly (2). This project output has been funded by Horticulture Innovation Australia Limited using the research and development vegetable levy and funds from the Australian Government.

Disclaimer: Horticulture Innovation Australia Limited (Hort Innovation) and Applied Horticultural Research (AHR) make no representations and expressly disclaim all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in this guide to Fruit Fly Management for Vegetable Growers. Reliance on any information provided by Hort Innovation or AHR is entirely at your own risk. Hort Innovation and AHR are not responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way, including from any Hort Innovation, AHR or other person's negligence or otherwise from your use or non-use of Fruit Fly Management for Vegetable Growers or from reliance on information contained in the material or that Hort Innovation provides to you by any other means.

ahr applied horticultural research

Horticulture Innovation Australia

01.

FRUIT FLIES CAN INFEST MANY FRUITING VEGETABLE CROPS. WHILE COVER SPRAY OPTIONS ARE DECREASING, THERE ARE MANY OTHER TOOLS GROWERS CAN USE. THIS PUBLICATION DESCRIBES THE OPTIONS AVAILABLE AND SUGGESTS BEST PRACTICE BASED ON CURRENT KNOWLEDGE.

Introduction

Fruit flies are a major pest of fruiting vegetable crops, not only because they damage production, but also because of their impact on market access.

Fruit fly management and control have two quite separate objectives

- Producing a marketable crop and
- Accessing fruit fly sensitive markets.

A pest free crop can be produced using a range of control measures to keep damage below an economic threshold. These can include exploitation of fruit fly biology and behaviour, chemical controls, food and para-pheromone lures, physical barriers and postharvest treatments. Systems approaches combine two or more of these strategies, and can be a form of integrated pest management for fruit flies.

In contrast, market access requires a much higher level of certainty that no pests are present. Either probit 9 (99.9968% mortality) or probit 8.7 (99.99% mortality) are likely to be used as a standard, with no consideration given to actual infestation levels in a given consignment, the probability of establishment, or other factors likely to limit risk to the importer. Market access usually requires a postharvest kill step, or at least an inspection, to ensure the product is pest free.

This publication is focused on the first objective – producing a marketable crop. Without this, there is little purpose to progressing towards objective two.

WHAT DO WE KNOW

Nearly all of the research on control measures for fruit flies has focused on tree fruits; a quick assessment suggests that at least 15 papers on tree fruits are published for every paper on vegetables. While research in orchards can provide some useful guidance, it is unclear how readily such strategies can be applied to vegetable crops.

For example, there has been considerable work on how Qfly (Queensland fruit fly, *Bactrocera tryoni*) and Medfly (Mediterranean fruit fly, *Ceratitis capitata)* move about within orchards, including flight distances and searching for hosts. However there is little or no information about how these pests behave in a vegetable crop such as capsicum or squash.

Cucumber fly (*Bactrocera cucumis*) is an important pest of cucurbits but has been barely studied, with little known about behaviour and biology. Other species including Jarvis fly (*Bactrocera jarvisi*), Island fly (*Dirioxa pornia*) and lesser Queensland fruit fly (*Bactrocera neohumeralis*) can also infest fruiting vegetables, but almost nothing is known about them.

THIS PUBLICATION

This publication aims to combine published literature, experimental data, and commercial practices to provide a “Best Bets” manual for fruit fly management on vegetable farms.

The guide is split into sections on:

- Species
- Lifecycle
- Monitoring
- Protein baits
- Male annihilation
- Female biased traps
- Physical protection
- Field hygiene

A number of cover sprays are currently allowed for fruit fly management. Regulations vary between states, and even between regions, with many products covered under temporary permits.

Due to the complexity of issues relating to chemical use, this aspect is not covered in the guide. Growers are advised to seek local professional advice on the use of cover sprays for control of fruit fly.

02.

THERE ARE MANY DIFFERENT FRUIT FLY SPECIES IN AUSTRALIA. IDENTIFYING WHICH ONES CREATE A PROBLEM IN THE CROP IS AN IMPORTANT STEP IN MANAGING THESE PESTS.

Fruit fly species

More than 78 species of fruit fly occur in Australia. While only a few are known to attack vegetable crops, many are of increasing quarantine concern with trading partners. Little is known of most species, including the effectiveness of current control strategies.

QUEENSLAND FRUIT FLY *(Bactrocera tryoni)*

Queensland fruit fly or Qfly is the species most people think about when discussing fruit fly control. Qfly can infest nearly all fruit and fruiting vegetables, including Solanaceae (capsicums, chillies) and cucurbits (zucchini, cucumber).

Qfly is found across the Northern Territory and throughout eastern Australia, stretching from Cape York to East Gippsland in Victoria.

The Fruit Fly Exclusion Zone (FFEZ) was developed to eliminate Qfly from the NSW Riverland and Sunraysia, including east to Shepparton and west to Waikerie. Government officers checked traps and took action if outbreaks occurred.

Over the last few years outbreaks have increased, with flies continuing to be trapped into late autumn. The FFEZ was withdrawn in 2003, leaving only Sunrasia as a designated pest free area. Qfly is now found throughout the eastern states of Australia.

Qfly adults are about 5–8mm long with reddish eyes. They are generally brown with yellow “shoulder pads” and other markings, including a yellow triangle at the base of the thorax (midsection).

MEDITERRANEAN FRUIT FLY *(Ceratitis capitata)*

Medfly is a native of Africa, but has spread widely throughout Europe, Central and South America and the Middle East. It is found in south-west WA, and north along the coast as far as Carnarvon.

Although introduced to eastern Australia, medfly has not been found in the NSW or Qld for more than 70 years, probably due to competition from Qfly.

Like Qfly, Medfly can infest a very wide range of fruit and fruiting vegetables. Medfly is somewhat smaller than Qfly, with adults around 3-5mm long. It is quite colourful, with black and silver patches on its thorax (middle) and a striped brown abdomen.

Female Qfly

Female Medfly (Photo by USDA)

Qfly (left) and lesser Qfly (right). Lesser Qfly lacks one set of yellow 'shoulder pads'. (Photo by UNSW Fruit Fly Lab)

LESSER QUEENSLAND FRUIT FLY *(Bactrocera neohumeralis)*

Lesser Qfly infests a similar range of crops as Qfly. It is thought to occur in large numbers, especially in northern areas, where populations may be similar to those of Qfly.

It is difficult to distinguish Lesser Qfly from Qfly, as they are closely related and look very similar. Lesser Qfly is slightly darker than Qfly, and lacks one set of yellow "shoulder pads". However the main difference between the two is that Lesser Qfly mates during the day, whereas Qfly mates at dusk.

Lesser Qfly has been raised as a quarantine pest by a number of trading partners.

CUCUMBER FLY *(Bactrocera cucumis)*

Until recently, cucumber fly was not considered of great economic importance. However, outbreaks are becoming more frequent in areas producing pumpkins, melons, squash, zucchini and other cucurbit crops. It can also occasionally infest capsicums and other Solanaceae. Cucumber fly is likely to present increasing problems in the future.

Cucumber fly does not respond to the lures used for other fly species. As a result its distribution is poorly understood, although it is known to occur in south-east Queensland and northern NSW.

Cucumber fly is lighter brown and more slender than Qfly. It also has a distinctive yellow keel in the centre of its back, so the two species are fairly easy to distinguish.

NB. Cucumber fly has recently been renamed *Zeugodacus cucumis*

JARVIS'S FLY *(Bactrocera jarvisi)*

Like cucumber fly, Jarvis fly is increasingly being recognized as a major pest. It attacks capsicums and chillies, and possibly other fruting vegetables. It is very common in north Queensland, where populations may be greater than Qfly. It is found from Broome through the Northern Territory, and south as far as Maryborough in Queensland. Jarvis fly has recently been discovered to respond to the lure zingerone, which should allow more information on distribution to be collected.

Jarvis fly looks somewhat similar to Qfly, which may be one reason it has only recently been recognized as an important pest. It can be distinguished by the more intense striping on its abdomen, which has a distinct, wide cream band with dark stripe either side and a dark keel to the tip of its tail (like a 'T'). The thorax is an even, red-brown colour and female flies have a longer ovipositor than Qfly.

Male cucumber fly (Photo by M Tattersall)

Female Jarvis fly (Photo by G Cocks)

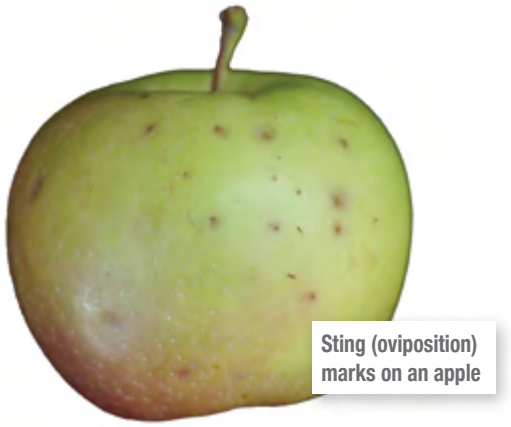
03.

UNDERSTANDING THE LIFECYCLE AND BEHAVIOUR OF FRUIT FLIES PROVIDES MANY CLUES AS TO THE BEST WAY TO PREVENT THEM INFESTING VEGETABLE CROPS.

The life of fruit flies

From a freshly laid egg to an adult fly laying several hundred eggs, a fruit fly generation can be completed in less than a month. Understanding this lifecycle can help identify management practices that can control these pests. The information in this section is based primarily on Qfly. Other species are similar, but specific details will vary.

Female Qfly laying eggs



Sting (oviposition) marks on an apple

LAYING EGGS

A female Qfly can potentially lay more than 500 eggs during her lifetime, while a Medfly can lay over 700. All female fruit flies are equipped with a sharp ovipositor, which they use to deposit eggs just under the skin of the host fruit. Both Qfly and Medfly ovipositors are not very strong, so they often use a natural opening, like a split, wound or the fruit lenticels (breathing holes) to lay into.

Female Qfly find it difficult to lay eggs directly into smooth, firm fruit with no natural openings – such as a cherry tomato. Their ovipositor simply slides off the surface, unable to pierce the skin.

EGGS

It takes a female fruit fly only 2–5 minutes to lay a batch of at least six, and up to 20, eggs into the host fruit. Fruit fly eggs are white, slender and around 1mm long, so barely visible with the naked eye. They hatch after around 1-2 days at 26°C.

"Sting" marks, where flies have laid eggs, are easy to see on light coloured fruit such as apples and loquats. However, they are more difficult to detect on vegetable crops.

Eggs laid into a red capsicum

When larvae hatch they use bacteria to dissolve the fruit flesh so they can digest it (left). They can eat out a capsicum, leaving only the fruit skin (centre). In other fruit, they head to the centre and eat out the core (right)

LARVAE

Qfly larvae are less than 2mm long when they hatch, but grow quickly. They mature after only 6 days at 26°C, reaching 5-9mm long. Medfly larvae are a little slower, taking around two weeks to mature in summer, but up to 45 days in winter. When mature, their black feeding hook can be easily seen. Both Qfly and Medfly larvae are a creamy colour, with guts coloured by the food they are eating.

Fruit fly larvae are associated with a number of bacteria. The bacteria help break down the fruit flesh into a semi liquid, making it easy for the larvae to scoop up and digest. This is why they cause so much damage.

Larvae feed underneath the fruit skin, so damage may not be easily seen from the outside. Sunken or discoloured areas can indicate where the underlying flesh has been broken down, leaving the skin intact.

Breaking the fruit open reveals soft, cavity riddled flesh but without obvious fungal infection. In orchard fruit such as stonefruit and apples, the maggots burrow their way into the centre of the fruit, which can become quite brown and slimy.

Pupal cases. Note that some pupae are intact, but in others the cap has come off and the fly emerged, leaving behind just the empty shell.

Infested capsicum from the outside

PUPAE

Once larvae mature they hop from the fruit and bury themselves in the soil. Here they form a pupae. Pupae look like large grains of brown rice.

It takes around 10 days for the larva to re-assemble itself inside its pupal case, becoming a fly. When it is ready to emerge the young fly breaks the top off the pupal case (operculum) and scrambles to the soil surface. In the picture above, some of the flies have emerged, leaving behind the empty pupal cases.

Fly feeding on sugar syrup on a leaf (left) and males gathered together in a citrus tree at dusk (right)

ADULTS

Once the adult fruit fly emerges and expands its new wings, the first thing it needs is a drink of water. In warm conditions, flies will die in less than 48 hours without water.

As flies can't feed on solids, they need either liquid food or food they can dissolve in regurgitated gut liquid. It is unclear what fruit flies feed on in nature, but it is believed food sources include nectar, juice from damaged fruit, honeydew and exudates on leaves.

Both male and female flies need to feed on protein to become sexually mature. This is especially important for the female in order to produce viable eggs. The more protein the female can find, the more eggs she

At dusk, male Qflies gather together at "lekking points" in trees and emit a pheromone to attract female flies

Female (left) and male (right) Qflies

is able to lay. Natural sources of protein include bird droppings and bacteria on leaves.

Fruit flies can breed when daily maximum temperatures are at least 20°C. Under these conditions, and with adequate water and protein, flies become sexually mature 10–14 days after emergence. They then search for a mate.

Qflies only mate for around 30 minutes at dusk. At this time, male flies gather in groups in trees (lekking points) and emit a cloud of pheromone to attract female flies. Males are more likely to mate if they have fed on the para-pheromone cue-lure, as well as if they are able to "sing" (produce a buzzing noise).

Females may mate once or many times. They are more likely to re-mate if they sense their first mate lacked fitness. Female flies can store sperm from a single mating for weeks, using it to fertilise eggs throughout their life.

It is easy to tell male and female flies apart. Female flies have an ovipositor, which protrudes behind them, whereas males simply have a rounded abdomen.

Once the female fly has mated, she searches for a suitable host to lay her eggs. It is believed she mainly uses visual cues, but smell is also important. Her preferred hosts are soft fruit such as peaches, loquats and feijoas. However, potential hosts also include lemons, grapes and even passionfruit. Fruit usually has to be ripe, but flies will lay eggs in unripe fruit if no other hosts are available or populations are high.

Female fruit flies only lay into attached fruit; fruit that is already rotting or on the ground is not attractive. However, infested fruit that has started to decay sometimes detaches from the plant. Orchards with a lot of fallen fruit can prove to be population centres for fruit flies.

Female Qfly on a backyard loquat tree, looking for a good place to lay eggs.

It is not clear how long flies can live in the wild. Adult Qfly survival is poor if average yearly minimum temperatures are below 2.6°C. However, it is widely believed that flies overwinter as adults, not as pupae or larvae. This suggests flies can live for at least three months, possibly longer.

Queensland fruit fly

Bactrocera tryoni

mating and oviposition

14 days

Adult

life c

fly emergence

10 days

Pupae

2 days

larvae hop from fruit

26°C

Eggs

2 days

1st instar larvae

cycle

2 days

2nd instar larvae

2 days

3rd instar larvae

FRUIT FLIES VS VINEGAR FLIES

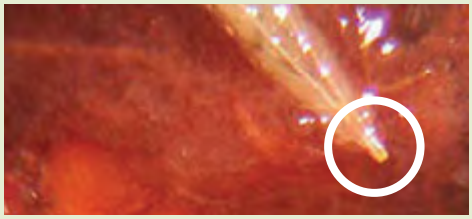
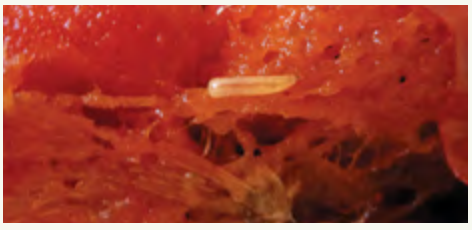
In general, if larvae are found in fruit already rotting on the ground, it has probably been infested by *Drosophila melanogaster* – vinegar fly. It is important to be able to tell the difference between these larvae and those of fruit flies; fruit fly damages intact fruit and can affect market access, whereas vinegar fly only attacks previously damaged fruit and is not a market access issue.

Another larvae sometimes found in rotting capsicums looks very like fruit fly, but has distinct black spiracles at its tail end and a large mouth hook. This is the larvae of *Atherigona* sp.. Like vinegar fly, *Atherigona* lays eggs in damaged or rotting fruit, so is not an economic pest.

Key differences between fruit fly and vinegar fly are shown below.

Atherigona larvae look similar to fruit fly but have black spiracles.

Key Differences Fruit Flies Vs Vinegar Flies:

	Qfly	Vinegar fly
	Generally intact fruit	Rotting fruit or vegetable
Larvae number	Usually 2 – 10 per fruit, but can be 20 or more.	Usually >30 per fruit, rarely <10 per fruit.
Larvae appearance	White to cream, black feeding hook visible in mature larvae, smooth bodied, 2–9mm long.	White with black feeding hook, slightly notched along body, 1–5mm long.
Larvae shape	Wedge shaped, plumper at tail than head.	Slender throughout.
Larvae breathing holes (spiracles)	Very slight bumps for breathing holes in tail end.	Distinct, long breathing tubes coming out of tail end. 
Host material	Soft, spongy, starting to rot. May be fully eaten out with only skin left. 	Liquified and rotting.
Pupae appearance	Like a large grain of brown rice, variable colour.	Like a small, rather slender grain of brown rice, with two small prongs at one end.

FRUIT FLY BEHAVIOUR

Natural habitat

The natural habitat of fruit flies is the forest, particularly the forest edges. They mate in trees, search for host fruit in trees, and generally feed, rest and shelter there as well.

Trees are sources of food and moisture. Bacteria on leaves and bird droppings on branches are also important foods for fruit flies. Food is therefore likely to be much easier to find in the forest than in vegetable crops, which represent a relatively barren environment for fruit flies.

This means that although flies will enter a crop to search for host fruit, they usually travel only a relatively short distance into it. Fruit near the crop edges is the most likely to become infested, especially if trees or other shelter is nearby. As the main reason for being in a vegetable crop is to lay eggs, it seems possible that more female flies enter crops than males.

Damp, tree lined areas along watercourses are good habitats for fruit flies.

Flight distance

Fruit flies are not strong fliers. They spend far more time walking around the tree canopy than flying. When they do fly, it tends to be relatively short distances (5–50cm) from branch to branch, or close to (~2m) the ground in between trees. However, flight is an essential skill. Without it, fruit flies are unable to find a mate or fruit in which to lay eggs.

Flight-ability is affected by factors such as temperature, humidity and nutrition. For example, Qfly is unable to fly at temperatures below 16°C, while Medfly is inactive below 12°C. Flight is also restricted by high winds or low humidity. Conversely, adult flies are able to fly better if they were well-fed as larvae.

As long as food and host fruit are available, 90% of Qflies will range only 600m from where they emerged. Medflies are similar, with 90% of flies travelling less than 700m. Both species rarely travel more than 1km during their lifetime.

One of the reasons flies rarely disperse widely is because it makes it difficult for them to find mates. In the case of Qfly, flies mate for only around 30 minutes at dusk. During this short period groups of males gather together, producing a plume of scented pheromone to attract female flies. It seems likely that the relatively small amount of pheromone produced by a single male makes it difficult to attract distant females. This may be why dispersal more than 1km from their origin results in 'non-viable density' of the population.

On the rare occasions flies do disperse long distances, it is probable this is by accidental "hitch-hiking" on vehicles, equipment or plant material. Reports of Qflies travelling tens of kilometers are likely to be human assisted journeys rather than ones taken by wing power alone! Most outbreaks of fruit flies in remote areas have been linked to infested fruit carried into the region, rather than incursions by travelling flies.

Likes and dislikes

There are conflicting reports about what colours attract or repel fruit flies. There is general agreement that yellow is attractive, which is why many monitoring traps are this colour. However the attractiveness of red, blue and other colours is unclear. This may be because flies see in shorter wavelengths than humans, so items that reflect a lot of ultraviolet (UV) might look quite different to flies than they do to us. It has been shown that reflected UV light can attract fruit flies, especially at dusk.

It is also clear that fruit flies prefer to gather in dark spaces rather than brightly lit ones, probably due to their origin in forests. Conversely, flies appear to be repelled by white. White plastic may be one of the reasons fruit flies almost never enter greenhouse environments.

Fruit flies can be attracted by certain fruit volatiles, as well as by ammonia. There is increasing interest in combining fruit aromas with fruit mimics – generally spheres – to attract female fruit flies.

As previously noted, fruit flies are also attracted to "tree shaped" objects. Damp, tree-lined areas around creeks and dams are good habitats for flies, and it has been suggested that creek-lines are the main route they use to move through the landscape; fruit flies rarely fly directly across open grassland or grain crops.

04.

MONITORING CAN HELP IDENTIFY WHERE FRUIT FLIES ARE COMING FROM, WHETHER POPULATIONS ARE INCREASING OR DECREASING, AND WHAT ACTIONS ARE NEEDED. TRAPS NEED TO BE PLACED IN HIGH-RISK AREAS AS WELL AS AROUND CROP PERIMETERS AND CHECKED REGULARLY.

Monitoring

The purpose of monitoring is to find out whether flies are present, and whether numbers are increasing or decreasing.

- *Monitoring DOES NOT indicate how many flies are in the crop, whether females are present, or fruit are infested. Depending on the crop, even significant numbers of flies in traps does not mean the product is infested.*
- *Monitoring DOES indicate whether control strategies are proving effective. It can also help focus extra control measures on fly hot spots, inside or outside the crop.*

GOVERNMENT MONITORING GRIDS

While there are clear differences between Government grids and monitoring on vegetable farms, these protocols do provide guidance as to trap spacing and actions to be taken.

Monitoring grids are maintained by Government authorities in certain growing regions. These are primarily areas where fruit fly is absent, or pest numbers are low enough to make claims in relation to market access. Monitoring grids may be targeted at detecting any fruit fly (in the case of a fruit fly free production zone) or for detecting incursions of species not present in that area (such as Qfly into WA).

Trapping grids are therefore maintained in areas around ports, in the north of Australia, and regions such as the Sunraysia Pest Free Area in Victoria / NSW. For example, the Tasmanian Government maintains a monitoring grid of over 900 traps for both Qfly and Medfly.

Urban monitoring grids have traps spaced at 400m intervals and are checked weekly, at least during summer. Grids in orchard areas more commonly use 1km spacing. Exotic fly incursions may be detected using grids spaced even more widely, on a 5km grid.

PARAPHEROMONE LURES

Monitoring usually involves traps baited with male attractants – 'parapheromones'. These are manufactured chemicals that have pheromone–like activity. Parapheromones improve mating performance in male flies that have been exposed to them. They do not usually attract female flies.

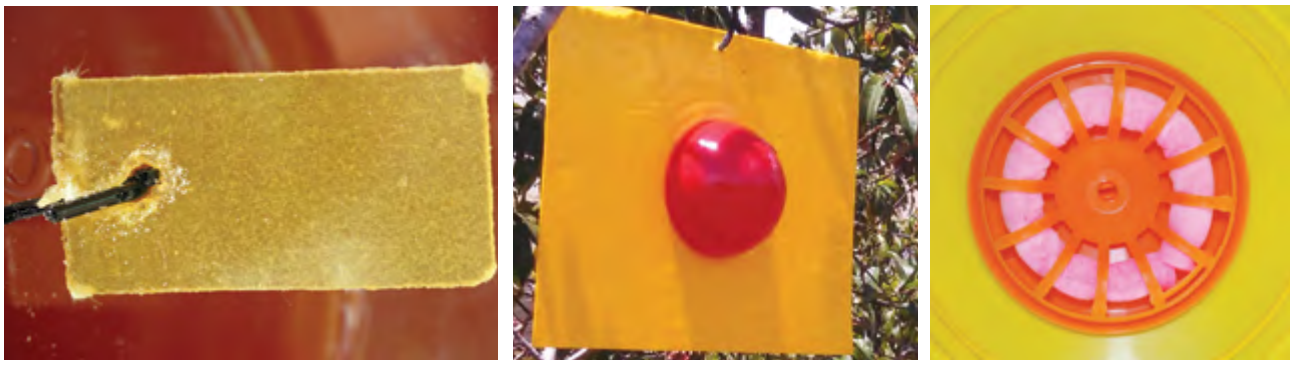
Attractiveness varies by lure and species;

- Cuelure attracts Qfly and lesser Qfly
- Trimedlure attracts Medfly.

Standard actions relating to detections on a 1km grid are:

Fruit Fly Code of Practice, 1993

Fly detection	Time interval	Action
One male	2 weeks	Do nothing
2-4 males	2 weeks	Supplementary trapping
5 males	2 weeks	Control program for >12 weeks within 1.5 km of trap
Gravid female	any	Control program
Larvae in fruit	any	Control program



Wafer type lure (left), Ladd trap (centre) and wick lure (right)

- Methyl eugenol mainly attracts exotic species such as Oriental fruit fly *(B. dorsalis).*
- Zingerone attracts Jarvis fly.

Approximately 40% of fruit fly species do not respond to any of the known para-pheromones. For example, Cucumber fly is an increasingly important pest of cucurbits. Unfortunately it does not respond to any of the existing parapheromones, so cannot be readily monitored. (note: a new lure using cucumber volatiles may provide a monitoring tool in the future).

In addition, monitoring traps have a limited zone of attractiveness. For example, the zone of attraction of cuelure to Qfly is unclear, but may be in the order of 10–20m. The attraction of Medfly to trimedlure is stronger, with flies drawn from 32–50m distance. However, even within this zone, only a percentage of the total population is likely to be captured by the lure. No lure will attract 100% of male flies.

OTHER TYPES OF LURE

If a parapheromone is being used as part of an attract and kill strategy (eg MAT) then monitoring using the same attractant becomes unreliable.

Although lures based on food or volatiles have a smaller zone of attraction than parapheromone lures, they can provide some information about fruit fly populations. Lures containing protein and/or volatiles can attract female as well as male flies. However liquid lures need to be topped up regularly and can become smelly and messy, especially when trying to count flies. They also attract by-catch, such as blowflies and other non-pest insects.

New gel lures are becoming available, but are relatively untested for monitoring purposes.

Fruit mimics can also be used to attract fruit flies. For example, the Ladd trap consists of a sticky yellow sheet and red ball in the centre. The sticky sheet has to be replaced regularly, with flies identified and counted.

TRAP TYPES

There are many different types and styles of traps sold for monitoring Qfly and Medfly. With the exception of visual / aroma based traps such as the Ladd trap, all contain a dispenser for the parapheromone. This is usually a fabric wick or a waxy 'wafer'. The new FT Mallett-CL wafer provides more controlled release of cuelure than fabric wicks, and is very attractive to Qfly.

Traps also contain a contact insecticide, which may be added by the operator or already included in the wick / wafer. Malathion (maldison) and DDVP (dichlorvos) are two insecticides commonly used.

The McPhail trap is the original fruit fly trap once widely used in Government trapping grids. It has a yellow base and clear lid. The lure can be suspended from the lid, or (more often) a liquid protein lure added. Flies enter through a hole in the base. Originally constructed of hard plastic, newer models are more lightweight and less expensive.

The Biotrap also has a clear lid with yellow base. Either a para-pheromone lure or a liquid can be added. When baited with a wax wafer impregnated with cuelure + maldison, the Biotrap has been demonstrated to be a very effective tool for monitoring Qfly.

The Probodelt Conetrap comes flat packed, and is easily clipped together. As the inside of the lid is pre-coated with an insecticide, it can be safely assembled even without gloves. The cuelure is contained inside a tyvec sachet, which is placed inside. Flies enter through inverted side holes but then move towards the light, and are killed on contact with the lid.

Other traps include the Lynfield trap, and similar, modified versions sold by companies such as Organic Crop Protectants (OCP) and Bugs for Bugs. The Lynfield trap is usually baited with dental wicks that have been soaked in cuelure, or other parapheromone, plus maldison. The OCP trap avoids handling risks by using a fabric wick already impregnated with cuelure plus maldison. The wick is secured inside a plastic protector, which is then safely installed under the lid.

Traps (clockwise from top left) – McPhail trap, Biotrap, Conetrap, Lynfield trap and modified Lynfield trap (Organic Crop Protectants, Bugs for Bugs)

TRAP PLACEMENT

The natural habitat of fruit flies is the forest. Flies tend to feed and rest in trees, preferring those near moist areas such as creek lines or dam edges. Trees are also where they go to mate. Fields of vegetables are not the natural habitat of fruit flies, although females will enter them to lay eggs.

The best place for traps is therefore in tree lines around the edges of the crop.

Extra traps can be placed around areas where infestation may come from, such as neighbouring orchards, town areas with backyard fruit trees, or creek lines. Areas with abandoned or unmanaged fruit crops are a particular risk, so well worth monitoring.

Under cold conditions, flies are likely to be attracted to warm spots, such the northern side of trees. However, if conditions are hot and dry, then the flies are more likely to be found on the eastern or southern side of trees.

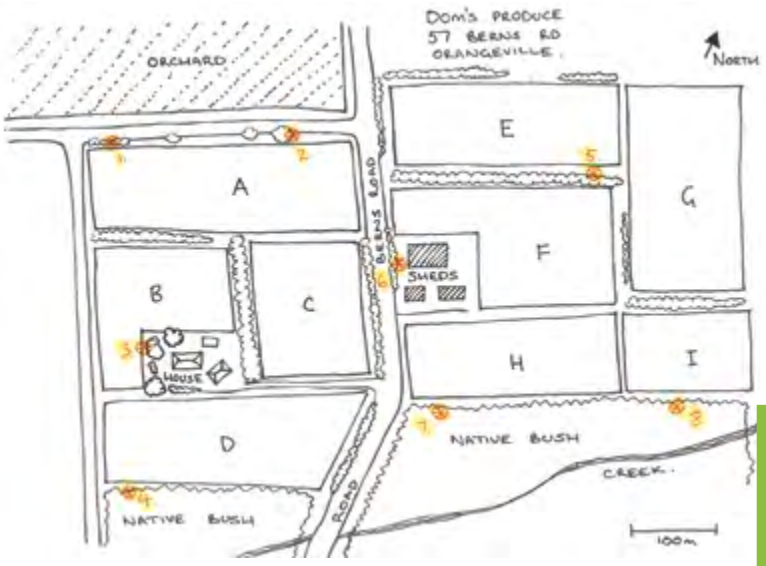
In large cropping areas, or where there are no alternatives, it may be necessary to place traps within the crop itself. However traps attract male flies, whereas it is the female flies that are searching for host fruit. Trap catches of male flies within a crop may therefore provide only limited information on the local population.

CHECKING TRAPS

Traps should be numbered and listed on a farm map, so that anyone can check them. They need to be checked weekly when populations are expected to be increasing or high. For Qfly, this is when daily maximums exceed 22°C. Traps may be checked every 2–4 weeks at other times. The operator needs to record the number of flies found using a record sheet. The trap should then be emptied and reset.

If possible, the operator should also record whether any female flies are found inside the trap – finding a female fly inside a para-pheromone baited can indicate that populations are high, and action needs to be taken.

Checking and maintaining traps takes time. However, the more traps there are, the better the warning of



Farm map showing placement of fruit fly traps

Fruit fly monitoring

Date	Trap no.	Fruit flies	Other

Example of fruit fly record sheet

incursions into the crop. Standard trap spacing is 400m, but it can be useful to include more traps in high-risk areas.

The purpose of monitoring is to detect incursions of fruit flies into the area, and determine whether populations are increasing or decreasing. How this information is used will depend on risk of crop infestation. The actions taken for Government trapping grids shown in Table on page 14 may be useful for areas with low pest populations. However, for areas where fruit flies are present throughout the year, higher action thresholds may be appropriate.

Abandoned citrus orchards are a major potential source of fruit flies, so well worth monitoring with an extra trap.

BEST PRACTICE

- ✔ Monitoring usually involves a para-pheromone lure. Lures need to be appropriate to the target species.
  - The FT Mallett-CL wafer is very effective **for Qfly and lesser Qfly.**
  - **Trimedlure is used for Medfly.**
  - There are currently no commercial lures **for Cucumber fly or Jarvis fly.**
- ✔ Suitable traps include the Biotrap, Conetrap **and versions of the Lynfield trap.**
- ✔ Monitoring traps should be located at least every 400m around the cropping area.
- ✔ It is recommended to install additional traps in high-risk areas, such as adjacent to orchards, near urban areas and along treed watercourses.
- ✔ During cool periods, traps are best located in warm spots, such as the northern side of trees. In hot conditions traps are best in cooler, sheltered areas.
- ✔ Traps need to be numbered and recorded on a farm map.
- ✔ Check traps weekly when populations are increasing or high and every 2–4 weeks at **other times. Record the number of flies,** noting if any are female, and re-set the trap.
- ✔ **For Government run fruit fly monitoring programs, catching 5 male flies or 1 female fly in a single trap within a fortnight** triggers a control program. Higher or lower thresholds may be appropriate for vegetable farms depending on the crop and farm circumstances.

05.

PROTEIN BAITS ARE AN IMPORTANT PART OF ANY FRUIT FLY MANAGEMENT PLAN AS THEY TARGET IMMATURE FEMALE FLIES. THEY SHOULD BE APPLIED WEEKLY ONCE FLIES START TO EMERGE.

Protein Baits

Protein baits can attract both male and female flies. They are especially attractive to newly emerged female flies, which need to feed on protein to mature and develop their eggs. The ingredients used, and how and when baits are applied, greatly influences their effectiveness in the field.

Sprayable baits can contain:

Protein + Insecticide + Carbohydrate + Thickeners

PROTEIN

Protein needs to be partially broken down (hydrolysed) to make it attractive to the flies. Yeast autolysate is the usual protein source used. Commercial products include;

Protein product	Formulation	Protein content	Bait consistency
Fruit Fly Lure™	Thick liquid	420 g/L	Suspension
Natflav 500™	Thick liquid	420 g/L	Suspension
CERABAIT™	Liquid	360 g/L	Suspension
Flavex® FL622	Liquid	140 g/L	Liquid
HYM-LURE™	Liquid	425 g/L	Liquid
ANAMED™ SPLAT (protein)	Paste		Paste
Flavex SPA400	Powder	420 g/L	Liquid
DacGEL™	Powder		Gel

While all of these products provide protein, they have different attractiveness to flies.

Trials conducted by QDAF suggest that Hym-Lure is highly attractive to both Qfly and Jarvis Fly. The bait was applied at 0.84% concentration (2L per 100L water), slightly more concentrated than the suggested label rate of 1.5L per 100L water. Qfly is also strongly attracted to Flavex SPA400, followed closely by Flavex FL622.

Cucumber fly was also strongly attracted to Flavex SPA400, as well as to Fruit Fly Lure.

Note that some growers have found that mixing bait the night before application helps to avoid any potential lumps in solution, especially if a powdered protein source is used.

Female fly feeding on protein bait

INSECTICIDE

Insecticide needs to be mixed with the protein source.

The main two insecticides currently used in protein bait sprays are Maldison and Spinosad. Trichlorfon (Dipterex™ 500) is also registered but considered to be less effective.

Fipronil (Regent® 200SC) and Abamectin (CroPro STEALTH©) have both been shown in trials to be effective against Qfly, while Fipronil and Spinetoram (Success™ Neo) were highly effective against cucumber fly. Unlike Maldison, these insecticides do not have a repellent effect on fruit fly feeding. However, none of these insecticides are currently registered for use in fruit fly baits.

Maldison

Maldison is a highly effective, contact insecticide. This means the fly is killed simply by landing on the bait. It is relatively stable, so remains active for weeks or even months after application. Registered commercial products include HyMal®, Maldison 500™, Amgrow Malathon® and Fyfanon 440 EW®.

Maldison is an anti-cholinesterase compound; it works as a nerve poison. As a result, it is hazardous to humans and other mammals, highly toxic to insects including bees and deadly to fish. Protective equipment must be worn when mixing or applying maldison based baits. Extreme care is needed if applying maldison baits in areas near water-courses or residential areas.

Applying maldison baits in the early morning while conditions are cool will help limit any effect on bees as well as maximise its effectiveness.

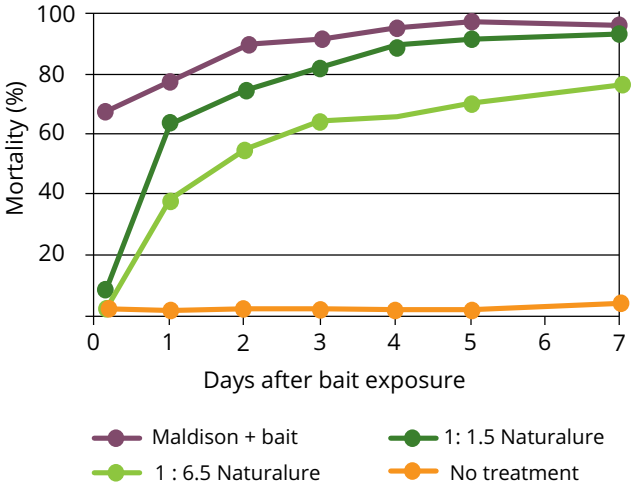
Spinosad

Spinosad kills by ingestion, making it safer for bees and other beneficial insects. It is applied as part of the pre-mixed bait Naturalure™; other formulations of spinosad (eg Success Naturalyte™) are not registered for use in fruit fly baits. Spinosad is derived from a naturally occurring soil bacterium. It is classified as organic (under some schemes) and has very low toxicity to humans. It can therefore be used in sensitive areas and poses minimal risk to worker health and safety.

Spinosad is degraded by UV light. Depending on weather conditions, it remains toxic for 3 to 7 days after application. Baits need to be applied at approximately weekly intervals anyway, and this is particularly important if using Naturalure.

Another factor to consider is that the fly has to eat enough Spinosad to get a toxic dose – if it only eats a little it will not be killed. Sub-lethal doses can increase development of resistance. If flies have already fed on protein they will be less attracted, and eat less of the bait if they do respond. Naturalure is therefore less effective against female flies that have already fed on protein.

The Naturalure label specifies two dilution rates; 1:1.5 and 1:6.5. Different volumes are applied for each rate, so as to deliver the same total amount of Naturalure per hectare. The more concentrated solution is a thick liquid, so difficult to apply through normal spray equipment. However, trials have found that the 1:1.5 dilution rate is more effective at controlling flies. It is also longer lasting in the environment, still killing flies for up to 7 days whereas the 1:6.5 solution loses effectiveness more quickly.



Mortality of Qfly exposed to two different label rates of Naturalure over a seven day period. Results are compared to a standard Maldison + protein bait and no treatment.

Windbreak plants such as sorghum are very suitable for applying baits. Baits for Qfly and Medfly should be applied 1.5-2m above the ground, whereas baits for cucumber fly are best at 1m above the ground, as that is where the flies are likely to be foraging (DeFaveri, 2016).

OTHER INGREDIENTS

Carbohydrate sources – sugars – can be added to baits to increase attractiveness. However, this may also attract non-target insects such as ants and even bees.

Thickeners can increase the time the bait remains effective. Thickened bait is more resistant to washing off during rain or irrigation. Thickeners can also help stop the bait from drying out, which is likely to extend the time it stays attractive.

WHERE TO PUT BAITS

In orchards, baits are usually sprayed on the bases of trees along every second row. However in vegetable crops it is not possible to spray within the crop itself.

Bait must therefore be applied to the perimeter vegetation. This is appropriate, as perimeter vegetation is where flies are most likely to feed, rest and search for mates. Baits have only a very small zone of attractiveness, so they need to be applied where flies are most likely to be.

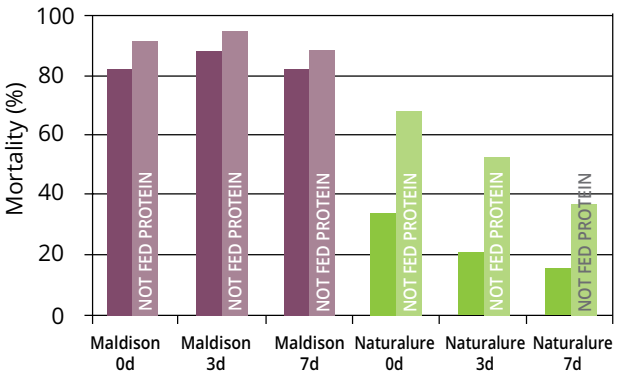
Baits perform better when sprayed onto vegetation than inert surfaces (such as posts, boards etc.). This is thought to be because baits stimulate bacteria already on the plant leaves, and it is volatiles from the bacteria that help attract hungry fruit flies.

The type of plants growing around the perimeter also affects baiting effectiveness. Research by Queensland DAF has found that windbreaks of sorghum, cassava and sweet corn were more suitable for baiting than vegetable crops or permanent hedging plants such as orange jessamine and lilly pilly. This may be due to the density of leaves, which provides sites for roosting and a larger surface for the bait itself.

One of the other criteria for plant suitability is height. Qfly tends to roost high in trees, so baits should be applied 1.5m to 2m above the ground. Cucumber fly, in contrast, tends to stay closer to the ground. In this case baits should be applied at approximately 1m height.

WHEN TO APPLY

After emerging from the pupae, it takes female flies around two weeks to reach full maturity. This is when they most actively search for protein to mature their eggs; once they have fed on protein they are less interested in finding more, although they will feed if it is there in front of them.



Effect of insecticide type and bait age on protein fed (dark bars) and protein deprived (light bars) female Qflies. The trial was conducted in small cages; even accidental contact with the Maldison bait killed flies. Naturalure kills by ingestion so mortality depends on how much the flies eat. Flies fed protein before the trial did not eat the bait, especially if it was a few days old. Flies that had NOT fed on protein before the trial were more likely to eat the bait but still ate less if the bait was old.

Baits need to be where flies will find them, right when they most need a protein meal.

Like bread from the bakery, baits are most attractive when they are fresh. Even though Maldison-based baits can remain active for several weeks, once they have dried out and aged they are not nearly so attractive to flies.

Bait applications therefore need to start when young, female flies are starting to emerge. They should be applied weekly for best effect, or at least every 10 days. Some growers apply every five days, just in case they are forced to miss a date.

Bait applications should use a coarse spray, resulting in droplets of 2mm across. If more than 5mm rain occurs it may be necessary to re-apply the bait.

Fruit flies most actively forage for food in the morning. Spraying early in the day not only reduces risk to bees, it ensures fresh bait is there when flies want it.

As with any other chemical, bait applications need to be recorded.

BEST PRACTICE

- ✔ Baits need to combine an attractive protein source with an effective insecticide.
  - Protein sources Hym-Lure and Flavex **are both very attractive to Qfly and Jarvis fly Natflav 500 is also appropriate.**
  - Flavex and Fruit Fly Lure are very **attractive to Cucumber fly.**
  - Maldison is an effective and long lasting insecticide.
  - Adding a thickener helps to preserve bait in the environment
- ✔ **Naturalure is a less toxic alternative to** maldison-based baits, so may be used in sensitive areas. Apply heavy droplets at the **1:1.5 dilution rate for best results.**
- ✔ **Newly emerged female flies are most** strongly attracted to protein baits. Bait **applications should start when flies are just** starting to appear, before fruit matures.
- ✔ Baits should be applied in the early **morning, when flies are actively searching** for food.
- ✔ **Apply baits weekly when fly populations are** high. If >5mm rain falls bait may need to be re-applied.
- ✔ Spray baits on windbreak plants around the crop perimeter.
  - Dense foliaged plants such as sorghum, cassava or sweet corn are very suitable.
  - Permanent hedging and vegetable crop plants are less attractive.
  - **Baits should be applied at least 1.5m from the ground to target Qfly and Medfly, but 1m from the ground for Cucumber fly.**
- ✔ Like any other chemical, bait applications must be recorded.

Protein bait application record

Date	Start time	Finish time	Location treated	Product	Rate	Equipment	Wind	Operator signature

Sample form for recording sprays of protein bait.

06.

MAT USES A PARA-PHEROMONE LURE PLUS INSECTICIDE TO LURE AND KILL A PERCENTAGE OF MALE FLIES IN THE POPULATION. AS MALES CAN MATE MANY TIMES, MAT NEEDS TO BE COMBINED WITH OTHER CONTROL STRATEGIES TO BE EFFECTIVE.

Male annihilation

The Male Annihilation Technique (MAT) involves the same lures and insecticides that are used for monitoring, just without the trap to retain dead flies.

MAT block made from caneite soaked in a mixture of cuelure and maldison (left), the OCP MAT cup (centre) and Amulet MAT containing cuelure plus fipronil insecticide (right, Photo by Daleys Nursery)

TYPES OF MAT

MAT combines a parapheromone such as cuelure with an insecticide, such as Maldison.

This mixture can be soaked into an absorbent material such as caneite blocks or compressed cardboard and simply hung out in the field. The wick lure used in the OCP / Bugs for Bugs trap can also be used separately as an MAT device. This unit has the advantage that the plastic cap protects the wick from rain and UV, extending its useful life.

Similarly, the Magnet MED trap contains trimedlure inside a protective, laminated shell. The outside of the device is coated with insecticide, and remains able to kill Medfly for approximately 6 months.

Flies which are not attracted to a known parapheromone, such as Cucumber fly, cannot be managed with MAT.

As no trap is involved, MAT blocks are cheap. They can remain both attractive and insecticidal for 3– 6 months depending on weather conditions.

Magnet MED trap for Medfly

Matching Fruit Fly to MAT

Species	Device
Qfly	Cuelure MAT
Lesser Qfly	Cuelure MAT
Medfly	Magnet MED
Jarvis fly	Zingerone lure
Cucumber fly	Unknown

HOW TO USE MAT

Just as with traps, not every male will be attracted to a lure. Parapheromones are attractive to male flies because feeding on them increases their mating success. Just as with protein in baits, they will be less responsive once they have been exposed to cuelure or a similar natural product. MAT is therefore most likely to be effective with newly matured male flies.

As previously noted, para-pheromones have a limited zone of attraction. For example, cuelure can attract Qfly from 10–20m distance. However even within this distance not all flies will respond.

For best results, MAT units need to be spaced regularly around the crop edges and other areas where flies are likely to gather, such as trees near watercourses. Spacing every 20m, or more frequently, will maximise the effects.

The other issue with MAT is that males can mate many times. Even eliminating a large number of males from the population will not prevent female flies from mating and laying eggs.

Finally, if the same lure and kill system is being used for MAT and in traps, this can affect the outcomes of the monitoring program. Reducing the number of male flies caught in traps can suggest that the population is low, when the number of female flies in the crop may actually be increasing in the crop.

MAT needs to be used in combination with other strategies, particularly protein baiting. MAT will be ineffective if used alone.

BEST PRACTICE

- ✔ MAT devices should be installed no more than 20m apart around the crop perimeter and other **places that flies may gather such as trees along watercourses.**
- ✔ Units need to be replaced every 3–6 months to ensure the insecticide remains effective.
- ✔ As MAT uses the same lures and insecticides that are used in monitoring traps, trap data should be interpreted cautiously if MAT is in place.
- ✔ MAT is ineffective used alone, but can be combined with other control strategies, particularly protein baiting.

07.

THERE ARE A NUMBER OF COMMERCIAL DEVICES AVAILABLE THAT LURE AND KILL FEMALE FRUIT FLIES. IT IS NOT CLEAR WHAT PERCENTAGE OF THE POPULATION IS REMOVED, AND SO FAR NONE HAVE BEEN DEMONSTRATED AS EFFECTIVE FOR VEGETABLE CROPS.

Female biased traps

Female biased traps aim to lure and kill a large percentage of the fly population. They can be based on food, fruit volatiles or fruit mimics. Despite many years of searching, there are no pheromone based lures for female fruit flies.

Cera Trap (left) and dead flies inside a trap (right)

CERA TRAP

The Cera Trap is food based, containing a liquid protein mixture with a mild ammonia smell. No insecticide is needed as flies simply drown. The liquid needs to be kept well topped up, so units need to be serviced regularly in hot weather.

Also, the trap can attract significant by-catch – blowflies, ants, etc – especially once captured insects start to rot. If large numbers are caught, the trap contents need to be strained to remove dead insects then replaced into the trap. This is a rather unpleasant and time consuming task.

Cera Traps attract both male and female fruit flies, with a bias to females. While Cera Traps can certainly kill Qfly, Jarvis fly and other fly species, it is unclear what percentage of the local population is trapped by this device.

Liquid protein does not have a strong smell, so the zone of attraction of the Cera Trap appears to be quite limited. Even placing traps at 15m intervals around the perimeter of a cropping area may only kill a relatively small percentage of the population. While it is satisfying to see dead flies in traps, this has not been demonstrated to significantly reduce the number of infested fruit in Australian vegetable crops.

Fruition trap (Photo by Griffith University)

Biotrap with gel attractant and DDVP cube

FRUITION TRAP

This new device (launched November 2016) combines a slow release sachet of fruit volatile aromas with a large, sticky, cobalt blue sphere. Flies attracted by visual and olfactory cues become stuck on the sphere. The developers claim that their synthetic ripe fruit aroma remains highly attractive to Qfly for up to eight weeks, as well as potentially other species. As this is a new device, its effectiveness for vegetable crops has not been tested.

BIOTRAP WITH GEL ATTRACTANT

The Biotrap Fruit Fly Attractant Gel is an ammonia and fruit volatile based gel which is stated to last up to three months. It is combined with a DDVP cube which kills flies entering the trap.

Suggested spacing is 15m intervals around the perimeter of the crop. As this is a new system, its effectiveness for vegetable crops has not been tested.

BEST PRACTICE

- ✔ **Female biased traps can kill a percentage of the fly population.**
- ✔ **They need to be installed at intervals of 15m or less around the crop perimeter then checked** and re-set regularly.
- ✔ There is no published evidence that they are effective in vegetable crops. However, they may be useful in combination with other control strategies.

08.

GREENHOUSE WALLS, NETTING AND EVEN PLANT COATINGS CAN PREVENT OR REDUCE FLIES ENTERING THE CROP AND INFESTING FRUIT. AS WELL AS BEING PHYSICAL BARRIERS, THESE DEFENSES CAN PREVENT FLIES FROM SEEING AND/OR SMELLING POTENTIAL HOSTS.

Physical protection

Physical protection can be expensive and is not suitable for all crops and field situations. However, it is a highly effective way to protect vegetables from fruit fly. It can also provide additional benefits in terms of productivity, quality, reduced irrigation requirements and control of other pests.

Greenhouses offer a major barrier to fruit flies, whether glass (left) or plastic (right). Even though the house shown at right has a retractable roof, flies rarely – if ever – enter this environment.

GREENHOUSES

Fruit flies rarely, if ever, enter greenhouses.

Greenhouse walls are clearly a physical barrier to fruit flies. They usually present a flat, white exterior, the crop inside being obscured.

In contrast, fruit flies are known to orient towards dark, tree shaped objects. They tend to avoid white or reflective areas. This suggests that greenhouses in general are likely to be relatively unattractive.

Although fruit flies could still enter through un-meshed roof vents or opened doors, they generally do not do so. This may be due to their habit of flying low to the ground or darting from tree to tree. Fruit flies rarely fly high across open spaces, such as pastures. They are only likely to enter roof vents if strongly attracted by fruit aroma or pheromone, or if they are blown there accidentally.

NET HOUSES

Net houses can be used to protect crops from weather, sunburn and pests ranging from wallabies to thrips.

The traditional view of netting against fruit fly was that the crop had to be fully enclosed in insect proof netting, with “air-locks” for entry of people and equipment.

However, most of the benefits of netting can be obtained with much lower levels of security.

Net houses, such as this one in Carnarvon WA, can greatly reduce the number of flies entering a crop. Even though flies can physically fit through or go under the mesh, the combination of a visual and a physical barrier greatly reduces incursions.

Hail netting is not fruit fly proof, as holes are large enough for flies to crawl through. Despite this, experience with orchard fruit has shown that installing white hail netting on both top and sidewalls greatly reduces entry of flies into the orchard. Note that white mesh is likely to be better at excluding flies than green or black, as white is repellent to fruit flies.

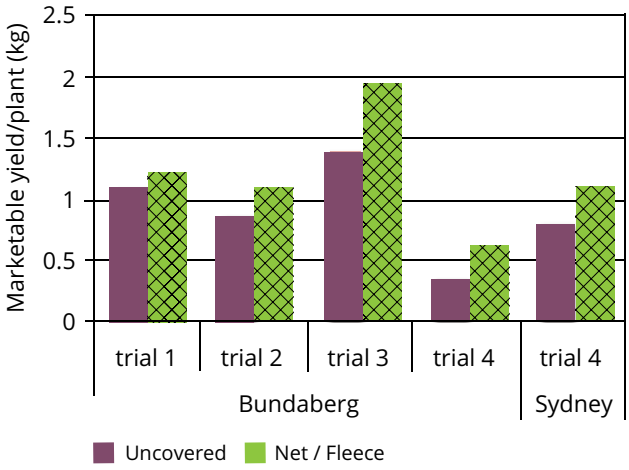
Flies use both visual and scent cues to find host fruit. Hail netting and windbreak materials hide the crop from flies, and may even reduce drifting of fruit aromas. If flies cannot see or smell the fruit, there is no reason for them to try to go inside.

FLOATING ROW COVERS

Unlike the permanent structures required to construct net houses, floating row covers involve simply draping netting over plants and securing the edges with shovelfuls of soil.

Various grades of netting can be used, ranging from coarse windbreak materials to extra fine nets designed to exclude all pests. The weight of materials can be an issue if they are not supported, but upright plants such as capsicums and eggplant can easily support lighter grade nets as they grow.

As with net houses, floating covers can give plants protection from wind, heavy rain and sunburn. They also reduce water requirements and exclude various pests. Light is diffused and evaporation is reduced, resulting in larger and healthier plants. For example, floating covers have been shown to increase marketable yield of capsicums, mainly through improved fruit set and reduced damage from wind and sun.



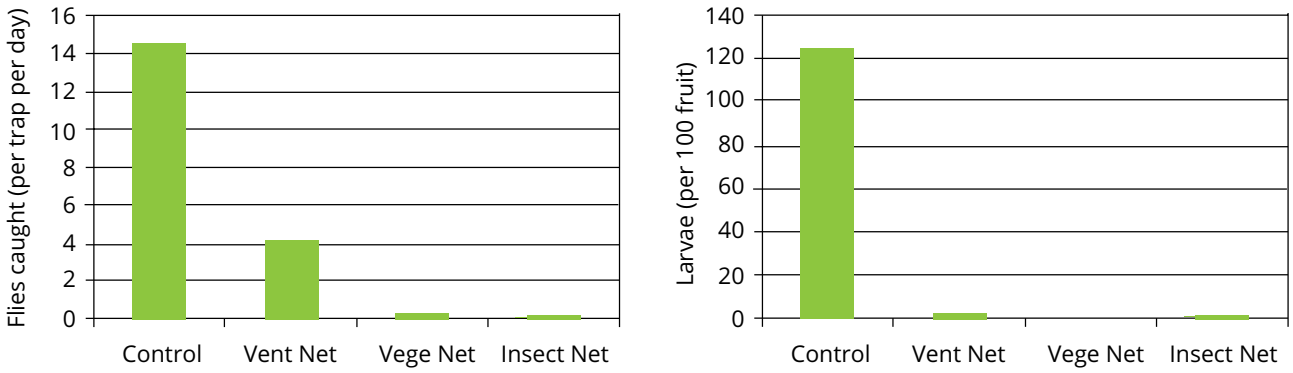
Marketable yield of capsicums (kg/plant) assessed at initial commercial maturity from four separate trials conducted in Bundaberg and southwest Sydney. Capsicums were grown under VegeNet or left uncovered (controls).

Like net houses, floating covers also provide a visual barrier to fruit flies. Even if a few flies do penetrate the netting, the number of infested fruit can be reduced to almost zero.

Lightweight materials such as VegeNet (NetPro) are very suitable for excluding fruit flies from vegetable crops. This material weighs 45g/m² and has mesh size approximately 1 x 3mm.

Trials in Bundaberg and Sydney testing various netting types found that;

- VegeNet was an effective visual barrier and did not exclude natural predators from the crop. No infested fruit were found under this material while it remained intact.



Number of flies caught (left) and number of larvae found per 100 fruit sampled (right) in a cayenne chilli crop where plants were left uncovered (control) or covered with VentNet (windbreak material), VegeNet (lightweight net) or Insect Net (fine net).

- Insect Net with mesh size 0.8mm was relatively transparent. No insecticides were used in the trial and the net excluded beneficial insects, with the result aphids infested the covered plants.
- Although flies could get into crops covered with Vent-Net screening material, oviposition was almost zero. It seems likely male flies were strongly attracted by cuelure in traps under the material, motivating them to find their way through the mesh, whereas female flies were less intent.

Placing netting over the crop while the plants are still small, even before fruit set, gave the best improvements in plant health.

Netting adds cost, both in materials and labour. Accessing the crop is more difficult, which is especially an issue if there are multiple harvests. While netting can be used for several years, cleaning the material between uses (to ensure disease is not spread) also creates challenges.

Single use frost protection fleece materials such as Daltex Groshield or Agryl can make effective insect barriers. While these materials are inexpensive, they tear easily if wind gets beneath the covers. These materials are therefore not suitable for application to upright plants such as capsicums and eggplant, but may be used for low growing crops such as pumpkin.

Male Qfly on the outside of VegeNet, unable to reach the cuelure baited trap inside.

In Europe, mechanical systems are used for installing and recovering floating covers. Such systems could potentially reduce costs and enable use of netting on large scale vegetable farms.

VegeNet (left) and Insect Net (centre) on capsicum plants. VegeNet is 1 x 3mm mesh size and 45g/m^2 whereas Insect Net is 0.8mm mesh and 70g/m^2. Vent-Net (right) on capsicum plants, with plague soldier beetle on the outside.

Kaolin on chilli plants (left), showing the effect after two kaolin applications followed by several rain events. Although some of the material has been washed from the plants, they still appear white from a distance. Kaolin on a potted chili plant (right).

KAOLIN CLAY

Kaolin – aluminium silicate – comes from kaolinite, a natural mineral. It is allowed under organic systems, and has a wide range of both industrial and agricultural uses.

Commercial sprayable kaolin products (eg Surround WP) are most commonly applied to tree crops such as apples and pears to prevent sunburn. The suspension is sprayed on using an agitated tank, coating the plants with fine, white powder. The crystalline structure of the clay reflects red light wavelengths and diffuses sunlight, so photosynthesis is actually increased. Kaolin lowers temperatures on the leaf surface and reduces water loss.

Plants sprayed with kaolin look white – which is repellent to fruit flies. The material also disguises the fruit, which are hard to distinguish from the foliage. Additionally, the fine clay particles are believed to irritate flies that land on the material, discouraging them from settling.

Trials using kaolin clay have found that it can reduce the number of larvae in fruit by 90 to 100% compared to untreated controls.

Kaolin is not without drawbacks. The material is relatively expensive, and has to be applied several times to get a good coating. Kaolin will likely need re-application if it rains or overhead irrigation is used. After harvest fruit needs to be thoroughly washed to remove the material, which usually requires water jets and brushes. It is likely to be difficult to remove all kaolin residues from irregularly shaped products such as capsicums.

BEST PRACTICE

- ✔ Physical barriers are highly effective **against fruit fly.**
- ✔ **Fruit flies rarely enter greenhouses, even** if the roof is open.
- ✔ Floating covers are an effective way to **reduce the number of flies entering a crop** and can also improve plant health.
  - **Net with 1 x 3mm diameter mesh is very suitable for excluding fruit flies.**
  - **Nets that are not insect-proof can still** be effective if they provide a visual barrier.
  - Secure nets well around the edges using shovelfuls of soil.
  - Clean nets between uses to avoid transferring disease to new crops.
  - **Disposable fleece materials could** potentially be used to exclude fruit **flies from low growing plants.**
- ✔ Coating plants with kaolin may be a useful management tool, but cost and issues with removal must be considered.

09.

REMOVING POTENTIAL SOURCES OF INFESTATION CAN STOP FRUIT FLY POPULATIONS BUILDING UP ON FARMS AND HELP PREVENT INCURSIONS FROM NEIGHBOURING AREAS.

Hygiene

On-farm hygiene and biosecurity are good practice in terms of managing ALL pests and diseases, not just fruit flies. Fruit flies can move, which creates additional challenges. However, limiting incursions into a crop can both reduce infestation of fruit and increase the effectiveness of other control measures.

ISOLATING THE CROP

As previously described, fruit flies are tree dwellers, at home in vegetation. They are not strong flyers, generally travelling less than 1km, and usually less than 600m, during their lifetime.

Grassy fields and vacant paddocks offer no food, shelter or potential hosts. Traps located in cereal crops or pastures consistently fail to trap any flies. Fruit flies just don't go there.

Crops that are located well away from orchards, town areas, and natural bushland are likely to be less susceptible to incursions by flies. While flies do move, a 200–400m wide "no-mans-land" around cropping areas still presents a significant barrier to infestation from the surrounding countryside.

Of course, it is not always possible to maintain such a large distance between a fruiting vegetable crop and potential hosts and roosting sites. However, it is worthwhile considering how and where flies can move into the crop from other areas.

This hydroponic tomato farm is located in an area endemic to fruit fly. However the farm is isolated, with more than 1km dry grassland in all directions. Combined with low pest pressure and the high walls of the greenhouse itself, fruit flies are effectively prevented from entering the crop.

Once harvesting has finished, potential fruit fly host crops need to be destroyed as soon as possible.

Cucurbit fruit such as melons or pumpkins can persist for a long time in the field, even after the plants have died (left). This can allow large populations of Cucumber fly to build up (right), then potentially transfer to neighbouring crops.

REDUCING INCURSIONS

Removing feral fruit trees is key to managing fruit flies; a single feijoa tree can produce up to 30,000 flies in a season if left unmanaged.

Backyard trees and urban areas in general are common breeding grounds for fruit flies. Tree owners may be unwilling or unable to control fruit flies themselves.

In addition, urban areas provide overwintering refuges. This is particularly important in regions with cold climates, which are only marginal for fruit fly survival. Microclimates around houses and shops are often significantly warmer than the surrounding countryside, and allow adult flies to survive temperatures that would normally kill them. The flies then disperse to neighbouring crops when the weather is warm enough to fly (>16°C for Qfly, >12°C for Medfly).

Physical barriers, or bare zones, can help prevent incursions from such areas.

Fruit fly outbreaks have also been associated with holidaymakers and workers, who unknowingly bring infested fruit into production areas. Ensuring that staff and contractors do not bring suspect fruit on-site can also reduce the chance of an outbreak.

A biosecurity sign on the front gate reminding visitors not to bring fruit onto the property is a simple but useful inclusion.

FARM HYGIENE

Standard recommendations for fruit fly management in orchards state that all fruit needs to be removed to prevent further infestation.

For vegetables this is not feasible, as picking and removing every single chilli, capsicum or squash is uneconomic. Moreover, flies do not usually lay eggs in fruit already on the ground and rotting. Unmarketable fruit noticed during harvest should therefore be pulled from the plant, dropped into the inter-row and crushed. Stomping with a boot or driving through with the tractor will help ensure waste fruit decays quickly.

In addition, host crops should be destroyed as soon as possible once harvesting is complete. This could just involve turning off the irrigation to kill the plants. Preferably, plants should be mulched into the ground.

If infested fruit is found, it is essential it should be destroyed to make sure the larvae do not survive. To do this either:

- Freeze the infested product overnight.
- Place inside black plastic garbage bags and leave in the sun (solarise).
- Bury at least 50cm deep.

BEST PRACTICE

- ✔ Remove unmanaged fruit trees within 600m of the crop.
- ✔ Fruit trees within 600m of the crop that can't be removed need to be treated with insecticide during fruiting, or fruit picked before maturity.
- ✔ Ensure workers and contractors do not bring infested fruit onsite.
- ✔ Instruct harvesting staff to pull unmarketable fruit from the plant and crush them to speed decay.
- ✔ **Destroy fruit fly host crops as soon as** possible once harvesting is complete.
- ✔ If infested fruit is found, it must be destroyed by freezing, solarisation or burial.

KEY REFERENCES

Balagawi S. *et al*. 2012. Spatial and temporal foraging patterns of Queensland fruit fly *Bactrocera tryoni* for protein and implications for managmeent. Aust. J. Ent. 51:279-288.

Balagawi S. Jackson K. Clarke AR. 2013. Resting sites, edge effects and dispersion of a polyphagous *Bactrocera* fruit fly within crops of different architecture. J. App. Ent. 138:510-515.

Broughton S, DeLima CPF. Field evaluation of female attractants for monitoring *Ceratitis capitata* under a range of climatic conditions and population levels in Western Australia. J. Econ. Entomol. 95:507-512.

Clarke AR *et al.* 2010. The ecology of *Bactrocera tryoni:* What do we know to assist pest management? Ann. App. Biol. 158:26-54.

D'Aquino S *et al.* 2011. Effects of kaolin based particle film to control *Ceratitis capitata* infestations and postharvest decay in citrus and stone fruit. Crop Prot. 30:1079-1086.

DeFaveri S *et al*. 2016. Farm-wide fruit fly management systems for the east coast of Australia. HIA Final Report MT12050.

Dominiak BC, Daniels D, Mapson R. 2011. Review of the outbreak threshold for Queensland fruit fly (*Bactrocera tryoni*). Plant Prot. Quart. 26:141-147.

Dominiak BC, Daniels D. 2012. Review of the past and present distribution of Mediterranean fruit fly (*Ceratitis capitata*) and Queensland fruit fly (*Bactrocera tryoni*) in Australia. Aust. J. Ent. 51:104-115.

Dominiak BC, Ekman JH. 2013. The rise and demise of control options for fruit fly in Australia. Crop Prot. 51:57-67.

Dominiak BC, Mavi HS, Nicol HI. 2006. Effect of town microclimate on the Queensland fruit fly *Bactrocera tryoni*. Aust. J. Exp. Ag. 46:1239-1249.

Dominiak BC. 2012. Review of dispersal, survival and establishment of *Bactrocera tryoni* for quarantine purposes. Ann. Ent. Soc. Am. 105:434-446.

Ekman JH. 2015. Fruit fly research gap analysis. HIA Final Report VG13040.

Fay HA. 2012. A highly effective and selective male lure for *Bactrocera jarvisi.* Aust. J. Entomol. 51:189-197.

Mazor M, Erez A. 2004. Processed kaolin protects fruits from Mediterranean fruit fly infestations. Crop Prot. 23:47-51.

Meats A, Edgerton JE. 2008. Short and long range dispersal of the Queensland fruit fly *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Ag. 48:1237-1245.

Meats A, Hartland CL. 1999. Upwind anemotaxis in response to cuelure by the Queensland fruit fly *Bactrocera tryoni*. Phys. Ent. 24:90-97.

Meats A, Smallridge CJ. 2007. Short and long-range dispersal of medfly *Ceratitis capitata* and its invasive potential. J. Appl. Ent. 131:518-523.

Mo J *et al.* 2014. Pest behaviour insights from quarantine surveillance of male Queensland fruit fly *Bactrocera tryoni*. Crop Prot. 62:55-63.

Pinerao JC, Mau RFL, Vargas RI. 2011. A comparative assessment of the response of three fruit fly species to a spinosad-based bait: effect of ammonium acetate, female age and protein hunger. Bull. Ent. Res. 101:373-381.

Royer JE *et al*. 2014. Cucumber volatile blend, a promising female-biased lure for *Bactrocera cucumis*, a pest fruit fly that does not respond to male attractants. Aust. Ent. 53:347-352.

Schutze MK *et al*. 2016. 'Ladd traps' as a visual trap for male and female Queensland fruit fly *Bactrocera tryoni.* Aust. Ent. 55:324-329.

Senior LJ *et al.* 2016. Protein feeding of Queensland fruit fly Bactrocera tryoni and cucumber fly Zeugodacus cucumis on non-host vegetation: effect of plant species and bait height. Austral. Entomol. *In Press.*

Subramaniam S. 2011. Alternative fruit fly control and market access for capsicums and tomatoes. HIA Final Report VG06028.

Vijaysegaran S, Walter GH, Drew RAI. 1997. Mouthpart structure, feeding mechanisms and natural food sources of adult *Bactrocera*. Ann. Ent. Soc. Am. 90:184-201.

Weldon C, Meats A. 2007. Short-range dispersal of recently emerged males and females of *Bactrocera tryoni* monitored by sticky sphere traps baited with protein and Lynfield traps baited with cuelure. Aust. Ent. 46:160-166.

1 Central Ave, Eveleigh NSW 2015

p: (02) 9527 0826

ahr.com.au

ahr applied horticultural research

Food and Agriculture Organization of the United Nations

International Plant Protection Convention

ISPM 4

ENG

INTERNATIONAL STANDARD FOR PHYTOSANITARY MEASURES 4

Requirements for the establishment of pest free areas

Produced by the Secretariat of the International Plant Protection Convention (IPPC)

This page is intentionally left blank

INTERNATIONAL STANDARDS FOR
PHYTOSANITARY MEASURES

ISPM 4

Requirements for the establishment of pest free areas

Produced by the Secretariat of the
International Plant Protection Convention
Adopted 2024; published 2024

© FAO 2024

Required citation:
IPPC Secretariat. 2024. *Requirements for the establishment of pest free areas*. International Standard for Phytosanitary Measures No. 4. Rome. FAO on behalf of the Secretariat of the International Plant Protection Convention.

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

© FAO, 2024

Some rights reserved. This work is made available under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO; https://creativecommons.org/licenses/by-nc-sa/3.0/igo/legalcode).

Under the terms of this licence, this work may be copied, redistributed and adapted for non-commercial purposes, provided that the work is appropriately cited. In any use of this work, there should be no suggestion that FAO endorses any specific organization, products or services. The use of the FAO logo is not permitted. If the work is adapted, then it must be licensed under the same or equivalent Creative Commons licence. If a translation of this work is created, it must include the following disclaimer along with the required citation: "This translation was not created by the Food and Agriculture Organization of the United Nations (FAO). FAO is not responsible for the content or accuracy of this translation. The original English edition shall be the authoritative edition."

Disputes arising under the licence that cannot be settled amicably will be resolved by mediation and arbitration as described in Article 8 of the licence except as otherwise provided herein. The applicable mediation rules will be the mediation rules of the World Intellectual Property Organization https://www.wipo.int/amc/en/mediation/rules and any arbitration will be conducted in accordance with the Arbitration Rules of the United Nations Commission on International Trade Law (UNCITRAL).

Third-party materials. Users wishing to reuse material from this work that is attributed to a third party, such as tables, figures or images, are responsible for determining whether permission is needed for that reuse and for obtaining permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

Sales, rights and licensing. FAO information products are available on the FAO website (https://www.fao.org/publications) and can be purchased through publications-sales@fao.org. Requests for commercial use should be submitted via: https://www.fao.org/contact-us/licence-request. Queries regarding rights and licensing should be submitted to: copyright@fao.org.

When this ISPM is reproduced, it should be mentioned that current adopted versions of ISPMs are available for download on https://www.ippc.int.

For official reference, policy-making or dispute avoidance and settlement purposes, the only ISPMs that may be referred to are those published under https://www.ippc.int/en/core-activities/standards-setting/ispms/#614.

Publication history

This is not an official part of the standard

1993-05 Technical Consultation among Regional Plant Protection Organizations added topic *Pest free areas* (1993-001).

1993-05 Expert working group developed draft text.

1994-05 CEPM-1 revised draft text and requested that sufficient details be provided.

1995-05 CEPM-2 revised draft text for adoption.

1995-11 28th FAO Conference adopted the standard.

ISPM 4. 1995. *Requirements for the establishment of pest free areas*. IPPC Secretariat. Rome, FAO.

2015-06 IPPC Secretariat incorporated ink amendments and reformatted standards following revoking of standards procedure from CPM-10 (2015).

2017-04 CPM noted ink amendments to avoid the use of "trade partner". The IPPC Secretariat incorporated the ink amendments.

2010-03 CPM-5 added topic Revision to ISPM 4 (*Requirements for the establishment of pest free areas*) (2009-002) to the work programme.

2010-11 SC deferred.

2013-11 SC approved Specification 58.

2015-10 Secretariat revised Specification 58 to incorporate task on references to ISPM 4 as requested by the 2014-11 SC.

2020-12 / 2021-01 Expert working group met virtually and drafted standard.

2021-05 SC revised and approved for first consultation.

2021-07 First consultation.

2022-05 SC-7 revised and approved for second consultation.

2022-07 Second consultation.

2022-10 Revision of the draft by the steward.

2022-11 SC revised.

2023-05 SC revised and recommended the draft for adoption by CPM.

2024-04 CPM-18 adopted the standard.

ISPM 4. 2024. *Requirements for the establishment of pest free areas*. IPPC Secretariat. Rome, FAO.

Publication history last updated: 2024-04

CONTENTS

Adoption 4

INTRODUCTION 4

Scope 4

References 4

Definitions 4

Outline of requirements 4

BACKGROUND 4

IMPACTS ON BIODIVERSITY AND THE ENVIRONMENT 5

REQUIREMENTS 5

1. Initiation of a pest free area 6
   - 1.1 Pest to be controlled 6
   - 1.2 Identification of the area 6
   - 1.3 Suitability of environmental conditions in the area 6
2. Establishment of the pest free area 6
   - 2.1 Determination of pest status in the area 6
   - 2.2 Controls on the movement of regulated articles 6
   - 2.3 Establishment of buffer zones 7
   - 2.4 Official declaration of pest free area 7
3. Maintenance of the pest free area 7
   - 3.1 Regulatory framework 7
   - 3.2 Surveillance for the maintenance of the pest free area 7
   - 3.3 Notification of detection of the pest 7
   - 3.4 Response to an outbreak 8
   - 3.4.1 Delimiting survey to demarcate the outbreak area 8
   - 3.4.2 Implementation of control measures 8
   - 3.4.3 Increased surveillance in the outbreak area 8
   - 3.5 Provisions for suspension, reinstatement or withdrawal of the pest free area status 8
4. Regular review and verification of implementation 9
5. Data collection, documentation and record-keeping 9
6. Communication and stakeholder engagement 9
7. Recognition of pest free areas 9

Adoption

This standard was first adopted by the Twenty-Eighth Session of the FAO Conference in November 1995. This first revision was adopted by the Eighteenth Session of the Commission on Phytosanitary Measures in April 2024 as the present standard.

INTRODUCTION

Scope

This standard describes the requirements for initiating, establishing and maintaining pest free areas (PFAs) as a phytosanitary measure to support the phytosanitary certification of plants, plant products and other regulated articles exported from the PFA or, if technically justified, as a phytosanitary measure required by the national plant protection organization (NPPO) of an importing country for the protection of an endangered area in its territory.

This standard does not cover pest free places of production or pest free production sites, the requirements for which can be found in ISPM 10 (*Requirements for the establishment of pest free places of production and pest free production sites*).

References

The present standard refers to ISPMs. ISPMs are available on the International Phytosanitary Portal (IPP) at www.ippc.int/core-activities/standards-setting/ispms.

Definitions

Definitions of phytosanitary terms used in this standard can be found in ISPM 5 (*Glossary of phytosanitary terms*).

Outline of requirements

A PFA is a phytosanitary measure that may be used to facilitate safe trade and protect plant resources. National plant protection organizations should consider a PFA to be a phytosanitary measure that, when used alone, is sufficient for managing the risk associated with a specified pest.

When initiating, establishing or maintaining a PFA, NPPOs should follow the requirements outlined in this standard. Requirements include programmes to establish and maintain a PFA, verification that PFA status has been attained or maintained, appropriate corrective actions for pest detections, proper documentation of these activities and appropriate record-keeping, and transparency and stakeholder communication.

In this standard, “pest” is used to refer to a “pest or group of pests”, except where the text explicitly refers to one pest species or to a group of pests. Where an area being established or maintained as a PFA covers all or parts of several countries, references in this standard to the NPPO that establishes or maintains the PFA, or to the NPPO of the country in which the PFA is situated, apply to the NPPOs of all the countries in which the PFA is situated.

BACKGROUND

A PFA is recognized as a pest risk management option that contracting parties may consider implementing as a phytosanitary measure to protect the plant resources of an area for agricultural, forestry or ecological conservation purposes, facilitate safe trade, or increase the market-access opportunities for exporting countries. Pest free areas can offer a cost-effective way for NPPOs and industry in both importing and exporting countries to manage pest risk.

According to Article IV.2(e) of the IPPC, the responsibility for the designation, maintenance and surveillance of PFAs lies with NPPOs. The operational principles outlined in ISPM 1 (*Phytosanitary principles for the protection of plants and the application of phytosanitary measures in international trade*) also require contracting parties to take into account the status of an area (e.g. PFA or area with a pest status of "absent" for the targeted pest) when determining phytosanitary measures for imports from that area.

A PFA may be applied to an entire country or a part or parts of it. A PFA may also cover areas in several adjacent countries. Within a single country, more than one PFA may be established for the same pest, depending on the geography of the country, the distribution of the pest and its hosts, and the biology of the pest.

When a PFA is established, it is usually for one pest species, but a PFA may also be established for a defined group of pests with similar biology.

IMPACTS ON BIODIVERSITY AND THE ENVIRONMENT

This standard may contribute to the protection of biodiversity and the environment by preventing the introduction of regulated pests into an area. When establishing and maintaining PFAs, countries are encouraged to consider phytosanitary procedures that minimize impact on the environment.

REQUIREMENTS

A PFA should be considered a phytosanitary measure that, when used alone, is sufficient for managing the pest risk associated with a specified pest. Where a PFA has been established and maintained in accordance with the requirements of this standard, additional phytosanitary measures in relation to the pest should not be imposed.

The requirements that should be met for a PFA to be established and maintained, and used as a phytosanitary measure for trade, are detailed below. Depending on the pest concerned, an individual or a combination of measures may be used to meet these requirements.

Requirements for the establishment and maintenance of a PFA by an NPPO include:

- programmes to establish a PFA;
- programmes to maintain PFA status;
- verification that a PFA has been attained and its status is maintained;
- corrective actions for detections of the specified pest;
- documentation of these activities and appropriate record-keeping; and
- transparency and communication with other NPPOs and stakeholders.

The following elements should be considered when establishing and maintaining a PFA:

- the necessity to base measures on the biology of the pest, the relevant pathways and the characteristics of the area;
- the availability of appropriate surveillance tools, technology and trained personnel to detect and identify the pest;
- the existence of an appropriate regulatory framework to support the establishment and maintenance of the PFA;
- the support from relevant stakeholders, such as domestic industries and local regulatory bodies; and
- the importance of communicating with and raising awareness among other NPPOs, stakeholders and the general public.

In addition, NPPOs may wish to consider the feasibility of establishing and maintaining the PFA in terms of resource availability (economic, human and technical) and the cost benefit.

1. Initiation of a pest free area

1.1 Pest to be controlled

When initiating the establishment of a PFA, an NPPO should first specify the pest that is to be controlled (including its scientific name) and identify valid detection and diagnostic methods and relevant aspects of its biology.

1.2 Identification of the area

The area being considered for a PFA may be a part or parts of a country, the entire country, or all or part of several countries. Pest free areas are generally delimited by readily recognizable boundaries, considered to coincide acceptably with a pest's biological limits. These may be administrative (e.g. country, province, commune or property boundaries) or they may be natural barriers such as bodies of water, mountains, deserts or other geographical features that prevent pest movement from one area to another.

The area should be described specifically enough to allow it to be readily identified. This is important when the NPPO is providing evidence to support the claim that the area is free of the pest, but also when the NPPO is subsequently reporting the status of the targeted pest in the PFA and when raising public awareness.

1.3 Suitability of environmental conditions in the area

The NPPO of the country in which the area is situated should determine the availability of host plants in the area. Potential differences in host susceptibility in the area, the climatic suitability of the area, and the potential for entry and establishment of the pest in the area should also be considered.

2. Establishment of the pest free area

2.1 Determination of pest status in the area

Once the pest has been specified and the area identified, the NPPO should determine the pest status in the area by conducting surveillance in accordance with the requirements outlined in ISPM 8 (*Determination of pest status in an area*) and ISPM 6 (*Surveillance*).

If an exporting country has declared a pest to be absent in an area in accordance with ISPM 8, then establishing a PFA in that area should not be required, unless there is technical justification by importing countries.

2.2 Controls on the movement of regulated articles

To prevent the entry of the pest into the area, the pest should be regulated in relation to the area, the potential pathways should be identified and appropriate controls on the movement of regulated articles should be established. The movement controls should depend on the assessed pest risk, including the probability of pest establishment. Such controls should include:

- regulation of the pathways and articles that require control;
- imposition of domestic restrictions, phytosanitary import requirements, or other measures to control the movement of regulated articles into or through the area; and
- inspection and testing of regulated articles where technically justified, examination of the relevant documentation and, where necessary for cases of non-compliance, the application of appropriate measures.

2.3 Establishment of buffer zones

Where the geographical isolation of the area is not adequate to prevent the natural spread of the pest into it, the establishment of a buffer zone should be considered. The population of the pest in the buffer zone should be maintained at or below a specified level, which should be verified by surveillance. The extent of the buffer zone should be determined by the NPPO, based on the distance over which the likely natural spread of the pest population to the area could not occur during the season when hosts are available. The NPPO should describe, with the use of supporting maps, the boundaries of the buffer zone.

2.4 Official declaration of pest free area

When the pest status is determined as absent (in accordance with ISPM 8) or eradication of the pest from the area is achieved (in accordance with ISPM 9 (*Guidelines for pest eradication programmes*)), the NPPO should make an official declaration that the area is free from the pest. All internal management procedures and measures to maintain the PFA (see section 3) should be in place before any declaration is made.

3. Maintenance of the pest free area

The NPPO of the country in which the PFA is situated should set up a programme to ensure maintenance of the PFA. This programme should be risk-based and should incorporate at least the following elements: a regulatory framework to control the movement of regulated articles; surveillance and collection of relevant data to inform the management of the PFA, including outbreak management; a framework for reporting pest detections; and a corrective action plan in case of an outbreak, with associated provisions for suspension and reinstatement of the PFA status.

3.1 Regulatory framework

The regulation of the pest through the controls on the movement of regulated articles (see section 2.2) should be sufficient to prevent its entry into the PFA. Where appropriate, buffer zones should be established to ensure early detection of the spread of the pest into the vicinity of the PFA. The measures should also allow traceability of regulated articles introduced into the PFA or moving within the PFA so that the appropriate corrective actions can be taken in a timely manner.

3.2 Surveillance for the maintenance of the pest free area

Surveillance should be conducted on a regular basis to verify that the absence of the pest from the PFA is maintained.

The decision about whether general surveillance for the pest is sufficient or specific surveillance is needed should be based on the risk of the pest's entry and establishment in the PFA and depends on the biology of the pest, the relevant pathways and the characteristics of the PFA.

General surveillance may be sufficient in cases where the pest has never been introduced into the PFA, nor into the surrounding areas, and there have been no records of the pest's presence in the PFA.

Specific surveillance to detect possible outbreaks of the pest at an early stage should be the standard procedure in all other cases. The type and frequency of the detection surveys should be based on an assessment of the potential for pest entry and establishment in the PFA and should allow detection of the pest with an appropriate level of confidence.

3.3 Notification of detection of the pest

A reporting framework should be established to ensure that detections of the pest in the PFA are immediately notified to the NPPO (or other competent authority delegated by the NPPO) and officially confirmed. In the event of immediate or potential danger of pest spread, such as when an outbreak occurs or a non-compliant commodity is intercepted, the relevant NPPOs should follow the guidance in

ISPM 13 (*Guidelines for the notification of non-compliance and emergency action*) and ISPM 17 (*Pest reporting*) and relevant bilateral arrangements.

3.4 Response to an outbreak

Preparedness for rapid intervention may be ensured by developing, in advance, a contingency plan to support the development and implementation of a corrective action plan in the event of an outbreak. The contingency plan may detail the triggers for corrective actions, plans for rapid technical assessment of the situation, the availability of financial and human resources, the roles and responsibilities of the parties concerned, and the operational activities that are likely to be needed. To assist in preparedness, regular simulation exercises may be used to review the effectiveness of the contingency plan.

In the event of the pest being detected in the PFA, the NPPO should determine, based on survey results, the corrective actions to be taken. An eradication programme should be initiated for an outbreak of a pest, but not for an interception when the consignment containing the pest can be immediately destroyed, or where evidence indicates that there is no risk of the pest establishing or causing economic damage.

An eradication programme should follow ISPM 9 and include the following steps.

3.4.1 Delimiting survey to demarcate the outbreak area

As soon as the detection of the pest outbreak has been officially confirmed in the PFA, a delimiting survey should be conducted to determine the boundary of the infested area. Based on this determination and an assessment of the pest biology, the relevant pathways and the characteristics of the PFA, an outbreak area within the PFA should be demarcated and the PFA status should be temporarily suspended therein. This demarcated outbreak area should consist of the infested area surrounded by a buffer zone, the size of which should depend on the biology of the pest, the availability of host plants and the ecological conditions.

3.4.2 Implementation of control measures

Control measures should be applied to prevent the pest moving out of the outbreak area by human activities (e.g. through the movement of infested host plants or plant products, or contaminated means of conveyance) or, to the extent that is reasonably achievable, by natural spread.

Measures to eradicate the pest should be implemented in accordance with ISPM 9.

3.4.3 Increased surveillance in the outbreak area

Surveys should be used in the outbreak area to determine and record the distribution of the pest and its population dynamics, and to assess the effectiveness of the eradication measures. This level of survey should be maintained until the pest is eradicated from the outbreak area.

3.5 Provisions for suspension, reinstatement or withdrawal of the pest free area status

Criteria for successful eradication in accordance with ISPM 9 should be established in advance of the need to eradicate an outbreak. These criteria should include the intensity of the survey in the outbreak area and the minimum period that the outbreak area needs to be free from the pest before lifting the suspension of the PFA.

If the criteria are fulfilled, then eradication may be officially declared successful and the temporary control and eradication measures may be lifted. The status of the full PFA may then be reinstated.

If the criteria for eradication within the outbreak area cannot be fulfilled within a reasonable time frame (as determined by the relevant NPPO in advance), then either the PFA status should be withdrawn or the delimitation of the PFA should be reviewed.

4. Regular review and verification of implementation

Once the PFA is established, including the administrative activities, the performance of the PFA maintenance programme should be regularly reviewed by the NPPO to verify correct implementation of the maintenance programme. This review should allow the NPPO to find and correct deficiencies, incorporate any new and relevant information on the pest or associated pathways, and adjust and improve the maintenance programme accordingly.

Traceability procedures for the movement of regulated articles should allow the verification of their origin and conformity with the phytosanitary requirements set for the PFA.

5. Data collection, documentation and record-keeping

The data from the surveillance (e.g. time of survey, number and type of plants inspected, number of samples taken for inspection, number of samples taken for laboratory analysis, diagnostic protocols used, data analysis methods used, results of the analyses, and other relevant information as required by ISPM 6) should be stored and kept. To facilitate traceability and verification, this information should be made available for as long as the PFA is based on these data.

The measures used to establish and maintain the PFA should be adequately documented. The documentation should be reviewed regularly, updated as needed, and include any amendments to the PFA maintenance programme. Records of the procedures to establish, implement and maintain corrective actions should be kept as needed or for at least 24 months, depending on the biology of the pest and the duration of the commodity being moved from the PFA.

6. Communication and stakeholder engagement

Individuals, groups or organizations other than the NPPO of the country in which the PFA is situated can also affect, or be affected by, the actions to establish and maintain the PFA. The NPPO may establish partnerships with stakeholders, which may include seeking contributions of resources.

Information about the establishment and maintenance of the PFA, including information about the methodology used, results of surveys and pest diagnostics, and other relevant information supporting the PFA claim, should be made available on request to other NPPOs and, if appropriate, to relevant stakeholders.

Maps and information about the measures applied to maintain the PFA may be communicated to relevant stakeholders.

To achieve the support of the community, NPPOs are encouraged to raise public awareness about PFAs in their territory, including the framework for reporting detections or cases of suspected presence of the pest in the PFAs, measures applied in the PFAs, and the importance of maintaining the PFAs.

7. Recognition of pest free areas

Recognition of PFAs should take place in accordance with ISPM 29 (*Recognition of pest free areas and areas of low pest prevalence*).

IPPC

The International Plant Protection Convention (IPPC) is an international plant-health agreement that aims to protect global plant resources and facilitate safe trade. The IPPC vision is that all countries have the capacity to implement harmonized measures to prevent pest introductions and spread, and minimize the impacts of pests on food security, trade, economic growth, and the environment.

Organization

- There are over 180 IPPC contracting parties.
- Each contracting party has a national plant protection organization (NPPO) and an official IPPC contact point.
- Ten regional plant protection organizations (RPPOs) have been established to coordinate NPPOs in various regions of the world.
- The IPPC Secretariat liaises with relevant international organizations to help build regional and national capacities.
- The secretariat is provided by the Food and Agriculture Organization of the United Nations (FAO).

International Plant Protection Convention Secretariat
ippc@fao.org | www.ippc.int

Food and Agriculture Organization of the United Nations
Rome, Italy

National Fruit Fly Strategy Implementation Report 2021-22

NATIONAL FRUIT FLY COUNCIL

Funding Statement

National Fruit Fly Council Phase 4 is funded by Hort Innovation with contributions from fruit fly affected industry research and development levies, Plant Health Australia, state and territory governments, and the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Copyright statement

Copyright in this publication is owned by Plant Health Australia, except when content has been provided by other contributors, in which case another person may own copyright. With the exception of any material protected by a trademark, and except where otherwise indicated, these publications are licensed under a Creative Commons Attribution 3.0 Australia licence. Any use of the publication, other than as authorised under this licence or copyright law, is prohibited.

Attribution

You are free to copy, communicate and adapt the material in this publication, so long as you attribute the Plant Health Australia, and the authors in the following manner:

National Fruit Fly Council (2020) *National Fruit Fly Strategy Implementation Plan 2021-22*, Plant Health Australia

© Plant Health Australia 2021

Plant Health Australia

ABN 97 092 607 997
Level 1, 1 Phipps Close
Deakin ACT 2600

Phone 02 6215 7700
Email fruitfly@phau.com.au
preventfruitfly.com.au

Contents

Glossary of Terms 3
About this report 4
The strategic framework 2020 - 25 5
Purpose 5
Vision 5
Goal 5
Strategic objectives 5
Priority areas 6
1. Market access 7
2. Management of established fruit fly 15
3. Prevention, preparedness and response 17
4. Research 21
5. Surveillance 23
6. Diagnostics 25
7. Communication and engagement 27
8. Cooperation 31
Notes 33

Glossary of Terms

ACRONYM	TERM
AFFTAC	Australian Fruit Fly Technical Advisory Committee (a subcommittee of Plant Health Committee)
ANQAP	Australian National Quality Assurance Program
ATGA	ATGA
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry (pre-June 2022, DAWE, Department of Agriculture, Water and the Environment)
DPIRD	Department of Primary Industries and Regional Development WA
GSPFA	Greater Sunraysia Pest Free Area
ICA	Interstate Certification Assurance
LAMP	Loop-Mediated Isothermal Amplification
NRE Tasmania	Department of Natural Resources and Environment Tasmania
NSW DPI	NSW Department of Primary Industries
PFA	Pest Free Area
PHA	Plant Health Australia
PHC	Plant Health Committee
PIRSA	The Department of Primary Industries and Regions, South Australia
QDAF	Queensland Department of Agriculture and Fisheries
SIT	Sterile Insect Technology
SDQMA	The Subcommittee on Domestic Quarantine and Market Access

About this report

The 2021–22 Implementation Report summarises progress and achievements from 1 July 2021 to 30 June 2022. Progress in each of the eight key result areas from the National Fruit Fly Strategic (NFFS) 2020-25 is tracked against the strategic framework and objectives within the NFFS.

The Implementation Report is finalised in June of the previous financial year and published along with the next financial year's Implementation Plan.

A colour code is used to report on performance, as shown below.

Performance reporting key

	Activity is completed
	Activity is on schedule
	Activity is behind schedule or has been modified
	Activity will not be met

Where a KPI has been modified due to COVID-19 restrictions, such as interstate travel or the size of events, the symbol is used.

Where a KPI has been modified due to the flooding in northern NSW and QLD, the symbol is used.

The strategic framework 2020 - 25

Purpose

To reduce the risk of exotic fruit fly incursion, enable the effective and efficient management of established fruit fly species, and aid a robust national system to manage risk and underpin market access.

Vision

Australia has a robust fruit fly management system that supports growth in horticultural production, market access and trade.

Goal

Australia will have a contemporary, viable, cost-effective, and coordinated national approach to fruit fly management, with stakeholders committed to the national strategy.

Strategic objectives

1. MAINTAIN AUSTRALIA'S FREEDOM FROM EXOTIC FRUIT FLY

Maintaining freedom from exotic fruit flies is essential to the sustainability of Australia's horticultural industries.

Key Performance Indicator: *Incursion(s) of exotic fruit flies in Australia are detected early and eradicated*

2. MINIMISE THE INCIDENCE AND SPREAD OF FRUIT FLY

Improving the management and suppression of established fruit fly species and preventing their further spread will help support productivity, reduce management costs, and enable trade and market access opportunities through low pest prevalence and pest-free areas.

Key Performance Indicator: *Domestic and international recognition of fruit fly pest free areas is retained or increased.*

3. IMPLEMENT NATIONAL SYSTEMS THAT SUPPORT MARKET ACCESS

Providing markets (domestic and international) confidence in our fruit fly system will ensure Australian growers can capitalise on our reputation for high-quality produce.

Key Performance Indicator: *There is no critical non-conformance in the national fruit fly assurance system.*

4. FACILITATE A COOPERATIVE AND COMMITTED NATIONAL APPROACH TO FRUIT FLY MANAGEMENT

The cooperation of governments, industries and communities that operate in different fruit fly management areas is vital to the success of the fruit fly system.

Key Performance Indicator: *Consistency between governments, industries, and communities' strategy and strategic fruit fly objectives.*

Priority areas

Eight different yet interdependent priority areas have been identified for the strategy.

1. **Market access** Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures and is legally enforceable and technically justified.	**5. Surveillance** Ensure a nationally consistent surveillance framework that clarifies fruit fly distribution, prevalence and control.
2. Management of established fruit fly Build and promote efficient and effective methods to manage established fruit fly species, reduce the impact on production, and facilitate access to sensitive markets.	**6. Diagnostics** Maintain and enhance rapid diagnostic capability and capacity to support responses to incursions or outbreaks and to confirm area freedom.
3. Prevention, preparedness and response Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.	**7. Communication and engagement** Adopt systems and mechanisms for the efficient and effective communication, training, extension and uptake of fruit fly information by a broad range of audiences.
4. **Research** Maintain and enhance fruit fly research capability, capacity and resources, pursuing research and extension that focus on nationally agreed priorities.	**8. Cooperation** Maintain and enhance engagement processes that coordinate, progress and improve fruit fly management systems.

1. Market access

Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures and is legally enforceable and technically justified.

Australia has strong domestic and international biosecurity systems vital for supporting market access for fruit fly affected industries. These systems must reflect internationally accepted standards and protocols, uphold risk management principles, and be transparent and scientifically robust to maintain confidence among domestic and international trading partners. It is essential that fruit fly policy, legislation, and operations continuously improve to meet market access needs.

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
	Create awareness for generic insect and fruit fly treatment schedule for irradiation while supporting the inclusion of new insect pests with relevant research		Steritech	Work is underway through an International Atomic Energy Agency (IAEA) project researching bands of generic dose rates for irradiation across crops and various pests including fruit fly
2	Continue to explore and develop systems approaches to fill the void left by chemical losses		NSW DPI	Cherry seasonal pest absence protocol referred from SDQMA to AFFTAC for final technical review. Systems approaches are being developed to continued use of ICA-21 for blueberries
	Explore the strategic and technical application of irradiation as a fresh produce fruit fly treatment at a national irradiation forum		Steritech	A Strategic workshop: building capacity in phytosanitary irradiation is being held in Melbourne on Thursday 15 Sept and will bring together key stakeholders including industry, research and government organisations to ensure phytosanitary irradiation continues to be developed effectively to protect and grow Australia's horticultural sector
2	Support Victoria's work to strengthen the domestic protocol for fumigation of host fruit (ICA04) to better address risk and align with arrangements at the national border		Multiple agencies	Agriculture Victoria submitted the revised version of national ICA-04 protocol which was supported by the states and agreed to by SDQMA

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Hort Innovation ST15030 National Medfly R&D Centre		Murdoch University	This project is nearing completion
2	Monitor and report against the domestic phytosanitary system for fruit fly through the National ICA Audit Program.		Multiple agencies	COVID restrictions have impacted on the delivery of the national audit program. SDQMA has since agreed to an alternative approach to undertaking NIAP audits

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
3	Investigate and rectify areas of non-compliance identified in the national and domestic systems that underpin market access		Multiple agencies	QDAF continues to implement surveillance activities (including maintaining a trapping network at international ports and other high-risk sites), risk mitigation measures for key risk pathways, and to respond to suspect reports and new detections, to support area freedom claims for exotic fruit flies, including Mediterranean fruit fly. In NSW DPI, trap base has been introduced and monthly monitoring is taking place for other fruit fly of concern Agriculture Victoria: Pest Quarantine Manual now live and accessible through the Agriculture Victoria website. Ongoing support and advice for industry in relation to movement of produce domestically. PIRSA: The Department has followed and investigated reports of non-certified produce entering South Australia. No non-compliance identified. DPIRD WA: continued maintenance of trapping base as agreed. NRE Tasmania: Undertaken minor ICA updates (i.e., labelling) plus continuing focus on maintaining securing our borders and collaboration with Agriculture Victoria pre-border. DAFF: States and territories will be subject to a minimum of one periodic audit within every 24 months against the relevant performance standards as endorsed by PHC. Compliance will be assessed against the performance standards and follow up audits will be conducted to verify that agreed corrective actions have been taken to address non-compliances
3	Develop new and amend existing Interstate Certification Assurance and Certification Assurance to meet market access needs for NSW growers		NSW DPI	DRAFT ICA17 protocol circulated to include Phyto Certificates & ePHC/PHAC-Possible CA for blueberry rust to WA. Support ICA-21 for blueberries to continue trade
3	Undertake Risk analysis to support proposed market access tools proposed by other jurisdictions		NSW DPI	Risk analysis of TPP and RIFA undertaken to determine entry conditions

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
3	Provide support in market access protocol development where warranted		NSW DPI	Research efficacy of treatment conditions to support ICA-21 for blueberries
3	Continue to contribute to the development and periodic review of domestic trading protocols used to support trade of host produce across jurisdictional borders with varying fruit fly status. This includes working with DAWE to achieve an elevated level of consistency in the use of Methyl Bromide (MeBr) fumigation and irradiation/microwave technology as measures to enable domestic and international market access		Agriculture Victoria	Work continues to support the application of end point treatments for fruit fly such as fumigation and irradiation
3	Hort Innovation AM19002 Building capacity in irradiation pathways for export – Aims to build confidence in, acceptance, and capacity to use phytosanitary irradiation for market access		Agriculture Victoria	The project completed 5 literature reviews concerning the impact of phytosanitary irradiation on pest mortality and sterility, pest vectoring of disease, impacts on horticulture products (quality and shelf life), available methods to detect the irradiated products, and cultural and regulatory barriers to adoption. Research has commenced to identify the effective dose for a priority pest for the table grape industry; pest vectoring of disease and impacts on product quality for priority horticulture exports crops (fruits and vegetables)
3	Negotiate international market access protocols for fruit fly that maintain, improve or open market access		DAFF	In 2021-22, access for peaches and nectarines to Vietnam utilising irradiation and cold treatment, was achieved. Furthermore, a pathway for in-transit cold treated citrus and table grapes (sourced from a PFA) with Korea has been established and pathway access has been improved with New Zealand and Vietnam for several commodities with the use of irradiation treatment
3	Communicate international market access requirements for fruit fly and associated issues to industry and state/territory governments		DAFF	DAFF continues to routinely provide technical, policy and operational advice to states and territories regarding fruit fly management and international market access, both informally and via formal interstate committees and working groups, and to industry as required via established communication channels. The department has provided written advice to South Australia, Tasmania and Western Australia regarding ICA 21

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
3	Support development of alternative market access approaches (e.g., Areas of Low Pest Prevalence, winter windows, system approach, climate models) to underpin trade negotiations for fruit flies		DAFF	Work in this space is ongoing including research into systems approach
3	Strengthen current market access data packages and address any perceived gaps to support market access negotiation of international market access		DAFF	PHC have endorsed the overarching Management Principles (Part A) for Australia's National Fruit Fly Management Protocol (Protocol) as well as Operations Standard No.1 – Pest Free Areas (Part B) which is the key market access document for trade from fruit fly free areas. Delivery Guidelines and Delivery References continue to be progressed through AFFTAC in a more modernised format, working towards clarification of ambiguities and current procedures of fruit fly management, in-line with state and territory priorities
3	Hort Innovation AM17001 Developing a national systems approach for meeting biosecurity requirements to access key Asian Markets		CSIRO	This project is nearing completion with potential to extend
3	Hort Innovation MT14052 project developing phytosanitary data packages to support industries long-term international market access aspirations		QDAF	Covid restrictions, flood damage and problems sourcing equipment have resulted in delays
4	Continue to maintain and fully implement heightened border inspections through to 2021/2022 as one of the Tasmanian governments' highest biosecurity priorities to maintain Tasmania's pest-free status with respect to fruit flies		NRE Tasmania	The 'Securing Our Borders' initiative successfully completed its third season of operation. Consisting of risk-based targeting of high-risk fruit fly host produce pre-border and at the border, it has ensured intensive inspections have occurred. The initiative runs from September to march each year. During the remaining period a lower level of inspection occurs based on a reduced entry of high-risk product
4	Continue to work with the Australian Government and other governments and industries contributing to the national progression of the fruit fly management system		NRE Tasmania	Participation at all levels and in all associated national for a including NBC, PHC, SDQMA, and NFFC

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
4	Finalise the stabilisation phase of Australia's National Fruit Fly Management Protocol		DAFF & multiple agencies	DAWE: The overarching documents within the Protocol have been endorsed by PHC (Dec 2021). However, supporting documentation intending to provide consistent guidance, instruction and technical requirements to maintain fruit fly management systems continue to be progressed through AFFTAC in line with state and territory priorities. Fruit fly management processes and procedures lacking subordinate documentation continues to present a risk for consistency of fruit fly management actions and the department will continue to provide advice on where this impacts market access to assist with prioritisation. State jurisdictions continue to be represented on AFFTAC and to respond to requests for input/approval of Australia's National Fruit Fly Management Protocols and associated documents

Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
4	Monitor national fruit fly system assurance activities that underpin international market access, including obligations to demonstrate pest status		Multiple agencies	QDAF: Qld continues to implement surveillance activities (including maintaining a trapping network at international ports and other high-risk sites), risk mitigation measures for key risk pathways, and to respond to suspect reports and new detections, to support area freedom claims for exotic fruit flies, including Mediterranean fruit fly. NSW DPI: Trap base has been introduced and monthly monitoring is taking place for other fruit fly of concern Agriculture Victoria: continued work on maintaining trapping network re export. PIRSA: ongoing investigation of options to enhance assurance activities particularly through the Commonwealth 'Building Resilience' program. DPIRD WA: ongoing maintenance of trapping grid. NRE Tasmania: Continuation commitment to the securing our borders initiative as well as ongoing maintenance of updated trapping grids. DAFF: Australia's National Fruit Fly Management Assurance Framework (Assurance Framework) has been endorsed by PHC. The package includes an overarching Assurance Framework policy document and the Audit Guideline and Performance Standards. This document set provides clarity around the expectations of states and territories by the Australian Government to assure itself, and trading partners, that it can continue to certify that host produce for international export meets the conditions required by the authorities of importing countries. Accordingly, the Australian Government intends to audit all state and territory jurisdictions within the next 24 months

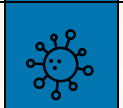
Stakeholder Activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
4	Seek acceptance of Australia's National Fruit Fly Management Protocol from trading partners		DAFF	The overarching documents within the Protocol have been endorsed by PHC. The Australian Government will issue Operations Standard No.1 – Pest Free Areas (Part B of the Protocol) to international trading partners where requested. Issuance of Part B will be in accordance with the international impact assessment submitted to PHC in January 2022 (OoS2022-01) and PHC will be kept informed of onward distribution

2. Management of established fruit fly

Build and promote efficient and effective methods to manage established fruit fly species, reduce the impact on production, and facilitate access to sensitive markets.

A better understanding of established fruit flies helps to improve the effectiveness of control methods and tools. Growers must have management and disinfestation options to control fruit flies and maintain or gain market access. These options must be economical and underpinned by evidence and confidence in supporting assurance systems.

KEY STAKEHOLDER ACTIVITIES				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Status**
2	Convert existing trapping in the Sydney basin, MIA and Sunraysia to trap base		NSW DPI	Trapbase has been implemented in Sydney basin, Guyra and MIA. Surveillance in Sunraysia is continuing under Ag Vic
2	Implement reviewed trapping grid in the Sydney basin		NSW DPI	The trapping grid has been reviewed and is compliant with requirements
2	Agriculture Victoria will work with regional coordinators and governance groups of the Goulburn Murray Valley, the Yarra Valley and the greater Sunraysia region to develop implementation plans to meet agreed outcomes specified in the strategy implementation plan, a key outcome being an investigation of sustainable funding mechanisms for industries to secure funding for biosecurity activities		Agriculture Victoria	Implementation plans have been developed and will be updated annually. Sustainable funding options are to be investigated and have been included in the current round of grants
2	Connect Agriculture Victoria researchers with local agronomists to provide input and feedback on short term research project into trapping strategy for table grapes		ATGA	A meeting was facilitated by ATGA in June ensuring fine tuning of the trapping strategy for the table grape industry.
3	Hort Innovation FF18003 SITplus production facility – proof of concept		PIRSA / Western Sydney University	Final project fly releases conducted in April 2022. SA Factory facility secured funding until June 2023
4	Continue to provide management information from DPI and the Local Land Services website		NSW DPI	The LLS website continues to be used to communicate fruit fly related information (i.e., 'Action Guide' and 'Facts Sheets')
2	Replace Pestmon with MAXX for efficiencies in diagnostic and reporting		NSW DPI	No surveillance or diagnostic data now entering Pestmon. Historical surveillance and diagnostics data in Pestmon available in MAXX

KEY STAKEHOLDER ACTIVITIES				
3	Hort Innovation MT19003 Parasitoids for the management of fruit flies (Diptera: Tephritidae) in Australia		Agriculture Victoria	An update was provided via Hort Innovation Website Sep 2021. Article published in Winter 22 edition of Australian Fruit Grower Magazine (APAL) Final Report being prepared. Due 30 May 2022.
3	Hort Innovation FF17001 Post factory pilot SITplus fly production		Macquarie University	Final aerial delivery of sterile flies completed in Apr 22, with data analysis by Plant and Food Research (NZ). Project variation approved for a no cost extension until May 2024 to enable additional work to translate outcomes for community/grower operated programs
2	Hort Innovation TG19001 Trapping efficacy in table grape vineyards for area wide management of Queensland fruit fly that supports market access (is not a market access project – it is about working out where Queensland fruit fly comes from to invade vineyards, which part of the vineyards at most at risk, etc)		Agriculture Victoria	Final Report being prepared
2	In collaboration with Local Land Services and Growers, DPI run weekend information stalls targeting backyard growers in the Murrumbidgee Irrigation Area and Sunraysia areas		NSW DPI	This activity has been delayed until further notice
2	Implement a revised trapping grid in Sunraysia		NSW DPI	Draft review is currently being circulated for feedback
2	Evaluate the southwest general fruit fly surveillance program and use the key findings to inform decision making processes across the broader fruit fly reporting and awareness program		Agriculture Victoria	Draft report prepared with findings proposed to be actioned through DQ communications plan over 2022/23 financial year
2	Grower workshop with updates from Agriculture Victoria researchers regarding mass releases and trapping strategy plus updates from the Greater Sunraysia Pest Free Area		Citrus Australia, ATGA , Agriculture Victoria and GSPFA	This activity has been delayed until 2022

3. Prevention, preparedness and response

Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

Australia works hard to maintain freedom from exotic fruit flies and minimise the spread of established fruit flies into pest-free areas. Understanding fruit fly characteristics and risk pathways can help in the design of detection and control measures to manage incursions and prevent fruit fly spread. Governments, industries, and communities also have a role to play in taking steps to prepare for potential risks, including planning for fruit fly eradication and for business continuity. There are high returns on investment for prevention and preparedness activities and these remain a priority for Australia's fruit fly management system.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Update map of all commercial and abandoned mango orchards in Australia (including the Cape York Peninsula) to assist with managing biosecurity threats		Australian Mango Industry Association / Uni of New England / Central Queensland University	All associated mapping web apps can be found on the platform below. https://www.une.edu.au/research/research-centres-institutes/applied-agricultural-remote-sensing-centre/collaborative-r-and-d-opportunities/industry-applications-and-maps The National Mango Tree Crop Dashboard has also been added to the Australian Mangoes website. www.industry.mangoes.net.au/ resources/resources-library/national-mango-tree-crop-map-dashboard
2	Agriculture Victoria is working with the NSW DPI on a Mediterranean fruit fly preparedness and response simulation activity which is anticipated to occur in August/September 2021		NSW DPI	NSW delivered a successful exercise on 8-9 March 2022 with learnings ensuring enhanced responses in the future.
1	Engage with stakeholders on pest prioritisation of exotic fruit flies		DAFF	Stakeholders were engaged as part of the 2019 development of the National Priority Plan Pests on the prioritisation of exotic fruit flies
3	Complete translation of all existing regulatory requirements associated with fruit fly for operation under the new Biosecurity Act 2019. This includes updated listings and translation of import processes to work under the Biosecurity Act		NRE Tasmania	Translation of remaining components of the Plant Quarantine Act 1997 to the Biosecurity Act 2019 is expected to be completed by the end of the calendar year 2022 with the former legislation being rescinded

1	Administer the Exotic Fruit Fly in Torres Strait Response Plan to eradicate incursions of exotic fruit fly species from Torres Strait in response to detections from Northern Australia Quarantine Strategy surveillance		QDAF, DAFF	The program is delivering Milestone 2 of 6, as per the agreed Response Plan. DAFF: The National Exotic Fruit Fly in Torres Strait Eradication Program Version 1.0 was endorsed by the National Management Group and implemented on 1 July 2021. QLD continues to successfully administer the Response Plan with NAQS providing significant operational and technical support for the response. Specific elements of the eradication program include a: · pre-emptive male annihilation technique (MAT) and protein bait spray program on islands where annual incursions are considered probable. · reactive eradication program that is implemented on a needs basis according to the monitoring results
1	Communicate potential or identified areas of risk of exotic fruit fly incursion		DAFF / QDAF	Qld continues to communicate and engage with stakeholders with regard to the risk pathways for introduction of exotic fruit fly through a range of mechanisms, in particular Torres Strait and Northern Peninsula Area communities
2	Implement incursion and eradication procedures for exotic incursions on an as needs basis		States, Territories, PHA, DAFF and Industry	National Exotic Fruit Fly in Torres Strait Eradication Program is being implemented in accordance with the approved Response Plan. No other exotic fruit fly incursions during the period. VIC: Victoria's Med Fly preparedness plan has been updated. Including ensuring adequate training and personnel to perform roles in the event of detection. PIRSA: Updates have been undertaken on the South Australian Plant Quarantine Standard to ensure alignment with the new National Management Protocols DPIRD WA: baseline activities have continued with a CSIRO project being prepared to work on post-harvest disinfestation as well as ongoing work through the Hort Innovation funded phenology and ecology research project.

				NRE Tasmania: Updated Tasmanian Fruit Fly Standard to ensure alignment with new National Management Protocols (i.e., consistency of language) DAFF: Process for implementation and eradication of exotic incursions would be undertaken under the Emergency Plant Pest Response Deed and PLANTPLAN as required
2	Implement incursion and eradication procedures in pest-free areas in accordance with Australia's National Fruit Fly Management Protocols		States, Territories, PHA, DAFF and Industry	No incursions or eradication procedures required in pest free areas in QLD/VIC/NSW during the period. PIRSA: large scale response underway in Riverland. DAFF: DAFF continues to provide advice on an 'as needs' basis to jurisdictions eradication programs in alignment with the Protocols and international standards. It is the aim of the Protocols to eliminate this need by clarifying ambiguities and policy requirements
1	Hort Innovation FF18001 Biosecurity preparedness for oriental fruit fly and exotic fruit flies		NSW DPI	Milestone 103 submitted, in collaboration with PHA a biosecurity incursion exercise is scheduled for early 2023
2	Continue to maintain the trapping grid for exotic fruit flies in metro Adelaide and in the SA Riverland		PIRSA	On track with temporary increase in density of the trapping grid in key areas for additional assurance.
1	Hort Innovation ST19017 Biosecurity preparedness through developing capacity for in-field detection of spotted wing Drosophila (part of RRD4P project: Boosting diagnostic capacity for plant production industries)		Agriculture Victoria	New surveillance trap / metabarcoding assay developed and validated. Surveillance system successfully trialled in initial field study
2	Continue to invest significantly to eradicate 11 outbreaks of Medfly and six outbreaks of Queensland fruit fly in South Australia		PIRSA	Investment continues with 11 MedFly and 1 Qfly outbreaks completed in Metro and Pt Augusta
4	Deliver fruit fly control responsibilities in the areas of Victoria adjacent to Riverland Pest Free Area		Agriculture Victoria / PIRSA	Victoria (Vic) and South Australia (SA) have an agreement under a Memorandum of Understanding that enables SA quarantine officers to enter Lyndsay Point (just across border in Vic) to undertake vital surveillance work

2	Continue preparedness/contingency planning workshops in the SA Riverland and other growing areas to prepare growers for the event that more outbreaks of fruit fly are detected		PIRSA	Workshops and preparedness activities delivered in collaboration with the Riverland Fruit Fly Committee
4	Formalise a national SIT policy for consistent application of this technology		DAFF / PHC	A draft proposal on the use of Sterile Insect Technique (SIT) in PFAs has been provided to DAFF and will be provided to the NFFC, governments, industries and SIT providers for consideration once finalised. In 2021 DAFF provided detailed information on the options and pathways to implementation of SIT deployment in (and adjacent to) pest free areas. Because these all entail risks and opportunity costs to a range of stakeholders, interested groups were asked to consider these and return with a proposal for further consultation and consideration by affected stakeholders

4. Research

Maintain and enhance fruit fly research capability, capacity and resources, pursuing research and extension that focus on nationally agreed priorities.

Research, development and extension activities underpin all elements of fruit fly management, including operations, legislation, regulation, market access, biosecurity and improvements in management practices. Research provides technically justifiable approaches and innovative solutions to enable market access and sustainable production. Capability and capacity must be maintained, and that research, development and extension are prioritised, coordinated and strengthened through national and international research linkages.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Assist in the development of an irradiation diagnostic tool		NSW DPI	Completed
1	Hort Innovation FF19000 Sex determination of fruit fly pupa using Near-Infrared Spectroscopy		QDAF	An extension has been sought to allow for upscaling of trial results
1	Australian Centre for International Agricultural Research Development of the area-wide management approach for fruit flies in mango for Indonesia, Philippines, Australia and the Asia Pacific Region		QDAF	Good progress has been made and an extension to expand activities in the region
2	Phenology, demography and distribution of Australia's fruit flies		QDAF	Project has been extended to Nov 2022
3	International Atomic Energy Agency - Coordinated Research Project: Irradiation Technology for Phytosanitary Treatment of Food Commodities and Promotion of Trade		QDAF	First meeting held and research priorities identified for delivery of work. Next meeting to be held in Cairns in late 2022
3	Victoria is undertaking a range of research projects to ensure surveillance, diagnostics and management are improved through the development and application of new technologies and practices. Research activities that will continue into the 2021/22 FY include: • A national biocontrol program to manage pest fruit flies in Australia. • Parisitoids for the management of fruit flies in Australia.		Agriculture Victoria	Research delivering well against project milestones. In the biocontrol project, the parasitoid release is progressing well, with overwintering studies and parasitosis being made available in regional Victoria and metro Melbourne. The biopesticide project is yielding promising early results, with investigation of entomopathogenic fungi isolates in laboratory trials

	• Trapping efficacy in table grape vineyards for area wide management of Queensland fruit fly. • Phenology, demography, and distribution of fruit flies (Metabarcoding and LAMP). • A post factory pilot for SITPlus. • Mortality of Queensland fruit fly in cherries following hydrocooling and packhouse surveillance. • Host suitability of strawberry and Rubus for Queensland fruit fly			
2	Contribute to Post factory pilot of SIT (FF17001)		NSW DPI	Final releases of sterile flies completed in April 2022 with data analysis is in progress
2	Undertake research into the use of fruit fly baits and lures to better inform the use of these tools during outbreak response		PIRSA	The research is on track with results pending
3	Hort Innovation MT14052 Essential market access data packages		QDAF	Covid restrictions, flood damage and problems sourcing equipment have resulted in delays
3	Efficacy data to support methyl bromide disinfestation treatments against fruit flies		QDAF	Covid restrictions, flood damage and problems sourcing equipment have resulted in delays
3	Hort Innovation BB19001 Additional cold treatment schedule for Queensland Fruit Fly in blueberries for market access to China		QDAF	Covid restrictions and problems sourcing insecticide-free fruit has led to minor delays
3	Coordinate the Research Program under the Intergovernmental Agreement on Strengthening Australia's Fruit Fly Management System		DAFF / PHA	The research program projects are progressing well, with some projects running to June 2023 due to covid related delays and natural disasters
2	Host a fruit fly research exchange forum (8th Australian Biology of Tephritid Fruit Flies Conference) in 2022		QUT / QDAF	Due to covid and other circumstances it has been decided to not proceed with this at this stage

5. Surveillance

Ensure a nationally consistent surveillance framework that clarifies fruit fly distribution, prevalence and control.

Surveillance systems provide early detection of fruit flies, deliver information for risk analyses and demonstrate the fruit fly status of an area. They are an integral part of fruit fly management and essential for rapid response and market access.
While surveillance must be done in accordance with agreed standards and protocols, it is also increasingly important that it is efficient, effective and able to harness information from both specific (programs to formally demonstrate pest presence or absence) and general (drawn from various government or non-government) sources.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Maintain Tasmania's permanent fruit fly trapping grid with associated maintenance as required		NRE Tasmania	This has been maintained and fully updated to ensure optimal placement of traps and all traps functioning. Tasmania would like to see shifts towards an electronic trapping system subject to trade acceptance
4	Conduct fruit fly surveillance in mango orchards and packing sheds Collate and provide the data to PHA for inclusion into AUSPestCheck®		Australian Mango Industry Association	AMIA Industry Biosecurity Officers have conducted orchards and packing sheds surveillance as planned. AMIA staff will receive training from PHA to upload the data ourselves directly into AusPestCheck®. Please note that Mango Malformation Disease surveillance was not undertaken in Kununurra due to WA border restrictions
4	Facilitate and support integrated fruit fly surveillance programs for government and industry stakeholders using AUSPestCheck®		All jurisdictions	QLD: A specific data report has been developed to allow Queensland fruit fly surveillance data to be manually uploaded into AUSPestCheck® (APC) every two months as required under the NPHSP. An API may be used in the future as part of a fully integrated system. NSW: Monitoring data from Citrus and Cherry Seasonal Pest Absence trials uploaded VIC: NPHS fruit fly surveillance data is loaded into APC. PFA fruit fly data is provided to DAWE on request pending creation of an appropriate APC program.

				NRE Tasmania: Fully utilising and lodging data with Commonwealth through APC. DPIRD: The Department is utilising AUSPestCheck® for surveillance programs PIRSA: Full support and utilisation of AUSPestCheck®.
4	Provide a regional and national overview of the fruit fly surveillance and pest status for government and industry stakeholders by collating integrating and presenting trapping data in AUSPestCheck®		NSW DPI (cooperating with all jurisdictions)	Progressed nationally via SNPHS
1	Continue to maintain trapping grid for exotic fruit flies in metro Adelaide and in the SA Riverland		PIRSA	This additional trapping work has been undertaken as required.
4	Ensure surveillance meets national standards by updating Operating procedures		NSW DPI	Updated operating procedures delivered
2	Continue to maintain a trapping grid of over 7,500 fruit fly traps state-wide		PIRSA	Achieved as agreed
2	Undertake a review of the fruit fly trapping network to ensure that the network is fit for its purpose and provides the best outcomes for Victoria. The re-design of the network will continue to be primarily focused on the early detection of exotic flies but may also provide data to assist in the management of established fruit fly species		Agriculture Victoria	The fruit fly trapping network is currently being redesigned with a focus on early detection of exotics based on the latest research

6. Diagnostics

Maintain and enhance rapid diagnostic capability and capacity to support responses to incursions or outbreaks and to confirm area freedom.

Accurate and rapid fruit fly identification underpins responsiveness to potential incursions or outbreaks and increases the chance of successful eradication. Tools and materials that enhance the ease and throughput of identification of species complexes are of particular value. Confidence in diagnostic capability across a range of established and exotic fruit fly species is fundamental to providing national assurance of area freedom.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Maintain diagnostic capacity for rapid diagnosis of fruit flies. This includes dedicated specialist diagnostic expertise		NRE Tasmania	Dr Guy Westmore is Tasmania's primary expert on fruit fly. During the high-risk season additional diagnostic support (Dr John Ireson) was appointed also with fruit fly expertise
4	Redevelopment of the Australian Plant Pest Database (APPD). This database compiles information on vouchered specimens from the 18 major Australian reference collections of relevance to plant biosecurity		PHA	The new APPD was developed and launched in November 2021. DAFF have submitted a paper to NBC for potential cost sharing arrangements for both APPD and Pest and Disease Image Library (PaDIL) beyond June 2023. An APPD training workshop was recently delivered as part of the Annual Diagnostics and Surveillance workshop in Melbourne on 1st September with more online workshops planned in the next 6 months. The workshops and subsequent feedback will continually improve the system as well as train users on the new redesigned database
4	Redevelopment of the Pest and Disease Image Library (PaDIL). This database is a repository of high-quality diagnostic images and tools used to assist in taxonomic identification of pests and diseases of biosecurity importance to Australia		PHA	PaDIL was redeveloped in the last 12 months and was officially launched at the ADSW (see above) on 30th August in Melbourne. Future funding beyond June 2023 is being investigated.
4	Continue to provide maintenance and support for the fruit fly identification website		PHA	A workplan has been developed for updating the fruit fly identification website. Funding mechanism has yet to be confirmed

4	Continue to verify the performance of diagnostic laboratories for identification of species of interest through appropriate quality management systems		PHC/ ANQAP	There is an annual national plant health proficiency testing program that is run through ANQAP. PHA help deliver the proficiency testing program in collaboration with the proficiency testing coordinator and the Diagnostic Protocols Working Group. There are fruit fly samples that are included in the sample list from time to time, I don't recall fruit flies being in the 2021/22 period
4	Expand the National Plant Biosecurity Diagnostic Network (NPBDN) to be the central point for all activities within the national plant biosecurity diagnostics system		PHA with funding from DAFF	Renewed funding from DAFF. Increased member numbers for NPBDN
4	Provide a career pathway for diagnosticians, including through the National Professional Development Program		PHA with funding from DAFF	Part of NPBDN project deliverables is professional development for diagnosticians via skills-based workshops plus diagnostic residentials
4	Establish an expert group to develop and maintain a record of emerging plant pests that pose a potential threat to plant health in Australia		PHA with funding from DAFF	Expert group convened on an as needs basis with representation from across jurisdictions (i.e., Preparedness Working Working)
4	Identify, monitor and improve the scope and role of individual collections to support trade, biosecurity, and the national plant diagnostic system		PHA with funding from DAFF	The re-build of the Australian Plant Pest database and Pest and Disease Image Library (PaDIL)
4	Develop mechanisms to improve the capture of data from various sources including diagnostics, surveillance, collections, research and area freedom activities		PHA with funding from DAFF	The mechanisms to improve the capture of data includes re-build of new systems including new data standards and also feeding in to Working Groups within (SPHD and SNPHS – sub-committees for Plant Health Diagnostics and Surveillance
2	Incorporate a national diagnostic standard for Sterile Insect Technique fruit flies in the National Fruit Fly Management Protocols		DAFF / PHC	Awaiting draft national diagnostic standard for SIT flies to be submitted to AFFTAC for agreement. Advice from SDQMA is that a formalised national diagnostic protocol for fruit flies is not a priority. AFFTAC's forward workplan is full and no resources are available within DAWE to progress this item

7. Communication and engagement

Adopt systems and mechanisms for the efficient and effective communication, training, extension, and uptake of fruit fly information by a broad range of audiences.

A cohesive fruit fly management system relies on effective sharing and adoption of relevant information. It improves the quality of decision-making and ensures stakeholders at all levels are better equipped to manage fruit fly challenges. Reliable and up-to-date information is also instrumental in maintaining or enhancing industry competitiveness. Improved communication and engagement across fruit fly management systems will help increase innovation uptake and create shared outcomes. It is also essential that information reaches those who benefit from fruit fly management systems, including consumers, wholesalers, retailers, exporters, importers, transport operators and treatment providers.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	
2	Distribution of 2020 GFSPFA poster and flyer reintegrating Qfly bait spraying into table grape pest management programs		ATGA	Posters and flyers distributed to Growers at the Euston & Mildura Roadshows in December
2	Where and when appropriate, inclusion of Fruit Fly information into workshops for table grape growers nationally		ATGA	QFF information (trapping) at 2 Queensland workshops (Emerald & Mundubbera)
2	Respond to industry enquiries regarding inconsistencies between Queensland fruit fly phytosanitary requirements for export and the expectations of Area Wide Management and feedback to GSPFA		ATGA	ATGA is providing the chair of the GSPFA which underpins this activity
4	Berries Australia is represented on the Yarra Valley Regional Governance Group by the Victorian Industry Development Officer		Agriculture Victoria / Industry	Delivered with current funding for 3 Victorian regions to carry out Area Wide Management activities
2	Fruit fly features as a high-profile pest of concern in all of Biosecurity Tasmania's communications. Activities will include timely reminders to the public regarding import requirements and the importance of not introducing fruit flies to Tasmania		NRE Tasmania	A fruit fly-based communications program has been maintained with a focus on awareness and alertness. Appropriately timed communications e.g., e-advisories, Facebook posts, media stories provided ahead of covid border openings in mid-December

2	Ongoing communication of fruit fly related research outcomes, news etc through the industry's email newsletter, website, quarterly magazine, and roadshows where and when appropriate		Australian Mango Industry Association & ATGA	Articles were published in AMIA's communication channels: • National Fruit Fly symposium calls for national strategy commitment, p19, Mango Matters Winter edition, July 2021 • Practical biosecurity surveillance resource for tropical plant industries, p16-17, Mango Matters Spring edition, October 2021 • National Fruit Fly Council Webinar, My Mango, March 2022 • NFFC presented at our pre-season roadshow in Bowen, Qld
2	Undertake community engagement through events including stalls to target backyard growers and at research centres.		NSW DPI	The national engagement and extension project is progressing well, with the project extended to June 2023 to incorporate additional activities.
2	Provide support to Grower groups in managing hot spots and increasing public awareness of fruit flies and their control		NSW DPI	This activity has predominantly been delivered through the Local Land Services network and website
4	Provide DPI representatives to the Sunraysia industry meetings		NSW DPI	Meeting was held with NSW Sunraysia growers in March
4	Provide information through media and personally through Industry development Officers, Local Land Services biosecurity and Compliance staff		NSW DPI	Information exchange mainly through attendance of monthly meetings
2	Regional Governance Groups to develop implementation plans through the area-wide management grants program. These plans will include region-specific awareness and communications plans focusing on local messaging consistent with state and national campaigns and an annual calendar of communications		Agriculture Victoria / Industry	Implementation plans have been developed and each of the regional groups have been developed regionally specific communication and plans. The communications plans focus on delivering a range of communication outputs but are not in the form of a calendar

2	Agriculture Victoria to review and implement the 'State-wide communication and media plan' and implement the 'Queensland fruit fly: Melbourne Metro and fringe communication and engagement plan 2021-2025' to provide consistent key messaging across the state via a seasonal calendar of media, social media and direct contact with relevant organisations. Continue to support the local government by providing fruit fly management information suitable for their use and dissemination and include communications about fruit fly research projects undertaken by Agriculture Victoria Research to assist growers and communities recognise the potential long-term benefits of the research program		Agriculture Victoria	The state-wide communication plan has been developed and the state-wide social media/media calendar has been implemented this season including media releases and monthly/fortnightly during the season social media posts on Twitter and Facebook. Media packages have been provided to local governments in Metro Melbourne. More languages are available through our website. Updates to the Agriculture Victoria website will be happening soon
4	Continue to provide maintenance and support to the Prevent Fruit Fly website		PHA	The Prevent Fruit Fly website is currently being upgraded with changes uploaded in September. Improvements and new initiatives have been included ensuring ongoing communication mechanism across all key stakeholder groups. A member portal is one such improvement
4	Keep stakeholders informed and engaged on Smart Fruit Fly Management measure activities and progress		DAFF	DAFF website content has been updated on the status and progress of the research program projects, bimonthly status reports on the measure activities and progress have been provided to key stakeholders and research program reports have been provided to PHA
4	Undertake national engagement and extension activities to strengthen fruit fly management in Australia.		DAFF / NFFC	This has been undertaken through the Engagement and Extension project delivered by PHA through the NFFC. The project has successfully delivered key initiatives across four key themes including running 15 engagement sessions re National Fruit Fly System, delivery of 2 fruit fly hypothetical exercises with learnings across the system, and development of a Fruit Fly Extension Framework for ongoing extension program
2	Commenced Phase 2 of the "Restrictions are in place" fruit fly community awareness campaign and will undertake market research for effectiveness to inform future campaigns. Website will continue to be refined.		PIRSA	All the activities outlined have been delivered successfully as agreed with stakeholders

	Continue to provide the public with information on activities for the fruit fly outbreaks across metropolitan Adelaide and in the Riverland. This includes sharing information with key stakeholders such as local councils, multicultural community organisations, the Nursery and Gardening Association of SA, the SA Produce Market, horticulture and other retail industry bodies and representatives, sending information to residents within outbreak areas to help with the response, and be proactive in their gardens to help protect SA from fruit fly. An industry bulletin (emailed) and a regular column in the Riverland newspaper will continue to provide updates to targeted stakeholders. A school's engagement program and community speaking program are being developed for the July-Dec period. Engagement with targeted stakeholders in industry and media will promote key messaging to be shared on garden maintenance to reduce fruit fly risks			

8. Cooperation

Maintain and enhance engagement processes that coordinate, progress and improve fruit fly management systems.

A coordinated national system requires cooperation across disciplines and geographic boundaries toward achieving agreed common goals. Industry, government, research, and community forums all raise awareness of fruit fly issues, determine priorities, direct and provide resources, and monitor progress. Collectively, these forums represent the national system and are fundamental sources of information and influence that must be connected and serve the national interest.

Key stakeholder activities				
Strategic objective	**Activity**	**Status**	**Delivery Lead**	**Update**
2	Victoria is working with New South Wales on a cross border Medfly preparedness exercise		NSW DPI / Agriculture Victoria	NSW and Victoria delivered the exercise om 8-9 March 2022
2	The Victorian Government is providing funding for four years under Victoria's Fruit Fly Strategy 2021-2025 for Regional Coordinators and area-wide management programs in the three key horticultural areas of the Goulburn Murray Valley, the Yarra Valley and the Greater Sunraysia region (see also Priority Area 2)		Agriculture Victoria	Ongoing work is continuing with the Regional Fruit Fly Coordinators with tailored workplans for each area
4	Hort Innovation HA18000 National Fruit Fly Council – Phase 3		PHA	The project HA18000 National Fruit Fly Council – Phase 3 concluded in December 2021 with a final report submitted and accepted by Hort Innovation
2	Coordinate fruit fly management within each state, including the provision of information to stakeholders		States and Territories	Qld continues to engage with and assist key stakeholders to manage fruit fly related issues including research, market access, surveillance, diagnostics, agvet chemical availability and use, risk analysis, and incident response and preparedness. State and Regional Coordinators in Victoria meet monthly and have met with the new Manager National Fruit Fly Council to discuss links and future plans
2	Provide expert advice on AFFTAC and research projects		NSW DPI	Review of protocols and standard operating procedures
3	Develop and amend market access protocols in collaboration with other states and territories.		NSW DPI	The cherry seasonal pest absence protocol, ICA17, has been updated

4	Hort Innovation FF20000 National Fruit Fly Council – Phase 4		PHA	The project FF20000 National Fruit Fly Council – Phase 4 was contracted in December 2021 for a 5-year period. The review of the Council has recently been concluded with a new structure endorsed at the June NFFC meeting with the inclusion of an Executive Committee as well as Terms of Reference covering the formation of Council Working Groups
4	Uphold governance structures that serve to support fruit fly management, including the Plant Health Committee, Australian Fruit Fly Technical Advisory Sub-Committee and the National Fruit Fly Council		DAFF	DAFF: The department continue to engage with PHC, AFFTAC and NFFC. The department participated and provided papers for these committee meetings
2	Continue to support regional consultative mechanisms in South Australia to engage with industry and other stakeholders		PIRSA	Work has been ongoing meeting with regional consultative groups including the Riverland Fruit Fly Committee

Notes

NATIONAL FRUIT FLY STRATEGY

Implementation Report

2022-23

NFFC
NATIONAL FRUIT FLY COUNCIL

Funding Statement

The National Fruit Fly Council – Phase 4 (FF20000) is funded through the Hort Frontiers Strategic Partnership Initiative developed by Hort Innovation, with co-investment from fruit fly affected industry research and development levies, Plant Health Australia, state and territory governments and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Acknowledgement of Country

PHA acknowledges the Australian Aboriginal and Torres Strait Islander peoples as the traditional custodians of the lands where we work, live, and learn.

Copyright Statement

Copyright in this publication is owned by Plant Health Australia, except when content has been provided by other contributors, in which case another person may own copyright. With the exception of any material protected by a trademark, and except where otherwise indicated, these publications are licensed under a Creative Commons Attribution 3.0 Australia licence. Any use of the publication, other than as authorised under this licence or copyright law, is prohibited.

Attribution

You are free to copy, communicate and adapt the material in this publication, so long as you attribute the Plant Health Australia, and the authors in the following manner:

National Fruit Fly Council (2024) *National Fruit Fly Strategy Implementation Plan 2023-24*, Plant Health Australia.
© Plant Health Australia 2024

Plant Health Australia

ABN 97 092 607 997
Level 1, 1 Phipps Close
Deakin ACT 2600

Phone 02 6215 7700
Email fruitfly@phau.com.au
preventfruitfly.com.au

Contents

Glossary of Terms 4
About this Report 5
The Strategic Framework 2020-25 6
Vision 6
Goal 6
Strategic objectives and key performance indicators 6
Priority Areas 7
1. Market access 8
2. Management of established fruit fly 12
3. Prevention, preparedness, and response 14
4. Research 17
5. Surveillance 19
6. Diagnostics 22
7. Communication and engagement 24
8. Cooperation 27

NFFC
NATIONAL FRUIT FLY COUNCIL

Glossary of Terms

Acronym	Term
AFFTAC	Australian Fruit Fly Technical Advisory Committee (a Subcommittee of Plant Health Committee)
AMIA	Australian Mango Industry Association
ATGA	Australian Table Grape Association Inc.
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
DPIRD	Department of Primary Industries and Regional Development Western Australia
EPP	Emergency Plant Pest
GSPFA	Greater Sunraysia Pest Free Area
IAEA	International Atomic Energy Agency
ICA	Interstate Certification Assurance
LAMP	Loop-Mediated Isothermal Amplification
LLS	Local Land Services New South Wales
MoU	Memorandum of Understanding
NAQS	Northern Australia Quarantine Strategy
NIAP	National ICA Audit Program
NRE Tas	Department of Natural Resources and Environment, Tasmania
NSW DPI	New South Wales Department of Primary Industries
PFA	Pest Free Area
PHA	Plant Health Australia
PHC	Plant Health Committee
PIRSA	Department Of Primary Industries and Regions, South Australia
QDAF	Department of Agriculture and Fisheries, Queensland
SIT	Sterile Insect Technology
SMART	The Subcommittee for Market Access, Risk and Trade

NFFC
NATIONAL FRUIT FLY COUNCIL

About this Report

The 2022–23 Implementation Report summarises progress and achievements from 1 July 2022 to 30 June 2023. Progress in each of the eight key result areas from the National Fruit Fly Strategic (NFFS) 2020-25 is tracked against the strategic framework and objectives within the NFFS.

The Implementation Report is finalised in June of the previous financial year and published along with the next financial year's Implementation Plan.

A colour code is used to report on performance, as shown below.

Performance reporting key

	Activity is completed
	Activity is on schedule
	Activity is behind schedule or has been modified
	Activity will not be met

Strategic Framework 2020-25

Vision

Australia has a robust fruit fly management system that supports growth in horticultural production, market access and trade.

Goal

Australia will have a contemporary, viable, cost-effective, and coordinated national approach to fruit fly management, with stakeholders committed to the national strategy.

Strategic objectives and key performance indicators

1. Maintain Australia's freedom from exotic fruit fly

Maintaining freedom from exotic fruit flies is essential to the sustainability of Australia's horticultural industries.

Key Performance Indicator:
Incursion(s) of exotic fruit flies in Australia are detected early and eradicated.

2. Minimise the incidence and spread of fruit fly

Improving the management and suppression of established fruit fly species and preventing their further spread will help support productivity, reduce management costs, and enable trade and market access opportunities through low pest prevalence and pest-free areas.

Key Performance Indicator: *Domestic and international recognition of fruit fly pest free areas is retained or increased.*

3. Implement national systems that support market access

Providing markets (domestic and international) confidence in our fruit fly system will ensure Australian growers can capitalise on our reputation for high-quality produce.

Key Performance Indicator: *There is no critical non-conformance in the national fruit fly assurance system.*

4. Facilitate a cooperative and committed national approach to fruit fly management

The cooperation of governments, industries and communities that operate in different fruit fly management areas is vital to the success of the fruit fly system.

Key Performance Indicator: *Consistency between governments, industries, and communities' strategy and strategic fruit fly objectives.*

NFFC
NATIONAL FRUIT FLY COUNCIL

Priority Areas

Eight different yet interdependent priority areas have been identified for the strategy.

1. Market access

Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures and is legally enforceable and technically justified.

2. Management of established fruit fly

Build and promote efficient and effective methods to manage established fruit fly species, reduce the impact on production and facilitate access to sensitive markets.

3. Prevention, preparedness, and response

Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

4. Research

Maintain and enhance fruit fly research capability, capacity, and resources, pursuing research and extension that focus on nationally agreed priorities.

5. Surveillance

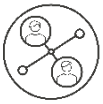
Ensure a nationally consistent surveillance framework that clarifies fruit fly distribution, prevalence, and control.

6. Diagnostics

Maintain and enhance rapid diagnostic capability and capacity to support responses to incursions or outbreaks and to confirm area freedom.

7. Communication and engagement

Adopt systems and mechanisms for the efficient and effective communication, training, extension, and uptake of fruit fly information by a broad range of audiences.



8. Cooperation

Maintain and enhance engagement processes that coordinate, progress, and improve fruit fly management systems.

NFFC
NATIONAL FRUIT FLY COUNCIL

1. Market access

Develop a framework of policy, legislation and operations that enables market access with the least trade-restrictive measures and is legally enforceable and technically justified.

Australia has strong domestic and international biosecurity systems vital for supporting market access for fruit fly affected industries. These systems must reflect internationally accepted standards and protocols, uphold risk management principles, and be transparent and scientifically robust to maintain confidence among domestic and international trading partners. It is essential that fruit fly policy, legislation, and operations continuously improve to meet market access needs.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Continue to work with the Australian Government as well as other governments and industry contributing to the national progression of the fruit fly management system.		NRE Tas	NRE Tas proactively engages with the Australian Government as well as other states & territories on a number of formal committees as well as state-based industry groups including through the Tasmanian Fruit Fly Task Force that meets regularly throughout the year.
Finalise the stabilisation phase of Australia's National Fruit Fly Management Protocol.		DAFF & Multiple Agencies	DAFF: The overarching documents within the Protocol have been endorsed by PHC (Dec 2021). However, supporting documentation intending to provide consistent guidance, instruction, and technical requirements to maintain fruit fly management systems continue to be progressed through Australian Fruit Fly Technical Advisory Committee (AFFTAC) in line with state and territory priorities. Fruit fly management processes and procedures lacking subordinate documentation continues to present a risk for consistency of fruit fly management actions and the department will continue to provide advice on where this impacts market access to assist with prioritisation. State jurisdictions continue to be represented on AFFTAC and to respond to requests for input/approval of Australia's National Fruit Fly Management Protocols and associated documents.
Monitor national fruit fly system assurance activities that underpin international market access, including obligations to demonstrate pest status.		DAFF/ States & Territories	DAFF and all states & territories compliant with requirements.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Seek acceptance of Australia's National Fruit Fly Management Protocol from trading partners.		DAFF	Ongoing activity with trading partners.
Communicate international market access requirements for fruit fly and associated issues to industry and state/territory governments.		DAFF	Series of industry engagement sessions commenced through appropriate reporting structures.
Develop new and amend existing Interstate Certification Assurance (ICA), CA and protocols to meet market access needs for NSW growers. Explore systems approaches to increase and support market access.		NSW DPI	Ongoing through ICA review processes.
Negotiate international market access protocols for fruit fly that maintain, improve, or open market access.		DAFF	Delivered as required.
Strengthen current market access data packages and address any perceived gaps to support market access negotiation of international market access.		DAFF	Significant investment through Hort Innovation funded research with future multi-year program in final stages of development.
Investigate and rectify areas of non-compliance identified in the national and domestic system that underpin market access, including National ICA Audit Program (NIAP).		DAFF/ States & Territories	All jurisdictions continue to be subject to periodic audits (at least once every 24 months). Audited against the relevant performance standards as endorsed by PHC. Compliance assessed against the performance standards and follow up audits conducted to verify that agreed corrective actions addressed.
Undertake risk analysis to support proposed market access tools proposed by other jurisdictions.		NSW DPI	Ongoing.
Continue to build confidence in, acceptance, and capacity in the use of phytosanitary irradiation for market access through involvement in the building capacity in irradiation pathways for export project.		Agriculture Victoria	Ongoing engagement with both commercial players (Steritech) and growers/packers.

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Support development of alternative market access approaches (e.g., Areas of Low Pest Prevalence, winter windows, system approach, climate models) to underpin trade negotiations for fruit flies.		DAFF	Ongoing work underway through associated Work Plans.
Continue development of product data packages to support phytosanitary trade.		QDAF	Ongoing with project funding being finalised for 8-year project with Hort Innovation.
Continue to contribute to the development and periodic review of domestic trading protocols used to support trade of host produce across jurisdictional borders with varying fruit fly status. This includes working with DAFF to achieve an elevated level of consistency in the use of Methyl Bromide fumigation and irradiation/microwave technology as measures to enable domestic and international market access.		Agriculture Victoria	Significant activity undertaken through numerous committee structures such as the AFFTAC.
Develop Protocol compliant trapping surveillance on cherry, *Rubus* and strawberry production properties for use in developing Systems Approach market access options.		Industry	Delivered through project.
Continue to explore and develop systems approaches to fill the void left by chemical losses.		NSW DPI	Ongoing engagement with Hort Innovation funded investment through the Safe Trade activities- Commonwealth Scientific and Industrial Research Organisation (CSIRO) team.
Monitor and report against the domestic phytosanitary system for fruit fly through the NIAP.		Multiple Agencies	COVID restrictions have impacted on the delivery of the national audit program. SMART has since agreed to an alternative approach to undertaking NIAP audits.

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Investigate and rectify areas of non-compliance identified in the national and domestic systems that underpin market access.		Multiple Agencies	QDAF: Continued implementation of surveillance activities (including maintaining a trapping network at international ports and other high-risk sites), risk mitigation measures for key risk pathways, and responding to suspect reports and new detections to support area freedom claims for exotic fruit flies, including Mediterranean fruit fly. NSW DPI: Trap base has been introduced and monthly monitoring is taking place for other fruit fly of concern. Agriculture Victoria: Pest Quarantine Manual now live and accessible through the Agriculture Victoria website. Ongoing support and advice for industry in relation to movement of produce domestically. PIRSA: The Department has followed and investigated reports of non-certified produce entering South Australia. No non-compliance identified. DPIRD WA: Continued maintenance of trapping base as agreed. NRE Tas: Undertaken minor ICA updates (i.e. labelling) plus continuing focus on maintaining securing our borders and collaboration with Agriculture Victoria pre-border. DAFF: States and territories will be subject to a minimum of one periodic audit within every 24 months against the relevant performance standards as endorsed by PHC. Compliance will be assessed against the performance standards and follow up audits will be conducted to verify that agreed corrective actions have been taken to address non-compliances.
Support Victoria's work to strengthen the domestic protocol for fumigation of host fruit (ICA04) to better address risk and align with arrangements at the national border.		Multiple Agencies	Agriculture Victoria submitted the revised version of national ICA-04 protocol which was supported by the states and agreed to by SMART.

NATIONAL FRUIT FLY COUNCIL

2. Management of established fruit fly

Build and promote efficient and effective methods to manage established fruit fly species, reduce the impact on production, and facilitate access to sensitive markets.

A better understanding of established fruit flies helps to improve the effectiveness of control methods and tools. Growers must have management and disinfestation options to control fruit flies and maintain or gain market access. These options must be economical and underpinned by evidence and confidence in supporting assurance systems.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Continue to provide fruit fly management information from DPI and LLS websites.		NSW DPI	Ongoing updating of website resources and development of regional fruit fly workshops. Monthly meetings convened to support this.
Advise industry of any relevant advancements in management practices.		NSW DPI	Undertaken particularly through regional fruit fly workshops delivered through the Local Land Services (LLS) network.
Continue development of parasitoids for the management of fruit flies in Australia.		Agriculture Victoria	Initial project completed with ongoing extension and integration work being explored through the national fruit fly research program.
Continue conducting field investigations to provide advice on Qfly management.		GSPFA	Ongoing through a combination of Ag Vic and industry-based biosecurity and extension programs including both citrus (Citrus Australia) and table grapes (ATGA).
Continue removal of host fruit tree across the region thereby reducing pest pressure and hosts.		GSPFA	Ongoing.
Ensure provision of Qfly control devices throughout the region.		GSPFA	Ongoing distribution of Qfly control devices throughout the region.
Development of hot spot action plans to address sites with habitual high pressure of Qfly.		GSPFA	Ongoing.
Development and trial of on-site fermentation processes for soft fruit to increase the viability of fruit destruction and reduce the need to transport waste off-site.		Yarra Valley Fruit Fly Project	Refer to Australian Berry Journal Summer 2022 "Biosecurity Field Day" page 38 and Spring 2022 "Fruit Waste management for QFF Prevention" page 24. The findings were also presented in a talk at BerryQuest International in Brisbane, April 2022. In the next phase of this project, the capacity of the unit design will be increased to 1000L to be able to empty the fermented product.

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Design and publication of brochures (paper and electronic versions) and videos detailing each best practice area for Qfly management.		Yarra Valley Fruit Fly Project	Brochures are still to be completed, video made on baiting (FFMV and YV). These brochures will sit in the e-learning platform.
Unmanaged Qfly host removal on public land alongside participating private properties.		Yarra Valley Fruit Fly Project	The Yarra Ranges Council has removed 243 trees & tree clusters from sites on council-maintained roadsides (cut, paint & mulch) in 2023. No further tree removals are forecast (no further funds allocated to this from state or local council).
Design and implement new trapping grid across jurisdictions.		DAFF	Reviews of trapping grids have been ongoing in jurisdictions.
Review and implementation of the review of the Sunraysia PFA trapping grid to support revocation of the PFA.		Agriculture Victoria	Technical trapping review complete. Yet to engage with industry stakeholders. Status of GSPFA to be determined, post industry engagement.
Evaluate the southwest general fruit fly surveillance program and use the key findings to inform decision making processes across the broader fruit fly reporting and awareness program.		Agriculture Victoria	Reviews of these areas are ongoing.
Grower workshop with updates from Agriculture Victoria researchers re: mass releases and trapping strategy plus updates from the GSPFA.		Citrus Australia	Undertaken with ongoing activity.
Connect Agriculture Victoria researchers with local agronomists to provide input and feedback on short-term research project into trapping strategy for table grapes.		ATGA	A meeting was facilitated by ATGA in June ensuring fine tuning of the trapping strategy for the table grape industry.

NFFC
NATIONAL FRUIT FLY COUNCIL

3. Prevention, preparedness, and response

Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

Australia works hard to maintain freedom from exotic fruit flies and minimise the spread of established fruit flies into pest-free areas. Understanding fruit fly characteristics and risk pathways can help in the design of detection and control measures to manage incursions and prevent fruit fly spread.

Governments, industries, and communities also have a role to play in taking steps to prepare for potential risks, including planning for fruit fly eradication and for business continuity. There are high returns on investment for prevention and preparedness activities and these remain a priority for Australia's fruit fly management system.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Formalise a national Sterile Insect Technique (SIT) policy for consistent application of this technology.		DAFF	A draft proposal on the use of Sterile Insect Technique (SIT) for exclusionary use in PFAs was provided firstly to DAFF and subsequently to the NFFC for consideration. Further work has been recommended at this stage. Ongoing research is underway in relation to SIT and its application including benefit cost assessments for their use in both the Goulburn / Murray and Riverland regions.
Implement incursion and eradication procedures for exotic incursions on an as-needs basis.		States & Territories	General: Ongoing delivery through QDAF project including deployment and management of trapping networks at international ports and other high-risk pathways. PIRSA: Ongoing response in SA Riverland. NRE Tas: Biosecurity Emergency Preparedness Program, updated Fruit Fly Operations Standard. All States & Territories: Have met requirements to respond to any suspect EPPs.
Implement incursion and eradication procedures in pest free areas in accordance with Australia's National Fruit Fly Management Protocol.		States & Territories	PIRSA: Ongoing response in SA Riverland. Agriculture Victoria: Ag Vic has met requirements to respond to detections of EPPs. NRE Tas: Compliance with national protocols, national audit pass.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Complete translation of all existing regulatory requirements associated with fruit fly for operation under the new Biosecurity Act 2019. This includes updated listings and translation of import processes to work under the Biosecurity Act.		NRE Tas	Fully operational under the Biosecurity Act 2019. Plant Quarantine Act now repealed. Plant Biosecurity Manual 2023 converted to Biosecurity Act inclusive of terminology and listings.
A series of workshops/ exercises will be held to improve internal processes for investigation of EPPs.		Agriculture Victoria	Agriculture Victoria has updated internal procedures when improvements have been identified.
Deliver fruit fly control responsibilities in the areas of Victoria adjacent to Riverland Pest Free Area.		PIRSA	Response activities in Lindsay Point area under MoU with Victoria.
Early Detection and Rapid Response hotline/email contact, support and sharing of best practice knowledge, followed up with targeted regional engagement workshops.		Yarra Valley Fruit Fly Project	Current and still operational whilst funded (end March 2025). Project close (June 2025).
Review and implementation of NSW statewide trapping network.		NSW DPI	Initial review of the Sunraysia, Sydney Basin, Gyra and Murrumbidgee Irrigation Area trapping grid has been undertaken with work ongoing regarding broader statewide network.
Update and implement incursion/ eradication responses response in line with national protocols.		NSW DPI	Ongoing as per current incursion review of Varroa and red imported fire ant.
Implement National Action Plan for Exotic Fruit Flies.		DAFF	Ongoing.
Develop and implement NSW fruit fly action plan.		NSW DPI	Further work required when resources allow.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Transition Port Augusta Qfly SIT factory pilot operation to commercial operation.		PIRSA	Completed 30/11/22 (DAWE-4EKSH327). BAS regional releases completed 1/12/22.
Complete work on biosecurity preparedness for oriental fruit fly and exotic fruit flies.		NSW DPI	This work is ongoing through the Hort Innovation funded project FF18001: Biosecurity preparedness for oriental fruit fly and exotic flies. The first stage of planning completed and second stage of work underway including international literature reviews of existing approaches overseas.
Continue work on ST19017 biosecurity preparedness through developing capacity for in-field detection of spotted wing *Drosophila* (part of RRD4P project: Boosting diagnostic capacity for plant production industries).		Agriculture Victoria	Completed 25/6/23. RRD4P project 9078081 (Boosting diagnostics).
Communicate potential or identified areas of risk of exotic fruit fly incursion.		DAFF	Ongoing particularly through the current Torres Strait and QDAF project.
Engage with stakeholders on pest prioritisation of exotic fruit flies.		DAFF	Ongoing activity.
Administer the Exotic Fruit Fly in Torres Strait Response Plan to eradicate incursions of exotic fruit fly species from Torres Strait in response to detections from Northern Australia Quarantine Strategy (NAQS) surveillance.		QDAF	Ongoing through the Emergency Response Fund (Deed) mechanism.
Ensure implementation of revised trapping grid in Sunraysia.		NSW DPI	Trapping grid implemented and compliant with requirements.

4. Research

Maintain and enhance fruit fly research capability, capacity, and resources, pursuing research and extension that focus on nationally agreed priorities.

Research, development, and extension activities underpin all elements of fruit fly management, including operations, legislation, regulation, market access, biosecurity, and improvements in management practices. Research provides technically justifiable approaches and innovative solutions to enable market access and sustainable production. Capability and capacity must be maintained, and that research, development and extension are prioritised, coordinated, and strengthened through national and international research linkages.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Finalise research on parasitoids for the management of fruit flies in Australia.		Agriculture Victoria	Completed 30/11/22 (DAWE-4EKSH327). BAS regional releases completed 1/12/22.
Deliver the IAEA Coordinated Research Project (CRP): Irradiation Technology for Phytosanitary Treatment of Food Commodities and Promotion of Trade.		QDAF	Work ongoing and closely linked to IAEA Integrated Regulatory Review Service (IRRS) team.
Finalise research on the Hort Innovation project BB19001: Additional cold treatment schedule for Qfly in blueberries for market access to China.		QDAF	Completed and submitted to Hort Innovation.
Complete research on efficacy data to support Methyl Bromide disinfestation treatments against fruit flies.		QDAF	Project nearing completion.
Coordinate the extension of Research Program under the Intergovernmental Agreement on Strengthening Australia's Fruit Fly Management System.		DAFF	Some areas of extension for research undertaken through this program are being explored through Hort Frontiers (i.e. parasitoids and alternative beneficials). The NFFC has been given ongoing carriage of the 'sustainable funding' of the national fruit fly system.
Provision of captured Qfly to research organisations for genetic sequencing, potentially to assist in determining Qfly pathways.		CSIRO	Completed through the respective projects (e.g. QDAF).

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Comparison of manual and automated traps in the field.		Yarra Valley Fruit Fly Project	The findings will be presented to the grower group in the Yarra Valley to choose a pathway forward, post-funded period.
Finalise post-factory pilot of SIT.		NSW DPI	Post-factory pilot project concluded.
Support delivery of DAFF-funded phenology, demography, and distribution of fruit fly project.		States & Territories	All states & territories provided support as required. Project final report drafted for submission.
Ensure delivery of the project: Biosecurity preparedness for Oriental Fruit Fly (FF18001).		NSW DPI	Project on track including completion of key workshop in Sydney post International Fruit Fly Symposium.
Ensure development of the Hort Innovation project FF19000: Sex determination of fruit fly pupa using Near Infrared Spectroscopy.		QDAF	Ongoing research being conducted.
Support delivery of the Australian Centre for International Agricultural Research (ACIAR) project development of area wide management approached for fruit flies in mango for Indonesia, Philippines, Australia, and the Asia Pacific Region.		QDAF	Ongoing.
Continue development of the IAEA Technical Cooperation Project in the Asia and Pacific promoting Food Irradiation by Electron Beam and X-Ray Technology to Enhance Food Safety, Security and Trade.		QDAF	Ongoing.

5. Surveillance

Ensure a nationally consistent surveillance framework that clarifies fruit fly distribution, prevalence, and control.

Surveillance systems provide early detection of fruit flies, deliver information for risk analyses, and demonstrate the fruit fly status of an area. They are an integral part of fruit fly management and essential for rapid response and market access.

While surveillance must be done in accordance with agreed standards and protocols, it is also increasingly important that it is efficient, effective, and able to harness information from both specific (programs to formally demonstrate pest presence or absence) and general (drawn from various government or non-government) sources.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Undertake a review of the fruit fly trapping network to ensure that the network is fit for purpose and provides the best outcomes for Victoria.		Agriculture Victoria	Review completed with recommendations planned for implementation.
Undertake surveillance of high-risk pathways for exotic fruit flies, including ports of entry surveillance conducted by states and territories and the Torres Strait surveillance conducted by NAQS.		Agriculture Victoria	Surveillance continues to be undertaken at high-risk entry pathways under the NPHSP. Trap pathways linked to pathway analysis.
Provide a regional and national overview of the fruit fly surveillance and pest status for government and industry stakeholders by collating, integrating, and presenting trapping data in AUSPest*Check®*.		Agriculture Victoria	Surveillance data is being uploaded to the NPHSP and JFFLY programs in AUSPest*Check®* as required (fortnightly). Some technical issues, including re-entry of data are being resolved as well as data sharing and privacy.
Facilitate and support integrated fruit fly surveillance programs for government and industry stakeholders using AUSPest*Check®*.		Agriculture Victoria	Industry has been supported to develop surveillance programs and data collection that meet AUSPest*Check®* requirements.
Conduct fruit fly surveillance in mango orchards and packing sheds. Collate and provide the data to PHA for inclusion into AUSPest*Check®*.		AMIA	AMIA Industry Biosecurity Officers have conducted ongoing orchard and packing shed surveillance as part of the project. Training regarding uploading to AUSPest*Check®* undertaken.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Ensure surveillance meets national standards by updating operating procedures.		NSW DPI	Reviews undertaken and compliant with national standards.
Provide a regional and national overview of the fruit fly surveillance and pest status for government and industry stakeholders by collating integrating and presenting trapping data in AUSPest*Check®*.		NSW DPI (cooperating with all jurisdictions)	Progressed nationally via Subcommittee on National Plant Health Surveillance (SNPHS).
Maintain Tasmania's permanent fruit fly trapping grid with associated maintenance as required.		NRE Tas	Effectively maintained with program of network checks- currency.
Further development of an improved set of domestic trade arrangements for Medfly based on the existing ICA arrangements that are accepted for Qfly.		PIRSA	Further development undertaken but protocols not finalised - Qfly prioritised.
Continue preparedness /contingency planning workshops in the SA Riverland and other growing areas to prepare growers for the event that more outbreaks of fruit fly are detected.		PIRSA	Ongoing response in SA Riverland.
Continue to maintain trapping grid for exotic fruit flies in metro Adelaide and in the SA Riverland.		PIRSA	Ongoing commitment.
Continue to invest significantly to eradicate any outbreaks of Medfly and of Qfly in SA.		PIRSA	No Medfly outbreaks - 43 Qfly outbreaks in Riverland.
Continue to maintain a trapping grid of over 7,500 fruit fly traps statewide.		PIRSA	Ongoing commitment.
Further development of research into the use of fruit fly baits and lures to better inform the use of these tools during outbreak response.		PIRSA	The South Australian Research and Development Institute (SARDI) are completing a second and third round of research on fruit fly baits and lures.

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Activity	Activity	Activity
Implement effective support programs for surveillance, diagnostics, and reporting. Including timely reporting of incursions.		PIRSA	Ongoing commitment and compliance from all states & territories. Implement ongoing phases of the "Restrictions are in place" fruit fly community awareness campaign and will undertake market research for effectiveness to inform future campaigns. Website will continue to be refined. Continue to provide the public with information on activities for the fruit fly outbreaks across metropolitan Adelaide and in the Riverland. This includes sharing information with key stakeholders such as local councils, multicultural community organisations, the Nursery and Gardening Association of SA, the SA Produce Market, horticulture and other retail industry bodies and representatives, sending information to residents within outbreak areas to help with the response, and be proactive in their gardens to help protect SA from fruit fly. An industry bulletin (emailed) and a regular column in the Riverland newspaper will continue to provide updates to targeted stakeholders. Continue delivery of the school's engagement program and community speaking program. Engage with targeted stakeholders in industry and media to promote key messaging to be shared on garden maintenance to reduce fruit fly risks.
Continue to support regional consultative mechanisms in South Australia to engage with industry and other stakeholders.		PIRSA	Ongoing commitment.
Continue area wide management surveillance grid, on farm intensive surveillance, emergency response trapping (additional), and citizen science trapping/reporting.		Yarra Valley Fruit Fly Project	Current and still operational whilst funded (end March 2025). Project close (June 2025).
Facilitate the deployment of RapidAIM Qfly monitoring traps.		GSPFA	Undertaken as required.

6. Diagnostics

Maintain and enhance rapid diagnostic capability and capacity to support responses to incursions or outbreaks and to confirm area freedom.

Accurate and rapid fruit fly identification underpins responsiveness to potential incursions or outbreaks and increases the chance of successful eradication. Tools and materials that enhance the ease and throughput of identification of species complexes are of particular value. Confidence in diagnostic capability across a range of established and exotic fruit fly species is fundamental to providing national assurance of area freedom.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Application of LAMP technology to suspect Qfly if initial ID cannot determine species.		Agriculture Victoria	LAMP successfully developed and validated (and utilised) for Qfly and other Australian pest tephritids.
Increase efficiencies in diagnostics and reporting with finalised trap base and implementation.		NSW DPI	Completed under review.
Ensure diagnostic and reporting is in line with national protocols. Including updating operating procedures.		NSW DPI	Completed under review and compliant with national standards.
Maintain diagnostic capacity for rapid diagnosis of fruit fly. This includes dedicated specialist diagnostic expertise.		NRE Tas	Senior entomologist identified as state lead for fruit fly and state expert. Diagnostic capacity and capability maintained. Surge capacity being addressed.
Increase efficiencies in diagnostics and reporting through support programs.		NSW DPI	Ongoing.
Ensure diagnostic and reporting is in line with national protocols.		NSW DPI	Undertaken under review and compliant with national protocols.
Incorporate a national diagnostic standard for Sterile Insect Technique fruit flies in the National Fruit Fly Management Protocol.		DAFF	Ongoing work progressing.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Complete redevelopment of the Australian Plant Pest Database (APPD).		PHA	Ongoing post launch in August 2021.
Complete redevelopment of the Pest and Disease Image Library (PaDIL).		PHA	Completed August 2022.
Continue to verify the performance of diagnostic laboratories for identification of species of interest through appropriate quality management systems.		DAFF	Ongoing.
Expand the National Plant Biosecurity Diagnostic Network (NPBDN) to be the central point for all activities within the national plant biosecurity diagnostics system.		DAFF	Ongoing.
Provide a career pathway for diagnosticians, including through the National Professional Development Program.		DAFF	Ongoing.

7. Communication and engagement

Adopt systems and mechanisms for the efficient and effective communication, training, extension, and uptake of fruit fly information by a broad range of audiences.

A cohesive fruit fly management system relies on effective sharing and adoption of relevant information. It improves the quality of decision-making and ensures stakeholders at all levels are better equipped to manage fruit fly challenges. Reliable and up-to-date information is also instrumental in maintaining or enhancing industry competitiveness. Improved communication and engagement across fruit fly management systems will help increase innovation uptake and create shared outcomes.

It is essential that information reaches those who benefit from fruit fly management systems, including consumers, wholesalers, retailers, exporters, importers, transport operators and treatment providers.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Agriculture Victoria to review and implement the 'State-wide communication and media plan' and implement the 'Qfly: Melbourne Metro and fringe communication and engagement plan 2021-2025' to provide consistent key messaging across the state via a seasonal calendar of media, social media, and direct contact with relevant organisations. Continue to support local government by providing fruit fly management information suitable for their use and dissemination and include communications about fruit fly research projects undertaken by Agriculture Victoria Research to assist growers and communities recognise the potential long-term benefits of the research program.		Agriculture Victoria	Seasonal calendar of social media messages has been implemented. Local organisations have been sent brochures for dissemination and links to translated materials have been provided. Queensland fruit fly research webpage has been updated and regional coordinators have been provided with parasitoid information.
Develop and deliver a comprehensive communication and awareness media campaign to enhance delivery of regional strategic messaging across the PFA.		GSPFA	Ongoing as per the Ag Vic funded project. Integrated with the various regional industry extension and communication programs regarding Qfly.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Develop and deliver community engagement activities including presentations, field days, markets, and events/production of videos.		GSPFA	Ongoing as per the Ag Vic funded project. Integrated with the various regional industry extension and communication programs regarding Qfly.
Development of newspaper, radio, podcast, web material, social media, articles, other publications, workshops, train the trainer sessions/resources for the general public, "champions", and organisations likely to come across fruit fly in the workplace.		Yarra Valley Fruit Fly Project	Current and still operational whilst funded (end March 2025). Project close (June 2025).
Develop new website called fruitflyexamples.com to enable greater engagement with stakeholders.		Yarra Valley Fruit Fly Project	Revamp of the Hort Innovation FF management booklet and development of an e-learning program for QFF management.
Provide representation for Sunraysia industry and government groups.		Agriculture Victoria	Agriculture Victoria contributes to a range of Sunraysia groups including the Murray Valley Advisory Group which includes representatives from Citrus, Table grapes and Summerfruit and its subcommittees.
Provide public information through media and personally through Industry Development Officers, LLS Biosecurity and Compliance Staff.		NSW DPI	Broad spectrum communication plan actioned.
Facilitate the delivery of the 11th International Symposium on fruit flies of Economic Importance in Sydney.		NSW DPI	Successful delivery of the 11th International Symposium held at Macquarie University.
Keep stakeholders informed and engaged on Smart Fruit Fly Management measure activities and progress.		DAFF	Regular project updates prepared, disseminated, and loaded onto the Smart Fruit Fly Management Measure web page.
Ensure DPI representatives are involved in the Sunraysia PFA industry meetings leading to greater engagement.		NSW DPI	NSW DPI representatives regularly involved in Sunraysia PFA meetings.
Undertake national engagement and extension activities to strengthen fruit fly management in Australia.		PHA	Progressed through the DAFF funded Engagement & Extension program. Funding concluded June 2023 with resourcing for new priority activities currently being explored.
Continue to provide maintenance and support for the Prevent Fruit Fly website to enable successful extension of information.		PHA	Ongoing through the Hort Innovation funded Phase 4 NFFC project.

NFFC
NATIONAL FRUIT FLY COUNCIL

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Fruit fly features as a high-profile pest of concern in all of Biosecurity Tasmania's communications. Activities will include timely reminders to the public regarding import requirements and the importance of not introducing fruit flies to Tasmania.		NRE Tas	Separate comms plan in relation to fruit fly inclusive of targeted articles, awareness campaigns, social media etc.
Ongoing communication of fruit fly related research outcomes, news etc through the industry's email newsletter, website, quarterly magazine, and roadshows where and when appropriate.		AMIA	Multiple fruit fly related articles published in Mango Matters newsletter as well as through social channels (e.g. Fruit Fly Placemats).
Regional Governance Groups to develop implementation plans through the area wide management grants program. These plans will include region specific awareness and communications plans focusing on local messaging consistent with state and national campaigns and an annual calendar of communications.		Agriculture Victoria	Regional groups have reviewed their plans and implemented their program. Reporting on the delivered regional specific communication plans underway.
Respond to industry enquiries regarding incompatibility between Qfly spray requirements to comply with ICAs and export Maximum Residue Limits (MRLs) and feedback to GSPFA.		ATGA	Significant industry support work required in relation ICA changes and reviews.
Undertake community engagement through events including stalls to target backyard growers and at research centres.		NSW DPI	Numerous regionally focused community engagement undertaken.
Provide support to grower groups in managing hot spots and increasing public awareness of fruit fly and its control.		NSW DPI	Ongoing activities.

NFFC
NATIONAL FRUIT FLY COUNCIL

8. Cooperation

Maintain and enhance engagement processes that coordinate, progress, and improve fruit fly management systems.

A coordinated national system requires cooperation across disciplines and geographic boundaries toward achieving agreed common goals. Industry, government, research, and community forums all raise awareness of fruit fly issues, determine priorities, direct, and provide resources, and monitor progress. Collectively, these forums represent the national system and are fundamental sources of information and influence that must be connected and serve the national interest.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
The Victorian Government is providing funding for four years under Victoria's Fruit Fly Strategy 2021-2025 for Regional Coordinators and area wide management programs in the three key horticultural areas of the Goulburn Murray Valley, the Yarra Valley and the Greater Sunraysia region.		Agriculture Victoria	Applications for the final round of Victoria's Fruit Fly Strategy grants have closed and the grant applications are going through the approval process. Regional grants have focused on embedding areawide management activities in regional organisations and providing a legacy for the program as the transition to industry and the community will be complete at the end of this round.
Regular meetings with industry leaders and fruit fly experts including regular check-ins with Agriculture Victoria and other co-ordinators.		Agriculture Victoria	The three Regional Governance groups which include Agriculture Victoria, industry representatives and local government have been meeting quarterly with some groups meeting more often to discuss delivery of the grants programs. Regional Coordinators have been meeting monthly with the Agriculture Victoria State-wide Coordinator.
Uphold governance structures that serve to support fruit fly management, including the PHC, AFFTAC and the NFFC.		DAFF	Governance structures including but not limited to the PHC, AFFTAC and the NFFC have been well supported throughout the reporting period.
Coordinate fruit fly management within each jurisdiction, including provision of information to stakeholders.		States & Territories	NRE Tas: Separate comms plan in relation to fruit fly inclusive of targeted articles, awareness campaigns, social media etc.
Contribute to national discussion on fruit fly management through forums such as NFFC activities.		States & Territories	All Chief Plant Health Officers or equivalent represented through the NFFC.

Key Stakeholder Activities			
Activity	Status	Delivery Lead	Update
Develop and amend market access protocols in collaboration with other states and territories.		States & Territories	Focus on Qfly trial protocols - CA 30, CA32 and CA33 for PIRSA. ICA 04 updates in relation to fruit fly as well as bilateral agreements with associated states with respect pre-treatment inspection offshore in addition to border checks in case of Tasmania. Contribution to broader ICA updates by all States & Territories.
Provide expert advice on AFFTAC and research projects.		States & Territories	Active membership by all States & Territories with Senior Entomologist or equivalent. Proposed updates to the National Fruit Fly Management protocol to be presented to PHC63. Issues around future chemical use in fruit fly trapping also to be raised at PHC63. Significant progress has been made towards updating the management guidelines. Three were endorsed at AFFTAC12 (May 2023). Three more are currently in progress. AFFTAC drafted another two documents for approval before presentation to PHC on the technical justification of the current guidelines and accompanying recommendations (including research, literature reviews, funding needs) in order to update the current guidelines. Not yet presented to AFFTAC.

PIRSA

Plant Quarantine Standard South Australia

Version 17.5

PLANT QUARANTINE STANDARD

The purpose of the Standard is to clearly specify the conditions of entry which must be met for plant and plant products to enter South Australia which may host plant pests or diseases.

The information within this Standard was current as of the date of release © Government of South Australia 2020

New entry conditions or amendments may be declared from time to time and become legally effective prior to them being incorporated into an updated Plant Quarantine Standard (PQS).

Any such new conditions or amendments are widely distributed to our stakeholder list and loaded to our website legislation page adjacent to the most current PQS .

You are strongly advised to regularly check the www.pir.sa.gov.au/planthealth website for the most up to date entry conditions that must be followed to avoid penalties and product being quarantined.

For Fact Sheets and information on pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

Disclaimer

PIRSA and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability and currency or otherwise. PIRSA and its employees expressly disclaim all liability or responsibility to any person using the information or advice.

All enquiries
Plant Health Operations Market Access
Biosecurity SA | **Primary Industries and Regions - PIRSA**
GPO Box 1671 Adelaide SA 5001
P: +61 8 8207 7814 | **F:** + 61 8 8349 8310 | **E:** PIRSA.PlantHealthMarketAccess@sa.gov.au

AMENDMENT RECORD

Amendment No.	Description	Date
1	Version 1: Various updates to all Sections of the Standard	December 1997
2	Version 1.2 Various updates to all Sections of the Standard	June 1998
3	Version 1.3 Conditions of Entry – Condition 8	January 2000
4	Version 2.0 Various updates to all Sections of the Standard	February 2006
5	Version 2.1 Updates to Contents Page and to Condition 7A	March 2006
6	Version 3.0 Contents Page, Index of Conditions of Entry and Conditions of Entry have been updated to reflect the removal of Currant Lettuce Aphid	July 2006
7	Version 4.0 Various updates to all Sections of the Standard	October 2009
8	Version 5.0 Various updates to some Sections of the Standard	March 2010
9	Version 6.0 Updated Index of Conditions of Entry, and inclusion of Conditions of Entry - Condition 26 - Myrtle Rust	May 2010
10	Version 8.0 Various updates to some Sections of the Standard	March 2011
11	Version 8.1 Various updates to some Sections of the Standard	July 2011
12	Version 9.0 Various updates to some Sections of the Standard	October 2011
13	Version 9.1 Revised Condition 4 European House Borer	March 2012
14	Version 9.2 Various updates to some Sections of the Standard	July 2012
15	Version 10.0 Various updates to some Sections of Standard	November 2013
16	Version 11.0 Multiple updates	Aug 2014
17	Version 11.1 Multiple updates	June 2015
18	Version 12 Multiple updates – see P4	April 2017
19	Version 13	October 2017
20	Version 14 – not released	January 2019
21	Version 14.1	March 2019
22	Version 15 – not released	May 2019
23	Version 16	August 2019
24	Version 16.1 – updates to conditions 8, 17 and 27	Nov 2019 effective Jan 6 2020
25	Version 16.1a – update to condition 27	Dec 2019 effective Jan 6 2020
26	Version 17.0 – Administrative changes, Condition 7 now consolidates Conditions 7, 7A, 8 & 8A, Addition of Appendix 15, Removal of Condition 12C and Modifications to Section 3 & 7 to reflect changes to Condition 7 and updates to interpretations of fruit fly management zones	May 2020
27	Version 17.1 – minor formatting and administrative changes; re-establishing CGMMV conditions and appendices; inclusion of bananas certified as mature green ICA16; inclusion of new clause under condition 12J accepting trial system approaches; inclusion of new clause providing avenue for prepacked fruit fly host material to be certified under QA processes; Removal of condition 13 to treat pummelo (*Citrus grandis*)	July 2020
28	Version 17.2, addition of measures to Condition 13, Fumigation, removal of CGMMV, Condition 24 and Citrus Canker, Condition 29 and any references throughout the PQS, modified Section 5 to reflect that the Chief Plant Health Inspector is the only one able to make an exception to the Standard, changes to section 7 concerning fruit grown and sold within a	April 2021

Amendment No.	Description	Date
	fruit fly affected area and removed the requirements around eradication of onion smut.	
29	Version 17.3 – updated webpage hyperlinks, addition of National Area Freedom table; amended pest code list; amended Index of Conditions table; modified conditions 1, 9-14, 26 and 27; addition of condition 30; amended section 7.	
30	Version 17.4 – Added words “MFF only” in the product column in index of conditions of entry “. Removed the word “mango” and “passionfruit” against the definition of “Authorised Inspection Person” in section 3 to reflect mangoes are no longer accepted under condition 13	January 2024
31	Version 17.5 – Added words “MFF only” in index of conditions of entry fruit and vegetables column and condition 13. Added words (“other than plums, which can be treated for MFF only”) next the words “stone fruit” against the definition of “Authorised Inspection Person” in section 3 “Interpretations” to reflect plums are no longer accepted under condition 13. Added words (“other than plums”) in high risk section of condition 13.	March 2024

KEY CHANGES IN THE PLANT QUARANTINE STANDARD SA VERSION 17.5

TITLE	CHANGE
Section 3 – Interpretations	• Added words (“other than plums”) next the words “stone fruit” against the definition of “Authorised Inspection Person” to reflect plums are no longer accepted under condition 13 • Removed passionfruit from definition of Authorised inspection person as these were removed as high risk produce from Condition 13 in version 17.3 of the Standard. • Added the words “for QFF” to make it clear these inspections are for high risk produce being fumigated for QFF only
Section 4 – Index of Conditions	• Added the words “MFF only” in the product column against plums as they are no longer accepted under methyl bromide fumigation if being treated for QFF.
Condition 13: Disinfestation with Methyl Bromide	• Added a note in the “Note” section to remind importers plums are no longer acceptable under Condition 13. • Added words “other than plums” after the word “stonefruit” in the high risk section to again reflect plums are no longer accepted under fumigation.

CONTENTS

SECTION 1 - INTRODUCTION **8**
SECTION 2 - MINISTERIAL NOTICES PURSUANT TO THE *PLANT HEALTH ACT 2009* **10**
DECLARATION OF PESTS **10**
QUARANTINE AREAS **10**
PROHIBITION ON INTRODUCING PEST AFFECTED PLANTS OR PLANT RELATED PRODUCTS **10**
SECTION 3 - INTERPRETATIONS **11**
SECTION 4 - INDEX OF CONDITIONS OF ENTRY / REGULATED MOVEMENT **16**
SECTION 5 - CONDITIONS OF ENTRY / REGULATED MOVEMENT **24**
1. FOREWORD 24
2. IMPORT / MOVEMENT REQUIREMENTS 24
3. CERTIFICATES, BRANDING AND PACKAGING 25
Condition 1: Blueberry Rust (Thekopsora minima) 29
Condition 2: Red Imported Fire ANT (*Solenopsis invicta*) - RIFA 32
Condition 3: Citrus – Stem Pitting Strain of Tristeza Virus and Citrus Blight 35
Condition 4: European House Borer 36
Condition 5: Citrus Red Mite 39
Condition 6: Plant Diagnostic Samples (excluding grapevine samples) 40
Condition 7: Grape Phylloxera 41
Condition 7A: VACANT 54
Condition 8: VACANT 54
Condition 8A: VACANT 54
Table 2 – Host Fruits of Mediterranean and Queensland Fruit Flies 55
Condition 9: Area Freedom from Fruit Flies / Secure Transportation 57
Condition 10: Hard Green or Similar Condition for Fruit Fly 58
Condition 11: Disinfestation by Cold Storage 60
Condition 12: Disinfestation using Dimethoate - Queensland fruit fly 61
Condition 12A: Mangoes – Pre-harvest systems approach - mangoes 63
Condition 12B: Pre harvest Field Control and Inspection of Strawberries 64
Condition 12C: VACANT 65
Condition 12D: Pre-harvest treatment and Inspection of Pome Fruit, Persimmon and Blueberry Fruit – Systems Approach 66
Condition 12E: Wine Grapes Secure Transportation – Systems Approach 67
Condition 12F: Pre-harvest treatment and Post-harvest Inspection of Table Grapes – Systems Approach 68
Condition 12G: Pre-harvest treatment and Post-harvest inspection of Tomatoes (Mediterranean Fruit Fly and Queensland Fruit Fly), Capsicums, Chillies and Eggplant (Queensland Fruit Fly) –Systems Approach 69
Condition 12H: Pre-harvest treatment and Inspection of Citrus – Systems Approach 70
Condition 12I: Vacant 71
Condition 12J: System Approaches for Pest Free Place of Production - Queensland Fruit Fly 72
Condition 12K: System Approaches for Specified Regions of Production 74
Condition 12L: Specified production systems 75

Condition 13: Disinfestation by Methyl Bromide Fumigation....76
Condition 14: Disinfestation by Irradiation....78
Condition 15: Maize Seed (includes popcorn and sweet corn varieties for sowing)....79
Condition 16: Melons and Other Hosts of Melon Thrips (*Thrips palmi)*....80
Condition 17: Tomato Potato Psyllid (TPP) (*Bactericera cockerelli*) and Zebra Chip (CLso) (*Candidatus Liberibacter solanacearum*)....84
Condition 18: Potatoes and Solanaceous Hosts - Potato Cyst Nematode (PCN) *(Globodera pallida* and *G. rostochiensis)*....91
Condition 18A: PSTVd – Potato Spindle Tuber Viroid....95
Condition 19: Vacant....96
Condition 20: Soil and Soil Products....97
Condition 21: Tomato Plants – *Fusarium oxysporum* Race 3....99
Condition 22: Date Palms- Parlatoria date scale....100
Condition 23: Hosts of Green Snail....101
Condition 24: vacant....109
Condition 25: Pyriform Scale – (*Protopulvinaria pyriformis*)....110
Condition 26: Myrtle Rust (*Puccinia psidii*, previously named *Uredo rangelii*) – ICA42....112
Condition 27: Machinery, Bins and Associated Farm / Horticultural Equipment....114
Condition 28: Fire Blight - Fruits, Plants and Plant Parts....115
Condition 29: VACANT....116
Condition 30: POLYPHAGOUS SHOT HOLE BORER – (*EUWALLACEA FORNICATUS*)....117
SECTION 6 - FRUIT AND PLANTS FOR OVERSEAS EXPORT OR IMPORTED FROM OVERSEAS....119
SECTION 7 – GENERAL PROVISIONS....121
1. **Compliance Agreements**....121
2. **Control & Eradication of Fruit Flies**....121
SECTION 8 - APPENDICES....130
Appendix 1: PLANT INSPECTION SERVICE OFFICES....130
Appendix 2: PLANT TISSUE CULTURES....131
Appendix 3: Plant Health Certificate....132
Appendix 4: Plant Health Assurnace Certificate....133
Appendix 4A: Biosecure HACCP Biosecurity Certificate....134
Appendix 5: Plant Health Import Certificate....135
Appendix 6: Declaration of Source Pyriform Scale....136
Appendix 7: Declaration of Source Citrus Blight and Stem Pitting Strain of Tristeza Virus....137
Appendix 8: Declaration of Source Citrus Red Mite....138
Appendix 9: Machinery Declaration....139
Appendix 10: Declaration of Soil Source....140
Appendix 11: Declaration of Source TPP and ZC....141
Appendix 12: Declaration of Source Blueberry Rust....142
Appendix 13: General Biosecurity Declaration....143
Appendix 14: Declaration of Melon Thrips....144
Appendix 15: Declaration for Grape Machinery & Equipment Servicing only....145
Appendix 16: Declaration of Source Polyphagous Shot Hole Borer....146

SECTION 1 - Introduction

Section 59 of the Plant Health Act 2009 (hereafter referred to as “the Act”) provides that a notice given by the Minister may "apply, adopt or incorporate, with or without modification, any code, standard or other document prepared or approved by a body or authority referred to in the notice or regulation as in force from time to time or as in force at a specified time."

The Plant Quarantine Standard South Australia, hereafter referred to as “the Standard”, has been established by Ministerial notice under Section 59 of the Act.

The Act – Part 2 Division 2 - provides that the Minister may, by notice published in the Government Gazette:

1. prohibit the entry of certain plant material into South Australia;
2. set conditions under which plant material may enter the State;
3. prescribe measures for the eradication or control of declared pests within South Australia's boundaries.

In keeping with these provisions, PIRSA Biosecurity SA prepares and operates the Standard under Ministerial approval.

PURPOSE

The purpose of the Standard is to clearly specify the conditions of entry which must be met for plant and plant products that may host plant pests or pathogens, to enter South Australia. The Standard also includes provisions specifically applying to the transit through South Australia of products covered by the Standard, and other general provisions, including those relating to quarantine areas declared by Ministerial notice in response to detections or outbreaks of specific pests such as fruit flies.

APPLICATION

The Ministerial notice which brings the Standard into force is reprinted in the South Australian Government Gazette (https://governmentgazette.sa.gov.au/).

Failure to observe the notice and provisions of the Standard represents an infringement of the Act and may attract significant court penalties or in some instances an expiation fee.

EXPLANATION

Prohibitions

Where a significant plant pest (or disease) exists interstate, but is either not present in South Australia or under official control in South Australia, its introduction is prohibited by Ministerial Notice pursuant to Section 7 of the Act (Annex 1). Since pests are most likely to be transported into the State by their host fruit, plants or soil, they too may be prohibited unless certain requirements are met.

Conditional Imports

Biosecurity SA has identified procedures by which plant material may move without unacceptable risk of spreading certain pests or diseases.

A number of these procedures are recognised and expressed in detail in the Standard.

Other

The Ministerial notice Annex 1 declares portions of the state to be quarantine areas and stipulates steps that must be undertaken to eradicate outbreaks of certain diseases and pests within South Australia. Such measures are detailed in this Standard – see Section 7.

For simplicity, both plant pests and diseases covered are referred to as "pests".

DISTRIBUTION

A controlled copy of the Standard shall be available on PIRSA’s web site located at:

www.pir.sa.gov.au/planthealth.

Registered importers and all interstate quarantine authorities will normally be advised by a courtesy email when updates are issued but PIRSA Biosecurity SA takes no responsibility if this process is not successful.

All stakeholders are therefore strongly advised to regularly check the above website to ensure they are operating with the latest version.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

SECTION 2 - MINISTERIAL NOTICES PURSUANT TO THE *PLANT HEALTH ACT 2009*

Declaration of Pests

Pursuant to Section 4 of the Act

The Ministerial notice which lists pests as being declared for the purposes of the Act is reprinted as Annex 1, available on the PIRSA website at www.pir.sa.gov.au/planthealth adjacent to the PQS.

Quarantine Areas

Pursuant to Section 8 of the Act

The Ministerial notice which specifies portions of the State that are declared to be quarantine areas under the Act is reprinted as Annex 1, available on the PIRSA website at www.pir.sa.gov.au/planthealth adjacent to the PQS.

Prohibition on Introducing Pest Affected Plants or Plant Related Products

Pursuant to Section 7 of the Act

The Ministerial notice which lists plants or plant related products as being prohibited for importation or introduction into the State for the purposes of the Act is reprinted as Annex 2, available on the PIRSA website at www.pir.sa.gov.au/planthealth adjacent to the PQS.

SECTION 3 - INTERPRETATIONS

For the purpose of the Standard, the words and terms appearing below shall be interpreted as follows:

"accredited business" means a Business that complies with the conditions outlined in Section 5 of the Standard relating to an Import Verification Compliance Agreement (IVCA) with Biosecurity SA or an Interstate Certification Assurance (ICA) or Compliance Arrangement (CA) with the Department in the exporting State or Territory.

"Act" means South Australia's *Plant Health Act 2009*.

"area free from fruit flies" means that the property on which the host fruit was grown and packed and all land within a 15 kilometre radius (or less as determined by the Chief Inspector, South Australia) of that property, is free from fruit flies in accordance with Australia's National Fruit Fly Management Protocols.

"Accredited Laboratory" means a laboratory accredited by Biosecurity SA under CA12 Laboratory Accreditation to receive, process and dispose of imported diagnostic quarantine material.

"Approved National Scheme" means a biosecurity accreditation scheme approved by Biosecurity SA that enables a business to operate a Biosecurity arrangement that allows it to certify quarantine material into SA in accordance with the requirements of the PQS.

"Approved Laboratory" means a laboratory approved under Biosecurity SA Chief Inspectors Import Certificate to receive, process and dispose of imported diagnostic quarantine material.

"Authorised Inspection Person" means a third party trained and authorised by the Department in their state or territory to conduct pre-fumigation inspections of citrus, stone fruit (other than plums, which can be treated for MFF only) and other high risk produce for businesses undertaking methyl bromide fumigation for QFF under Condition 13 of the Standard.

"Authorised Signatory" means an officer of an Accredited Business whose name and specimen signature is provided as an authorised signatory with the Business's Application for Accreditation.

"Biosecurity SA" means a division of the Department of Primary Industries and Regions (PIRSA).

"citrus" means the tribe Citrinae comprising the genera *Citropsis*, *Citrus*, *Eremocitrus*, *Fortunella*, *Microcitrus*, *Monanthocitrus*, *Pleurocitrus* and *Poncirus* or the hybrids thereof.

"compliance arrangement ("CA")" means an arrangement approved by the Chief Inspector.

"cutting" means a portion of a plant, often of a shoot or cane, taken for use as planting material, that has not been planted in soil or permitted to develop roots.

"Department" means the South Australian Department of Primary Industries and Regions (or interstate equivalent), or the Commonwealth Department of Agriculture Water and the Environment (or as subsequently termed).

"Direct Inspection" means, unless otherwise clearly stated, an inspection of arriving machinery/equipment or for produce 2% of or 600 items/pieces from a consignment, by inspector or business under accreditation procedures to verify the pest free status or condition of the consignment.

"Discovery Point (fruit fly)" means the physical location where:

- One or move suspect adult flies have been collected during a single inspection of a trap (regardless of whether or not the detection triggers a fruit fly outbreak); *or*
- Host material containing fruit fly larvae was grown.

"Departmental" means of, or relating to such Departments.

"disease" means any plant pest / disease defined in the Notice.

"Documentary proof" means the certification, declaration or other documents stipulated in a condition as required for entry into South Australia.

"Dormant" means a state in which a plant is alive but not actively growing

"enter South Australia" means to be imported or introduced into South Australia from other States or Territories of the Commonwealth. Except where a specific State or Territory is mentioned the term

shall have general application.

"equivalent law" means the law of another State or Territory equivalent to the Act.

"exempted" means the product does not have to meet the relevant prescribed condition or sub-condition to enter South Australia.

"fruit" or "host fruit" means fresh, and not processed, fruit.

"fruit flies" means economically important pest species of the family Tephritidae and includes those species commonly known as Mediterranean fruit fly, Queensland fruit fly (including var. *Bactrocera aquilonis)* together with *Bactrocera cucumis, B jarvisi, B musae, B neohumeralis*, Papaya fruit fly and Exotic fruit fly (*B philippinensis*).

“Fruit Fly Affected Area” (“FFAA", also known as the *Controlled Movement Zone*) means the entire area within a circle of predetermined radius surrounding a fruit fly *outbreak centre* in which area freedom status is suspended and movement controls are applied.

- The predetermined radius of the Fruit Fly Affected Area is 15 kilometres in the case of an outbreak of Queensland fruit fly.
- The predetermined radius of the Fruit Fly Affected Area is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly.

"fruit fly outbreak" means the criteria in Australia’s national fruit fly management agreements have been met, requiring quarantine areas/zones to take immediate effect and remain in place until the approved re-instatement criteria have been met; either 12 weeks or one generation plus 28 days (whichever is the greater) after the last detection of a fruit fly adult, eggs or larvae in the quarantine area. (Refer Section 7). The locations of current fruit fly outbreaks in South Australia are specified on the PIRSA website at http://pir.sa.gov.au/fruitfly.

“fruit fly outbreak area” (also known as the *Corrective Action Zone*) means an area within 1.5 kilometres radius of a fruit fly outbreak centre. The locations of current fruit fly outbreaks in South Australia are specified on the PIRSA website at http://pir.sa.gov.au/fruitfly.

“fruit fly outbreak centre” (also known as the *Epicentre*) means the location related to each single detection or grouping of detections that triggers an outbreak. An outbreak centre may be:

- the Discovery Point where the first larvae or gravid female was detected; or
- a location between a grouping of male flies that precipitated the outbreak.

The locations of current fruit fly outbreaks in South Australia are specified on the PIRSA website at http://pir.sa.gov.au/fruitfly.

“fruit fly outbreak trigger” means the detection of fruit fly larvae in locally grown fruit, the detection of one gravid female fruit fly, or the detection of a pre-determined number of male fruit flies or non-gravid female fruit flies within a 1-kilometre radius within a consecutive fourteen-day period

- The predetermined number of male fruit flies or non-gravid female fruit flies is five for Queensland fruit fly
- The predetermined number of male fruit flies or non-gravid female fruit flies is three for Mediterranean fruit fly

“fruit fly outbreak zone” (also known as the *Delimitation Zone*) means all of the land within a 200-metre radius around each Discovery Point once the outbreak trigger has been met. The locations of current fruit fly outbreaks in South Australia are specified on the PIRSA website at http://pir.sa.gov.au/fruitfly.

“fruit fly suspension area” (also known as *Export Assurance Zone*) means the area starting at the outer boundary of the outbreak area to the predetermined radius surrounding a fruit fly outbreak centre in which area freedom status is suspended and movement controls are applied.

- The predetermined radius of the suspension area is 15 kilometres in the case of an outbreak of Queensland fruit fly.
- The predetermined radius of the suspension area is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly.

The locations of current fruit fly outbreaks in South Australia are specified on the PIRSA website at http://pir.sa.gov.au/fruitfly.

"grapes" means whole grape berries and stalks but not leaves or other parts of grapevines.

"grapevines" means plant material of any *Vitis* species (including *Vitis vinifera*, wine grape and table grape varieties, ornamental vines and American rootstock species), and is in the form of whole grapevines or part thereof, cuttings, rootlings (including grafted rootlings), potted vines or other propagules and excluding grapevine tissue cultures and grapes and grape-related material.

"grapevine tissue cultures" means plant material of the genus *Vitis*, produced solely in accordance with Section 8 - Appendix 2 of the Standard.

“import certificate” means a Plant Health Import Certificate from the Chief Inspector or delegate.

"imported" and "introduced" are synonymous.

"inspection" means, unless otherwise stated, an inspection of 2% of or 600 items/pieces from a consignment to verify the pest free status or condition of the consignment.

"inspector" means an inspector appointed under section 41 of the Act or an inspector appointed under equivalent legislation interstate.

“Interstate Certification Assurance (ICA)” means a system of certification assurance developed to meet the requirements of State and Territory Governments for the plant health certification of produce for interstate and intrastate quarantine purposes.

“linked” means a potential quarantine risk vector may exist to an infected product or property capable of transmitting a pest by way of product, plant material, boundary connection, water path or any equipment used in connection to the farming, production, harvesting or packing of a product.

“mining” means the extraction of valuable minerals or other geological materials from the earth from an ore-body, lode, vein, seam, or reef, which forms the mineralized package of economic interest to the miner.

"Notice" means the Ministerial notice, as published in the SA Government Gazette, under which the Standard operates.

“official control” means the active enforcement under the Plant Health Act, 2009, of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment of quarantine pests or for the management of regulated non-quarantine pests.

“outbreak” means a recently detected pest population, including an incursion, or a sudden significant increase of an established pest population in an area.

"packaging" means the whole or any part of a package, container, crate, covering, packing or material of any description that is being or has been used to cover or contain a fruit or plant.

“Pest” – see “plant pest”

"Phylloxera Exclusion Zone" (PEZ) means a whole state or part thereof, recognised to be free from Grape Phylloxera (*Daktulosphaira vitifoliae*)
To acquire PEZ status, a region must have been established by historical information and/or a survey program as not being infested by grape phylloxera, AND be protected by appropriate legislation to control the movement of grape phylloxera host produce – including grapevine material, specified grape products and vineyard equipment – into the area. As a minimum, the requirements of the legislation must reflect the conditions for movement specified in this national protocol.

"Phylloxera Infested Zone" (PIZ) means an area in which at least one vineyard known to be infested with grape phylloxera or known to have been infested with grape phylloxera (*Daktulosphaira vitifoliae*) exists.

“Phylloxera Interim Buffer Zone” means a zone of 5 km radius around a new detection of grape phylloxera in Australia, as officially notified by the Chief Plant Health Manager of the jurisdiction in which the detection has been made, as an interim measure pending declaration of a new or amended PIZ in that jurisdiction.

“Phylloxera Risk Zone” (PRZ) means an area of unknown grape phylloxera (*Daktulosphaira vitifoliae*)

status

“phytosanitary certificate” means a certificate issued by the National Plant Protection Organisation for the international export of produce and products.

“pine wood” means wood from trees of the genera *Abies, Araucaria, Picea, Pinus and Pseudotsuga.*

“plant” or “host plant” means rooted plants (for example, nursery stock) and includes budwood and graftwood unless otherwise indicated.

“Plant Health Assurance Certificate” means a certificate issued by the authorised signatory for a Business that has been accredited by a Department for an Interstate Certification Assurance Arrangement accepted by Biosecurity SA.

“Plant Health Certificate” means a certificate that has been issued by an authorised officer for the Department of the exporting State / Territory or a certificate issued by Biosecurity SA.

“plant health certification” means a Plant Health Certificate, Plant Health Assurance Certificate, Plant Health Import Certificate, BioSecure HACCP Biosecurity Certificate (BHBC) or other certificate accepted by the Minister.

“Plant Health Import Certificate” means a certificate from the Biosecurity SA Chief Inspector or Delegate.

“Plant pest” (or “pest”) means any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products. Those declared to be pests for the purposes of the Act are listed in the Notice under Section 4 of the *Plant Health Act, 2009* (Annex 1).

“plug (or cell in horticulture)” means small-sized seedlings grown in trays made from expanded polystyrene or polythene filled usually with a peat or compost substrate.

“pome fruit” means certain members of the plant family Rosaceae, namely apple (*Malus pumila*), pear (*Pyrus* spp.), loquat (*Eriobotrya japonica*), medlar (*Mespilus germanica*) and quince (*Cydonia oblonga*).

“processed fruit” means, for fruit fly purposes, host fruit/fruiting vegetable which is dried, preserved, stewed, frozen or subjected to any other process approved by the Chief Inspector that effectively removes the quarantine risk.

“processor” means a business registered with Biosecurity SA to receive quarantine risk material for the purpose of converting to a final processed product.

“recognised authority” means an authorised officer of the Department, or the authorised signatory for an Accredited Business whose name and specimen signature is provided as an authorised signatory with the Business’s Application for Accreditation.

“regulated movement” means the movement of plant product within South Australia where restrictions or additional requirements apply.

"secure transportation” means, transported in a manner that prevents infestation of product with a quarantine pest and/or release of a quarantine pest. For fruit fly purposes see Condition 9.

"SDQMA” means, the Subcommittee for Domestic Quarantine and Market Access or any successor.

“soil” means topsoil and does not include clean sand, cave or marine sediment or geological materials from an ore-body, lode, vein, seam, or reef, which forms the mineralized package of economic interest to the miner.

"steam” means, unless stated otherwise, high pressure application at no less than 82°C.

“stone fruit” means certain members of the plant genus Prunus, namely peach, nectarine, plum, apricot, cherry, peacharine and plumcot

“topsoil” means the upper, outermost layer of soil, usually the top 20 cm having the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity and plant growth occurs.

"transiting" means the movement of securely contained plant product, either directly through South

Australia or through another control area for a plant pest, that is accompanied by documentation that can demonstrate both the origin and destination of product, and, whilst in South Australia or another control area, is not subject to off-loading, reloading or storage.

“vineyard soil” means earth, not limited to topsoil, from within 100 metres of an existing live commercial vine or a location where a vine was previously planted within the past 2 years.

SECTION 4 - INDEX OF CONDITIONS OF ENTRY / REGULATED MOVEMENT

This is an alpha/numerical index of plant material, equipment and soil which, although potential carriers of declared diseases and pests, may enter South Australia or move within South Australia under specified conditions.

The number(s) opposite each fruit or plant identify the relevant conditions, which are detailed in **Section 5** - **Conditions of Entry** of this Standard.

Particular attention is drawn to the requirements for certificates, declarations, and branding/packaging as set out in the Conditions of Entry / Regulated Movement.

The range of fruit fly hosts (**Conditions of Entry – Condition 9 – 14 and Table 2**) is not necessarily complete and any unlisted fruit will be assessed for its status as a host when demand arises. Some pests are specific to particular states or areas, so whilst the following index may indicate a condition/pest it may be the case that it is not applicable to product from some States.

PEST CODE LIST

Abbreviation	Common Name	Scientific Name
BR	Blueberry Rust	*Thekopsora minima*
BS	Boil Smut of Maize	*Ustilago maydis*
BW	Bacterial Wilt of Potato	*Ralstonia solanacearum Race 3*
CB	Citrus Blight	*(unknown causal agent)*
CRM	Citrus Red Mite	*Panonychus citri*
CTV	Citrus Tristeza Virus – sweet orange stem pitting strain	*Citrus tristeza closterovirus – sweet orange stem pitting strain*
EHB	European House Borer	*Hylotrupes bajulus*
FB	Fire Blight	*Erwinia amylovora*
FW	Fusarium Wilt	*Fusarium oxysporum f.sp. lycopersicon Race 3*
GS	Green Snail	*Helix aperta*
MFF	Mediterranean Fruit Fly	*Ceratitis capitata*
MT	Melon Thrip	*Thrips palmi*
MR	Myrtle Rust	*Puccinia psidii, prevously Uredo rangelii*
PDS	Parlatorial Date Scale	*Parlatoria blanchardii,*
PCN	Potato Cyst Nematode	*Globodera pallida*
PFS	Pyriform Scale	*Protopulvinaria pyriformis*
PHY	Grape Phylloxera	*Daktulosphaira vitifoliae*
PSTVd	Potato Spindle Tuber Viroid	*Potato spindle tuber pospiviroid*
QFF	Queensland Fruit Fly	*Bactrocera tryoni*
RIFA	Red Imported Fire Ant	*Solenopsis invicta*
TPP / ZC	Tomato Potato Psyllid	*Bactericera cockerelli*
ZC (CLso)	Zebra Chip	*Candidatus Liberibacter solanacearum*

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

Area Freedom claims

Pest status varies across the country. To assist businesses in identifying when the prescribed Conditions within the PQS must be met, the following pests are recognised as not being present in the following states and territories. This means that the Conditions relevant to those pests do not need to be applied if the material has moved from the areas in which the pests are not present:

Pest	Applicable from the following states
Blueberry Rust	NSW, Vic, and Tas
Red Imported Fire Ant	Qld
Stem Pitting Strain of Tristeza Virus	Qld
Citrus Blight	Qld
European House Borer	WA
Citrus Red Mite	NSW
Grape Phylloxera	PIZ or PRZ – Qld, NSW, and Vic
Queensland Fruit Fly	NT, Qld, NSW, Vic
Mediterranean Fruit Fly	WA
Melon Thrips	NT and Qld; WA and NSW (isolated)
Tomato Potato Psyllid	WA
Zebra Chip	Not known to exist in Australia
Potato Cyst Nematode	Vic
Potato Spindle Tuber Viroid	Qld and WA
Fusarium oxysporum Race 3	Qld
Parlatorial Date Scale	NT
Green Snail	WA and Vic (isolated)
Pyriform Scale	WA
Myrtle Rust	NT, Qld, NSW, Vic, and Tas
Fire Blight	Not known to exist in Australia
Polyphagous Shot Hole Borer	WA (isolated)

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Abiu (Caimito)	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Acerola	9, 12, 13, 14,	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Achachairu	9, 10 ,11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Allium spp (onion, leek, spring onion, garlic, shallots, etc (unless peeled and washed)	23, 20	2, 17, 20, 23		RIFA, GS, TPP
Almond (Green only)	9, 11, 12, 13, 14,17	2, 17, 20, 23, 25		MFF, RIFA, GS, PFS, TPP
Apple	9, 11, 12, 13, 14, 17, 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Apricot	9, 11, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Aquatic plants	Refer to www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity			
Asparagus	17, 23	2, 17, 20, 23		RIFA, GS, TPP
Avocado	9, 10 ,11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Babaco	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Banana	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Beans	16, 17, 23	2 ,16, 17, 20, 23, 25		RIFA, MT, GS, PFS, TPP
Breadfruit / Breadnut	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, RIFA, GS, PFS, TPP
Blackberry	9, 11, 12, 13, 14, 17, 28	2, 17, 20, 23, 28		MFF, QFF, RIFA, GS, FB, TPP
Black Sapote (Chocolate Persimmon)	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Blueberry	1, 9, 11, 12, 13, 14, 17	1, 2, 17, 20, 23	1	MFF, QFF, BR, RIFA GS, TPP
Caimito (Star Apple / Abiu)	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Cape Gooseberry	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Capsicum/Chillies	9, 12, 13, 14, 16, 17	2, 16, 17, 20, 23		MFF, QFF, MT, RIFA, TPP, GS, TPP
Carambola, (Star fruit, Star apple)	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Cashew Apple	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Casimiroa (White Sapote)	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Cherry / Cherry, Brazil	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Chinese Gooseberry (Kiwifruit)	9, 11, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Chives	17, 23	2, 17, 20, 23, 24		RIFA, GS, TPP
Choko	14, 16, 17	2, 16, 17, 20, 23		MT, RIFA, GS, TPP
Citrus (see interpretations)	9,10 (Tahitian lime),11, 12, 13, 14, 17	2, 3, 5, 17, 20, 23, 25		MFF, QFF, RIFA, GS, CTV, CB, CRM, PFS, TPP

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Coffee Berry	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Cranberry	1,	1, 2, 17		BR, RIFA, TPP
Cucumber	14, 16, 17	2,16, 17, 20, 23,		MT, RIFA, GS, TPP
Cucurbits	14, 16, 17	2, 16, 17, 20, 23		MT, RIFA, GS, TPP
Custard Apple (*Annona* spp. and Rollinia) Cherimoya, Sugar Apple / Sweetsop / Soursop / Ramphala/, Atemoya	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Cut flowers		1, 17, 23, 26		BR, TPP/CLso, GS, MR
Dates	9, 11, 13,14	2, 22, 20, 23		MFF, QFF, PDS, RIFA, GS
Dragon fruit (Pitaya)	9, 11, 12, 13, 14, 16, 17	2, 16, 17, 20, 23, 25		MFF, QFF, MT, RIFA, GS, PFS, TPP
Durian	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Eggplant (Eggfruit, Aubergine)	9, 12, 13, 14, 16, 17	2, 16, 20, 23, 17		MFF, QFF, MT, RIFA, GS, TPP
Equipment for grape production			7	PHY
Feijoa	9 , 11, 12, 13, 14, 17, 26	2, 17, 20, 23, 25, 26		MFF, QFF, MR, RIFA, GS, PFS, TPP
Fig	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Fire Blight Hosts – see listing condition 28	9, 11, 12, 13, 14, 17, 28	2, 17, 20, 23, 25, 28		FBB, MFF, QFF, RIFA, GS, PFS, TPP
Fodder / Hay		2, 23	2, 23	GS, RIFA
Fruit Fly Hosts **(not specifically listed)**	9, 10, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Garlic		2, 17, 20, 23		RIFA, GS, TPP
Gourds, Bitter (*Momordica charantia*) Bottle *(Lagenaria siceraria)* and Gourd, winter/white (hairy/winter melon) (*Benincasa hispida*)	13, 14, 16, 17	2, 17, 20, 23		RIFA, MT, GS, TPP
Grapes (Table)	7, 9, 11, 12, 13, 14	7, 17	2, 7	MFF, QFF, PHY, RIFA, TPP
Grapes (Wine)	7, 9, 11, 12, 13	7, 17	2, 7	MFF, QFF, PHY, RIFA, TPP
Grape marc & Grape must			7	PHY
Grapevines		7, 17, 23		PHY, GS, TPP
Grapevine Diagnostics and Vineyard soils			7	Various
Grapevine tissue cultures		7		PHY
Grumichama / Brazil Cherry	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Guava	9, 11, 12, 13, 14, 17, 26	2, 17, 20, 23, 25, 26		MFF, QFF, MR, RIFA, GS, PFS, TPP
Hay / Fodder		2, 23	2, 23	GS, RIFA
Herbs (fresh)	17, 23	2, 17, 20, 23, 25	2, 23	RIFA, GS, PFS, TPP

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Hog Plum	9, 10 ,11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Huckleberry	1,	1, 2, 17	1	BR, RIFA, TPP
Jaboticaba	9, 10 ,11, 12, 13, 14	2, 17, 20, 23, 25, 26	26	MFF, QFF, RIFA, GS, MR, PFS, TPP
Jackfruit	9, 10, 12, 13, 14	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Jambu / Wax Jambu / Rose Apple / Water Apple	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25, 26		MFF, QFF, RIFA, GS, MR, PFS, TPP
Jujube	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25, 26		MFF, QFF, RIFA, GS, MR, PFS, TPP
Kiwifruit (Chinese gooseberry)	9, 11, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Leaf vegetables (cabbage, lettuce, cauliflower, broccoli etc)	17, 23	2, 17, 20, 23		GS, RIFA, TPP
Leeks	17, 23	2, 17, 20, 23		RIFA, GS, TPP
Lettuce	17, 23	2, 17, 20, 23		RIFA, GS, TPP
Longan	9, 10, 12, 13, 14	2, ,17, 20, 23		MFF, QFF, RIFA, GS, TPP
Loganberry	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Lime – including Finger Lime; West Indian Lime; Rangpur Lime	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Loofah, smooth (*Luffa cylindrica*) and Loofah, angled/ridged.sinquar (*Luffa acutangula)*	9, 12, 13, 14, 16, 17	2, 17, 20, 23		MFF, RIFA, MT, GS, TPP
Loquat	9, 11, 12, 13, 14, 17, 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Lychee (Litchi Litchi)	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Machines and Equipment			2, 7, 17, 18, 18A , 27	RIFA, PHY, PCN, PSTVd, TPP
Maize (seed only)			15	BS
Mango	9, 12, 13 (MFF only), 14	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Mangosteen	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Medlar	9, 11, 12, 14, 17, 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Melons (watermelon, rockmelon, long etc)	14 ,16, 17	2, 16, 17, 20, 23		MT, RIFA, GS, TPP
Mulberry	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Myrtaceae Family Includes seeds, bark chips and firewood	26	2, 17, 20, 23, 25, 26	26	MR, RIFA, PFS GS, TPP

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Nectarine	9, 11, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Okra	16, 17	2,16, 17, 20, 23, 25		RIFA, MT, GS, PFS, TPP
Olive	9, 11, 12, 13, 14, 17	2, 20, 17, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Onions (seed & fresh unless peeled & washed)		2, 17, 20, 23		RIFA, GS, TPP
Passionfruit / Granadilla	9, 10 (purple type only), 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Pawpaw (Papaw, Papaya)	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Peach / Peacharine	9, 11, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Pear / Nashi	9, 11, 12, 13, 14, 17, 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Peas	16, 17, 23	2,16, 17, 20, 23, 25		RIFA, MT, GS, PFS, TPP
Persimmon	9, 11, 12 (inedible peel types only), 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Pepino, (Melon Pear)	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, TPP, GS
Pineapples	Unrestricted	2, 17, 20, 23		RIFA, GS
Plant Diagnostics			6	Various
Plants, general (including household and potted plants) Leafless bare-rooted trees are not deemed a GS host Pine trees and plant material are prohibited from entering KI unless otherwise permitted by the Chief Inspector		1, 2, 7, 17, 18, 20, 23, 25, 26, 28	28	BR, MR, PHY, PCN, GS, FB, RIFA, PFS, TPP
Plum / Plumcot	9, 11, 13 (MFF only), 14, 17 28 (for *Prunus salicina*)	2, 17, 20, 23, 25, and 28 (for *Prunus salicina*)	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Pome fruits (Apple, Pear, Loquat, Medlar and Quince)	9, 11, 12, 13, 14, 17 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Pomegranate	9, 10, 12, 13, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Potatoes Includes Kangaroo Island	17, 18	2, 17, 18, 18A, 23	18, 18A	TPP/CLso, PCN, PSTVd, RIFA, GS, BW (KI)
Prickly Pear (Opuntia spp only)	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Pumpkins (various)	16, 17	2,16, 17, 20, 23		MT, RIFA, GS, TPP
Pomelo (Shaddock)	9, 12, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Quandong	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 25, 26		MFF, QFF, RIFA, GS, MR, PFS, TPP
Quince	9, 11, 12, 14, 17, 28	2, 17, 20, 23, 25, 28	28	MFF, QFF, FB, RIFA, GS, PFS, TPP
Rambutan	9, 10, 12, 13, 14, 17	2, 17, 20, 23, 28		MFF, QFF, FB, RIFA, GS, TPP

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Raspberry	9, 11, 12, 13, 14, 17 28	2, 17, 20, 23, 28		MFF, QFF, FB, RIFA, GS, TPP
Rooted plants / Root vegetables (including turf, household plants)	1, 17, 18, 20, 23	2, 7, 17, 18, 20, 23, 25, 26		BR, PHY, PCN, GS, RIFA, TPP, MR, PFS, TPP
Rose Apple / Water Apple	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Sapodilla	9, 12, 13, 14	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Santol (Lolly Fruit)	9, 12, 13, 14	2, 20, 23		MFF, QFF, RIFA, GS
Sapote	9, 12, 13, 14, 17	2, 17, 20, 23, 25		MFF, QFF, RIFA, GS, PFS, TPP
Shallots		2, 20, 23		RIFA, GS
Silverbeet	16, 17, 23	2,16, 17, 20, 23		MT, RIFA, GS, TPP
Soil (scientific or commercial use)			2, 6, 7, 18, 18A, 20, 23	PHY, PCN, GS, RIFA, PSTVd
Soursop	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Spinach	16, 17, 23	2, 16, 17, 20, 23		MT, RIFA, GS, TPP
Spring onion	17, 23	2, 17, 20, 23		RIFA, GS, TPP
Squash (includes zucchini)	14, 16, 17	2,16, 17, 20, 23		RIFA, MT, GS, TPP
Star Apple, Carambola, Star Fruit	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Stone fruits (Apricot, Cherry, Plum, Peach, Nectarine)	9, 11, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Strawberry	9, 12, 13, 14, 17, 23	2, 17, 20, 23		QFF, RIFA, GS, TPP
Sweet corn	17	2, 17, 20, 23	15	RIFA, GS, BS, TPP
Sweet potato		2, 17, 20, 23	15, 17	RIFA, GS, BS, TPP/CLso
Tahitian Limes	9, 10, 11, 12, 13, 14, 17	2, 3, 5, 17, 20, 23, 25		MFF, QFF, RIFA, GS, CTV, CB, CRM, PFS, TPP
Tamarillo	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, TPP, GS
Timber (Coniferous) Needle pine, fir, spruce and includes pallets, firewood, dunnage, furniture etc			4	EHB
Tangor	9, 12, 13, 14, 17	2, 17, 20, 23		MFF, QFF, RIFA, GS, TPP
Tobacco		2, 16, 17, 20, 23		RIFA, MT, GS, TPP
Tomato	9, 10, 12, 13, 14, 16, 17	2, 16, 17, 21, 23		MFF, QFF, RIFA, FW, MT, GS, TPP
Turf		2, 17, 20, 23	2, 20, 23	RIFA, GS, PHY, PCN
Watermelon	14, 16	2, 16, 20, 23		MT, RIFA, GS
Water Apple / Wax Jambu (Rose Apple / Jambu)	9, 10 ,11, 12, 13, 14, 17	2, 17, 20, 23, 25, 26		MFF, QFF, RIFA, GS, MR, PFS, TPP

INDEX of CONDITIONS OF ENTRY / REGULATED MOVEMENT (one or more of these conditions may apply)				
PRODUCT	**FRUIT & VEGETABLES**	**PLANTS & FLOWERS**	**OTHER PRODUCTS**	**DISEASE (OR PEST)**
Zucchini	14, 16, 17	2, 16, 17, 20, 23		RIFA, MT, GS, TPP

SECTION 5 - CONDITIONS OF ENTRY / REGULATED MOVEMENT

1. FOREWORD

1.1 Fruit, vegetables, plants, plant products, machinery, equipment and certain related items may:

(1) be prohibited from entry into South Australia or movement within South Australia; **or**

(2) be subject to treatment or other requirements outlined within Conditions of this Section.

1.2 Where such requirements apply, the fruit, vegetables, plants, plant products, machinery, equipment, etc must be accompanied by a Plant Health Certificate, Plant Health Assurance Certificate, Plant Health Import Certificate, Declaration or other documentation approved by the Chief Inspector. Certificates must be completed in full by a "recognised authority" to certify that the appropriate entry requirements have been met. Copies of the Certificates and Declarations are in the appendices.
Applications for a Plant Health Certificate, Plant Health Import Certificate and other forms are available on www.pir.sa.gov.au/forms.

1.3 The Standard does not include aquatic plants prohibited from entry into South Australia. For aquatic plant information contact the Biosecurity SA Invasive Species Unit (telephone 8303 9620) or website www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity

1.4 Restrictions apply to the movement of potatoes, and machinery/ equipment used in the production of potatoes to Kangaroo Island. The Kangaroo Island Potato Production Area was proclaimed in August 2000 – (see condition 18.10). For further information see South Australian Gazettes or contact PIRSA Biosecurity SA Plant Health (telephone 08 8207 7820).

2. IMPORT / MOVEMENT REQUIREMENTS

2.1 Any fruit, vegetable or plant material that has been imported into Australia from an Overseas country and is being introduced into South Australia or transhipped through South Australia must be accompanied by a copy of the Department's Phytosanitary Certificate or a copy of the Quarantine Inspection Release form (or equivalent) and meet all other applicable requirements of this Standard.

2.2 Any fruit, vegetables, plant material, machinery or equipment that may be imported into South Australia from another Australian State or Territory or moved within South Australia subject to the Conditions of Entry / Regulated Movement of the Standard must comply with the specified conditions except as otherwise approved by the Chief Inspector and must be specified in conditions of registration or accreditation. Such consignments may be verified at the point of unloading, subsequently by a Biosecurity SA Plant Health Inspector or as specified in conditions of accreditation.

2.3 Pursuant to Section 33 of the *Plant Health Act 2009*, a person must not bring or introduce plants or plant related products into the State for sale or any other commercial purpose unless they are registered under Division 3 of Part 4 of the Act and have imported regulated products cleared using one of the following arrangements with Biosecurity SA Plant Health:

(1) Import Verification Compliance Agreement (IVCA)
The importing business applies for accreditation ("approval") to verify that the produce has the correct certification and is appropriately packaged and labelled. The verification process must comply with strict procedures and Biosecurity SA Plant Health will verify compliance through auditing of accredited businesses. IVCA includes IR01.

(2) Registered Premises
The importer must be registered (IR01) and nominate a premises for the receipt of the imported product. Upon arrival the importer will ensure that the consignment remains

securely packaged and isolated by one metre from other produce and arrange for a Direct Inspection by a Biosecurity SA Plant Health Inspector or clearance by an IVCA accredited business prior to the release of the produce.

Direct Inspection may, on a case by case basis where circumstances warrant, be conducted by a Biosecurity SA inspector by way of photographic and/or video evidence provided the evidence can clearly satisfy compliance.

(3) Approved Facilities/Premises
Under conditions stipulated by the Chief Inspector a facility or premises may be accredited an Approved Facility to receive host product which shall include IR01,

2.4 Products not regulated or otherwise exempted within this standard from requiring plant health certification as proof to enter South Australia will not be subject to Direct Inspection on arrival however importers must be registered (IR01).

2.5 Persons who bring or introduce into South Australia plants and plant related products for sale or any other commercial purposes must provide a copy of all relevant manifests to Biosecurity SA prior to the produce arriving into SA. These requirements also apply to transporters who transport such products through SA for sale in another State/Territory. (Section 14 of the Act).

The manifests must contain the following information:

- Name of Consignor and state of origin;
- Name and Address of Consignee;
- Number of Packaging types (i.e. carton and/or Pallet;
- Clear description of Produce Type;
- Carrier details;
- Estimated date and time of arrival, and
- If available, the consignment note number

All manifests must be sent via e-mail to: pirsa.planthealthmanifest@sa.gov.au

3. CERTIFICATES, BRANDING AND PACKAGING

3.1 Plant Health Certificate or a Plant Health Assurance Certificate

(1) Unless otherwise stipulated only a Plant Health Certificate or a Plant Health Assurance Certificate bearing a unique number and issued by and in the name of a recognised authority and in accordance with nationally agreed work instructions shall qualify goods for admission into South Australia. For these purposes “recognised authority” means:

(a) For all matters, the Department in the exporting State or Territory.

(b) Business operating under an Interstate Certification Assurance (ICA) arrangement or other Compliance Arrangement (CA) that is approved by Biosecurity SA for the product.

(c) For *Pinus* material, the Government Forestry Authority in the relevant State or Territory.

(2) Any certificate relating to regulated machinery and/or equipment must accurately describe that machinery and/or equipment.

(3) Certificates issued by a Department must bear the official Departmental stamp at these places:

(a) In the appropriate box provided on a certificate; and

(b) In association with any alteration to the quantity of a ‘line’ listed on a certificate.

(4) Only approved government officers or authorised persons from the accredited business that issued the certificate can amend or append certificates unless specified as a condition of accreditation.

(5) The certificate must be obtained prior to entry of the goods into South Australia and must accompany goods whilst in transit. The certificate must only be issued after the recognised authority has sighted and verified the consignment. Certificates will only remain valid for twenty one days from date of issue.

(6) Replacement certificates for those that have been lost during the transit of produce will only be accepted provided the following has been met:

(a) The copy is sent by a recognised authority.

(b) The copy is marked at the top of the certificate with the wording “This is a True Copy of the Original Certificate”; and

(c) The date and the printed name and signature of the person from the recognised authority accompany the statement.

(7) A person importing or introducing such goods must do the following with the certificate.

(a) Retain it for at least 2 years after the date of issue.

(b) Produce it to an inspector if so requested.

Declarations cannot be used as a sole form of proof unless indicated as such in a Condition of this standard, permitted under an accreditation or otherwise approved by the Chief Inspector.

Persons having difficulties with the above arrangements should contact:

PIRSA Biosecurity SA - Plant Health
33 Flemington Street
GLENSIDE SA 5065
Telephone: (08) 8207 7820

OR

PIRSA Biosecurity SA - Plant Health
South Australian Produce Market
POORAKA SA 5095
Telephone: 0417 800 723

Email; PIRSA.PlantHealthMarketAccess@sa.gov.au

3.2 Interstate Certification Assurance and Compliance Arrangements

(1) A Business may be accredited by the State or Territory Department in which their Business is located, to issue Plant Health Assurance Certificates that are accepted by Biosecurity SA.

Accreditation will be conditional based on:

(a) The business entering into an agreement with the Department in the exporting State or Territory to operate under an Interstate Certification Assurance or Compliance Arrangement that is accepted by Biosecurity SA;

(b) The Department in the exporting state undertaking the audits and compliance evaluation based on requirements of the “Rules for the operation of the ICA Scheme”.

(c) A Departmental inspector in the exporting State or Territory, or an approved third party provider auditing an accredited Business system and procedures at least annually or as specified in each individual ICA/CA Operational Procedure. All records and the system must be accessible for audit by any such inspector and may be subject to audit by a Biosecurity SA inspector.

Note: The finding of a declared pest or disease e.g. fruit fly, in a package that can be associated with an Accredited Business’s Plant Health Assurance Certificate will give Biosecurity SA, as the receiving Authority, cause to refuse the acceptance of any further Plant Health Assurance Certificates from the accredited business until the outcome of an investigative audit is known. This action is in line with the “Rules for the operation of the ICA Scheme”. **A business that is no longer accredited can only send fruit, vegetables or plant material into South Australia if accompanied by a Plant Health Certificate.**

Biosecurity SA's web page - www.pir.sa.gov.au/ica provides a list of accepted operational procedures under the Interstate Certification Assurance Scheme and Compliance Arrangement provisions for the entry of fruit, vegetables, plants and equipment into South Australia.

3.3 State Freedom Certificates

(1) A State or Territory may provide a State Freedom Certificate which indicates that the State or Territory is free of a particular declared disease. Such a State Freedom Certificate must be based upon agreed demonstration that the particular declared disease does not occur in that State or Territory and must be renewed annually. Where the declared disease status of an exporting State or Territory changes, the Chief Inspector must be notified immediately and the status revoked.

(2) Unless otherwise indicated in a Condition, where a State or Territory provides a State Freedom Certificate for a declared disease, the requirement for the provision of a Plant Health Certificate or a Plant Health Assurance Certificate to accompany each consignment no longer applies provided the packaging of each container in the consignment clearly identifies that the product was grown and packed in the State or Territory covered by such a State Freedom Certificate. (See also the Packaging and Branding requirements below.)

3.4 Packaging and Branding

(1) A person must not pack for sale or sell any fruit, vegetables or nuts in packaging unless the packaging:

- is in good repair; and
- is clean and free of extraneous visible matter; and
- is labelled in accordance with the regulations.

(2) Fruit, vegetables and nuts for commercial sale or distribution must be **labelled** as follows:

(a) The label must:
(i) be legibly written in English in permanent ink in letters at least 5 millimetres in height; and
(ii) be clearly visible on the outside of the packaging which also includes any smaller individual packaging able to be separately sold or distributed.

(b) If the person doing the packaging is doing so under an approved accreditation, the label must include:
(i) the date (or date code) on which the produce was packed; and
(ii) a brief description of the contents of the package; and
(iii) the IP number of the accredited person; and
(iv) **either**

(A) a code approved by the Chief Inspector for the purposes of indicating where the produce was grown;

Or

(B) the postcode of the town nearest to the place of production; and

(v) the applicable accreditation code e.g. "meets ICA-xx", "meets CAxx" or "meets xxxxx" where xx identifies the particular ICA/CA operational procedure or accreditations that have been followed and met in respect to the produce.

(c) In any other case:
(i) the date (or date code) on which the produce was packed; and
(ii) a brief description of the contents of the package; and
(iii) the district of production; and
(iv) **either**

(A) the name, address and postcode of both the grower and the packer of the produce;

Or

(B) the codes approved for the purposes of the Chief Inspector identifying both the packer and the grower.

Note: Any individual package should contain only one kind or variety of fruit, vegetable, plant material or product.

Processors who are registered with Biosecurity SA to receive bulk loads of produce (i.e. semi tippers, bulk bins or crates, etc.) for processing that removes the pest (and/or disease) risk of the final product are exempt from the above packaging and branding requirements but not the cleanliness requirement.

All used empty packaging that enters SA must be clean and free of extraneous visible soil and plant matter.

Note: Section 43 of the *Plant Health Act 2009* stipulates that fruit, plants or other items may be ordered into a quarantine station, disinfected or otherwise treated, destroyed or redirected. In consequence, packaging which is unclean or marked in an inadequate or misleading fashion may give an inspector cause to invoke such provisions in relation to that packaging and its contents. Such provisions can be applied to items which are not accompanied by appropriate certification or which do not comply with the import conditions specified within this Standard.

CONDITION 1: BLUEBERRY RUST (THEKOPSORA MINIMA)

Blueberry Rust (*Thekopsora minima*) poses a serious threat to the blueberry industry in South Australia and exists in some areas of Australia.

Hosts include any plant material of the species below (including fruit) as well as any agricultural equipment used in the cultivation, harvesting, handling, packing, processing of host fruit or plants and used packages which have contained fruit or plants of Vaccinium genus.

Frozen host fruits are not subject to meeting the conditions detailed below.

Hosts

Category 1: *Vaccinium spp*. (including blueberry, cranberry)

Category 2: *Gaylussacia spp*. (huckleberry); *Tsuga spp*. (hemlock); *Rhododendron spp*. (including azalea); *Lyonia spp.; Pernettya spp.; Hugeria spp.; Pieris spp.; Leucothoe spp.; Oxycoccus spp.*

The entry of Blueberry Rust (*Thekopsora minima*) host material into South Australia is prohibited unless it complies with one of the following requirements:

1. State/Area Freedom

1.1 Fruit, Cut Flowers or Nursery Stock

Grown and packed in a State or Territory or property which has a current Biosecurity SA recognised State/Area or Property Freedom Certificate for Blueberry Rust issued by an officer responsible for agriculture in the State or Territory where the Blueberry Rust host material was grown and packed;

Proof: For State Freedom Certification in place; Documentation that verifies origin may be required on entry.

Proof: Biosecurity SA recognised Area/Property Freedom Certification in place; Appendix 12: Declaration of Source Blueberry Rust that verifies property accreditation.
The Biosecurity SA Declaration is shown in SECTION 8 – APPENDICES or available at www.pir.sa.gov.au/forms

2. Category 1 Hosts (*Vaccinium spp.*)

2.1 Fruit/Cut Flowers

Blueberry Rust host fruit (any fruit of *Vaccinium* genus, including blueberry, cranberry or huckleberry) that doesn't meet 1 above must comply with the following;

(1) The crop has been;

a) sprayed within 14 days of harvest with a pre-harvest application of a fungicide registered for the treatment of blueberry rust as per label recommendations; or

b) inspected within 14 days prior to harvest and no blueberry rust detected;

And

(2) The fruit inspected at dispatch at the international sampling rate (600 piece or 2%) and found free of the symptoms of blueberry rust;

And

(3) Packaging must be clean and new and labelled in accordance with the Plant Health Regulations 2009 (SA).

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate (ICA31)

2.2 Nursery Stock and Plants

Category 1 host plant or plant product from a property not able to meet clause 1.1(1) above is prohibited unless accompanied by a Plant Health Import Certificate and treated and inspected as follows:

(1) Grown in an inert media or a commercial potting mix, and

(2) Sprayed within 14 days of dispatch from property with a pre-harvest application of a fungicide registered for the treatment of blueberry rust as per label recommendations prior to despatch, and

(3) Within 24 hours prior to dispatch inspected by an officer of the state authority and found free of symptoms of blueberry rust, and

(4) Moved to a Biosecurity SA approved quarantine facility located in the source state and held at that facility for a period of 30 days which may be extended if determined necessary by the pathologist in charge, and

(5) Within 3 days prior to release inspected by a biosecurity officer for absence of blueberry rust, and

(6) Prior to dispatch packaged in a secure manner to prevent infection by spores or contact with other plants during transit, and

(7) Complying with any additional requirement stipulated in the Plant Health Import Certificate, and

Proof: Accompanied by a Plant Health Import Certificate and any additional proof as detailed within said certificate.

3. Category 2 Hosts

3.1 Nursery Stock, Plants and Cut Flowers

Category 2 host plants and plant products from a property not able to meet clause 1.1(1) above is prohibited unless treated and consigned under the following conditions:

(1) treated with an approved fungicide * within 7 days of despatch: and

(2) inspected at the rate of 600 or two (2) percent of pieces within the consignment and found free from symptoms of Blueberry Rust.

**Approved fungicides are:*

a. fungicides which contain label instructions relating to treatment of "rust" diseases on ornamentals; and
b. other chemicals for which the Australian Pesticides and Veterinary Medicines Authority (APVMA) has issues a permit to treat Blueberry rust on plants.

Use of any chemicals must be in accordance with the approved label instructions. Chemicals used under APVMA permit conditions must be used in conjunction with relevant approved permit conditions.

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate (ICA29) or CA12 Laboratory documentation.

4. Agricultural Equipment and Packages

The entry of any agricultural equipment used in the cultivation, harvesting, handling, packing, processing of blueberry fruit or plants, or used package which have contained blueberry fruit or plants is prohibited unless certified it has been;

4.1 cleaned free of soil and organic matter; and

4.2 steam cleaned; or

4.3 disinfected with a solution containing not less than 100ppm available chlorine used as a spray or drench treatment.

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate or CA12 Laboratory documentation.

5. Pest Free Place of Production and Pest Free Production Sites

Grown in a Biosecurity SA approved place of production under conditions approved by the Chief Inspector that ensure its pest freedom for blueberry rust.

Proof: Accompanied by a Plant Health Import Certificate or Plant Health Assurance Certificate, and all other required proof as detailed by the Chief Inspector.

6. Chief Inspector Approval

Handled and consigned in a manner prescribed by the Chief Inspector under a Plant Health Import Certificate.

Proof: Accompanied by a Plant Health Import Certificate and all other required proof as detailed by the Chief Inspector.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 2: RED IMPORTED FIRE ANT (*SOLENOPSIS INVICTA*) - RIFA

Queensland currently has recorded infestations of Red Imported Fire Ant (RIFA).

The movement into South Australia of any host material including containerised plants, potting media, soil, organic mulch, turf, hay, straw, agriculture machinery or used containers is prohibited from Queensland **unless certified** as having met the following requirements:

Note: Bare rooted plants washed free of soil and commercial seedling plugs/cells are exempt.

1. Properties within 5kms of a known outbreak of the pest *Solenopsis invicta*

1.1 Property Freedom

(1) The property has been inspected and accredited by an officer of the State Department responsible for agriculture or officer of an approved national scheme as being inspected and found free of RIFA; and

(2) The property has been inspected within the past four weeks by an officer of a State Department responsible for agriculture or by an approved inspection person trained and accredited by the State Department responsible for agriculture under an approved ICA arrangement or an approved national scheme and no RIFA detected; and

(3) The property does not share host material with another property known to be infested with RIFA unless that host material has been given an approved treatment; and

(4) The host material has been inspected by a trained authorised inspection person under an approved ICA/CA or approved national scheme and found free of RIFA; and

(5) The host material has been stored in a manner to prevent infestation.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA40) or BioSecure HACCP Biosecurity Certificate.

1.2 Containerised, Potted and Root-balled Plants and Trees

Containerised plants must either be sourced from a property free of RIFA (see above requirement) or are subject to the following requirements:

(1) The plants have been inspected and found free of RIFA; and

(2) Isolated in a secure area, greater than 5 metres from plants that have not been treated in accordance with (3) or (4) and within 48 hours prior to dispatch, treated in accordance with either (3) or (4):

(3) For food plants and fruit trees (with fruit removed);

a) treated in accordance with label instructions and AVPMA permit with 30 - 40 mls of a 500 g/L chlorpyrifos concentrate per 100 L of water as either

i. a drench treatment, or

ii. by full immersion in a prepared dip, or

b) treated in accordance with label instructions and AVPMA permit with 16 mls of a 12.5 g/L cyfluthrin concentrate per 10 L of water as a drench treatment.

(4) For ornamental nursery plants (other than food plants or fruit trees);

a) treated in accordance with label instructions and AVPMA permit with 30

- 40 mls of a 500 g/L chlorpyrifos concentrate per 100 L of water as either

i. a drench treatment, or

ii. by full immersion in a prepared dip, or

b) treated in accordance with label instructions and APVMA permit with 16 mls of a 12.5 g/L cyfluthrin concentrate per 10 L of water as a drench treatment, or

c) treated in accordance with label instructions and APVMA permit with a 2 g/kg bifenthrin granular insecticide at 10-25 ppm per cubic metre of potting media; or

d) treated in accordance with label instructions and APVMA permit with a 100 g/kg chlorpyrifos granular insecticide (suSCon Green) at 1 kg per cubic metre of potting media.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA39).

1.3 Agricultural Machinery, Equipment and Used Containers

(1) The machinery, equipment or container has been inspected and found free of RIFA; and

(2) Cleaned free of organic matter and soil by brushing, using high pressure water or steam.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate or CA12 documentation.

1.4 Potting Media, Organic Mulch and Soil*

(1) Treated with Methyl Bromide fumigation at a rate of 48 g/m³ at 21ºC for 24 hours; or

(2) Heat treated to bring the entire mass to a maximum of 65.5ºC; and

(3) Stored, handled and consigned after treatment so as to prevent infestation with RIFA; or

(4) Produced, stored, handled and consigned in such a manner that would prevent infestation or destroy all life stages of RIFA.

The potting media, organic mulch and/or soil must be packed in the original sealed bag or other container in which they were commercially packed. ***NOTE:** Also refer to Condition 20.

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate, BioSecure HACCP Biosecurity Certificate or CA12 Laboratory documentation.

1.5 Hay/Straw (and similar baled products)

(1) Treated with Methyl Bromide fumigation at a rate of 48 g/m³ at 21ºC for 24 hours; and

(2) Stored in a manner that would prevent infestation of RIFA; and

(3) Inspected by the owner and found free of RIFA; and

(4) Consigned within 28 days.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate.

1.6 Turf

Turf for domestic and commercial purposes requires **prior written approval** outlined in

a Plant Health Import Certificate before it can enter the State.

Proof:	**Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate and a Plant Health Import Certificate**

2. Properties outside 5kms of a known outbreak of the pest *Solenopsis invicta*

The movement into South Australia of any host material including containerised plants, potting media, organic mulch, turf, hay, straw, agricultural machinery or used containers is prohibited from Queensland unless certified that:

2.1 The property is located more than 5kms from a known or suspected outbreak of RIFA.

Proof:	**Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate, BioSecure HACCP Biosecurity Certificate or CA12 Laboratory documentation.**

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 3: CITRUS – STEM PITTING STRAIN OF TRISTEZA VIRUS AND CITRUS BLIGHT

Citrus plants and citrus propagation material (excluding seeds) from Queensland are prohibited because of the existence in that State of suspected sweet orange stem pitting strain of citrus tristeza virus and citrus blight.

Citrus plants and citrus propagation material (excluding seeds) grown in other States must;

1. Be certified as having been grown in a State free of stem pitting strain of citrus tristeza virus and/or citrus blight,

OR

2. Provide a Declaration of Origin (Appendix 7.) that declares the plant material did not originate from Queensland, unless the State has been declared free of the pest by the relevant authority, whereby it can enter uncertified.

Proof: Accompanied by a Plant Health Certificate, a Plant Health Assurance Certificate or a Citrus Blight Declaration of Origin (Appendix 7).

The Biosecurity SA Declaration is shown in Appendix 7 or is available at www.pir.sa.gov.au/forms.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 4: EUROPEAN HOUSE BORER

The entry of specified Host Material (see "Definitions" below) of European House Borer (*Hylotrupes bajulus*) from Western Australia is prohibited unless it complies with the following requirements:

1. Host Materials Requiring Treatment

1.1 Pine Wood Timber

Pine wood timber entering South Australia from Western Australia may only do so if certified as;

(1) sourced and milled from within a pest free area in accordance with 2.1(1) & 2.1(2) below, or

(2) heat treated in accordance with 2.2 below, or

(3) fumigated with methyl bromide in accordance with 2.3 below, or

(4) preservative treated in accordance with 2.4 below.

Proof: Accompanied by a Plant Health Certificate a Plant Health Assurance Certificate or a Plant Health Import Certificate with prescribed verification documentation.

1.2 Pine pallets

Pine wood pallets entering South Australia from Western Australia are prohibited except for pallets sourced from a supplier accredited under a compliance arrangement approved by the Chief Inspector.

Pine wood pallets manufactured in Western Australia are prohibited from entering South Australia unless sourced from a supplier accredited under a pallet compliance arrangement approved by the Chief Inspector.

Proof: Pallet labelled with accredited suppliers details

OR

1.3 Alternatively sourced from a pest free area under 2.12.1(1).

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate or Plant Health Import Certificate.

1.4 Pine Firewood

Pine wood firewood entering South Australia from Western Australia is prohibited except for commercial lots of firewood that have been certified as being fumigation treated or alternatively certified as sourced from a pest free area under 2.12.1(1).

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate or Plant Health Import Certificate.

1.5 Pine dunnage, packaging material and untreated pinewood products.

Pine dunnage, pine timber packaging material and untreated pinewood products entering South Australia from Western Australia must be free of European House Borer upon arrival.

2. Treatment or Condition

2.1 Area Freedom Certification

A person proposing to consign pine timber into South Australia sourced from a pest free area in Western Australia must do so under the following requirements.

(1) All timber must have been sourced from (and milled in) an area that has been certified by Department of Agriculture and Food Western Australia (DAFWA) as

being free of European House Borer and have a Chief Inspectors Import Certificate outlining the import details.

(2) Prior to transportation of timber to South Australia it must be legibly marked with the following information

- The grade of timber (ie MGP10);
- The name of the company that prepared the timber;
- The condition of timber (ie. Seasoned);
- A description of the Australian/New Zealand standard which governs the preparation of the timber;
- The production time; and
- Each individual pack of timber must be enclosed within a plastic covering that must be legibly marked with the details of the company that prepared the timber.

Where a Plant Health Import Certificate (PHIC) is provided a copy of it must accompany each consignment along with a detailed cart note and a copy of any treatment record unless a Plant Health Certificate or Plant Health Assurance Certificate has been issued.

2.2 Heat Treatment

The core of the timber is heated to at least 56 degrees Celsius and held at that temperature for a minimum of 30 minutes. To enable verification of treatment each pinewood product must permanently bear a treatment symbol approved by the Chief Inspector, placed in a visible location and containing the treatment date. Treatment must have occurred within 21 days prior to the arrival in South Australia.

2.3 Fumigation with methyl bromide

The Host Material, which must have at least one physical dimension less than 200 mm thick, is treated with Methyl Bromide Fumigation for 24 hours at a concentration indicated below and monitored at 2, 4 12, and 24 hours to maintain those required concentrations;

Minimum Methyl Bromide Fumigation Standard

Temperature	Dosage (g/m^3)	Minimum concentration (g/m^3) at:			
		2hrs	4hrs	12hrs	24hrs
21°C or above	48	36	31	28	24
16°C or above	56	42	36	32	28
10°C or above	64	48	42	36	32

To enable verification of treatment each pinewood product must permanently bear a treatment symbol approved by the Chief Inspector, placed in a visible location and containing the treatment date. Treatment must have occurred within 21 days prior to the arrival in South Australia.

2.4 Preservative treatment (impregnation and envelope)

The Host Material has been treated with a specific insecticidal preservative treatment for European House Borer, either by vacuum pressure impregnation, dipping or spraying as specified within the Australian Standard for Preservative Treatments of Timber (AS1604) and approved by the Chief Inspector.

Definitions

"Free of European House Borer" means host material has been inspected and found free of any borer entry holes, or alternatively has been treated by either heat treatment, fumigation with methyl bromide or preservative treatment prior to leaving Western Australia.

"Host Material of European House Borer" means any raw, unprocessed and untreated coniferous

timbers including pine, fir and spruce for the purpose of this condition. It also includes untreated pinewood building timber, untreated pinewood pallets, dunnage and timber packing material, commercial lots of firewood, and furniture, ornaments, artefacts, craft materials, and household effects with pine wood components.

"Pine wood" means wood from trees of the genera Abies, Araucaria, Picea, Pinus, and Pseudotsuga.

For Fact Sheets and information on regulated pests go to following web page; https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 5: CITRUS RED MITE

1. Citrus plants grown in the Counties of Cumberland and Northumberland New South Wales are prohibited into South Australia unless the citrus plants are certified as having been treated against Citrus Red Mite (*Panonychus citri*) under the conditions of an approved accreditation (CA16 NSW) with miticide approved by the Australian Pesticides and Veterinary Medicines Authority (APVMA) and acknowledged as being efficacious on all stages (eggs, nymphs, adults) and used in accordance with label instructions for Citrus Red Mite.

2. Citrus plants grown in NSW outside the Counties of Cumberland and Northumberland must be accompanied by certification indicating the plants were grown in an area free of Citrus Red Mite or a valid Biosecurity SA Citrus Red Mite Declaration (Appendix 8).

3. Citrus plants grown outside of NSW must be accompanied by a valid Biosecurity SA Declaration of Origin (Appendix 8.) that declares the plant material did not originate from NSW, unless the State has been declared free of Citrus Red Mite by the relevant authority, whereby it can enter uncertified.

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate (CA16) or Citrus Red Mite Declaration of Origin (Appendix 8).

The Biosecurity SA Declaration is shown in Appendix 8 or is available at www.pir.sa.gov.au/forms

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 6: PLANT DIAGNOSTIC SAMPLES (EXCLUDING GRAPEVINE SAMPLES)

All diagnostic samples of regulated plant or plant material pose a potential risk of introducing either a declared pest or disease or an as yet unrecognised emergency plant pest or disease. As such, all regulated plant diagnostic samples from interstate sources must be handled in a laboratory accredited or approved by Biosecurity SA.

1. Accredited laboratories will operate under CA12 Laboratory Accreditation that will require them to maintain agreed procedures and documentation for the secure receipt, handling and disposal of plant diagnostic samples from interstate sources in accordance with an Operational Procedure.

2. Approved laboratories must receive and handle diagnostic samples from interstate sources in accordance with the conditions outlined in a Chief Inspectors Plant Health Import Certificate. The conditions, approved by the Chief Inspector, will ensure secure receipt, handling, disposal and documentation and manage the perceived risk associated with different classes of plant samples.

Note: For grapevine samples and vineyard soils refer to Condition 7 and for general soil samples refer to Condition 20 for specific requirements.

Proof: Documentation as prescribed under the Laboratory Accreditation (CA12) or for Approved Laboratories a Plant Health Import Certificate and Plant Health Certificate

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 7: GRAPE PHYLLOXERA

The pest grape phylloxera (*Daktulosphaira vitifoliae*) is present in parts of Victoria and New South Wales. The concern is for the movement of grape phylloxera risk vectors:

– Grapevine material (including for planting and/or propagation) (refer Clause 1)
– Machinery previously used in grape production (refer Clause 2)
– Equipment previously used in grape production (refer Clause 3)
– Grapes and grape-related materials (refer Clause 4)
– Grapevine diagnostic samples and vineyard soils (refer Clause 5)

General notes

a. Additional entry conditions or requirements may apply to importing or transiting grape-related material. Refer SECTION 4 of the Plant Quarantine Standard South Australia (PQS) for other relevant Conditions to be read, including Conditions 2, 9, 11, 12, 13, 14, 23 and SECTION 3 Interpretations.

b. Grape phylloxera is managed from a policy, regulatory and management perspective in three Phylloxera Management Zones, referenced throughout Condition 7:
   - Phylloxera Exclusion Zone (PEZ) including a state free of grape phylloxera
   - Phylloxera Risk Zone (PRZ)
   - Phylloxera Infested Zone (PIZ)

   South Australia has also introduced a 'Phylloxera Interim Buffer Zone (PIBZ)'.
   Refer to the latest Phylloxera Management Zones Map at http://vinehealth.com.au/industry/resources/maps/phylloxera-management-zones/ to determine the zone from which the item is to be moved.

c. Valid interstate compliance arrangements for winegrape and table grape materials with respect to grape phylloxera, include:
   - ICA-04 Fumigation with methyl bromide
   - ICA-22 Transfer of Grape Must and unfiltered juice from a PIZ or PRZ for Winemaking in a PEZ
   - ICA-23 Area or property freedom based on monitoring by the accrediting authority
   - ICA-33 Movement of wine grapes (grape phylloxera and fruit fly)
   - ICA-37 Hot water treatment of grapevines

d. Any vehicles involved in the transport of grapes, grape-related material, machinery or equipment must be clean of all soil and non-consigned plant material upon arrival into South Australia.

Unless stated otherwise in Condition 7 and as per Table 1, all consignments are subject to:

1. **Importer registration (IR01) – a person must not bring or introduce into the state, plants or plant-related products for sale or any other commercial purpose except as authorised by registration obtained through PIRSA (Biosecurity SA). IR01 is included with IVCA accreditation.**
2. **Direct Inspection – regulated items imported must be inspected and cleared on arrival into South Australia by a PIRSA Inspector or an IVCA Accredited Business. Penalties apply for failing to comply.**

Table 1. Requirements for importer registration and direct inspection under Condition 7.

This table only reflects allowable imports into South Australia.

	Allowable item	Method of 'Importer Registration'	Who does the 'Direct Inspection'
Clause 1	Lignified cuttings and dormant rootlings from a PEZ	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01 OR IVCA	Biosecurity SA OR accredited receiving business
	Grapevine tissue culture	Single or multiple imports in a year → PHIC	Biosecurity SA OR accredited receiving business
	Grapevines entering SA after overseas import	Refer SECTION 6 – fruit and plant for overseas export or imported from overseas	
Clause 2	Used machinery including grape harvester	Single or multiple imports in a year → PHIC	Biosecurity SA OR accredited receiving business
	Used machinery including grape harvester being sent to an interstate PEZ for servicing	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01	Nil Required
Clause 3	Equipment from a PEZ excluding netting, trellis posts, vine guards, dripper tube, wire, clips	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01 OR IVCA	Biosecurity SA OR accredited receiving business
	Any used vessel that has held grapes or used hand tools from a PRZ/PIZ/PIBZ		
	Used equipment sent to an interstate PEZ for servicing	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01	Nil Required
Clause 4	Table grapes & wine grapes from a PEZ	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01 OR IVCA	Biosecurity SA OR accredited receiving business
	Crushed fresh grapes (must) and unfiltered (fresh) juice from a PEZ		
	Crushed fresh grapes (must) and unfiltered (fresh) juice from a PRZ/PIZ/PIBZ	Single import → PHIC for each import Multiple imports in a year → Importer Registration via ICA22	Biosecurity SA OR accredited receiving business
	Filtered juice	Nil Required	
	Wine		
	Grape marc and destemmer waste from fresh grapes in a PEZ	Single import → PHIC for each import Multiple imports in a year → Importer Registration via IR01 OR IVCA	Biosecurity SA OR accredited receiving business
Clause 5	Diagnostic samples to an accredited laboratory	Covered by CA12 accreditation of the laboratory	
	Diagnostic samples to an approved laboratory	PHIC organised by the approved laboratory	Biosecurity SA
	Diagnostic samples from a PRZ/PIZ/PIBZ to a CA12 accredited or approved laboratory where disinfestation at the origin has been proven to compromise the test	Single or multiple imports in a year → PHIC	Biosecurity SA OR accredited receiving business

Notes for Table 1:

1. To obtain a Plant Health Import Certificate (PHIC), complete the application form at https://www.pir.sa.gov.au/forms
2. To obtain an Importer Registration (IR01), complete the application form at https://www.pir.sa.gov.au/forms
3. To obtain an Import Verification Compliance Arrangement (IVCA) CA-01 accreditation, complete the application form at https://www.pir.sa.gov.au/forms. This includes importer registration and allows businesses to self-inspect and verify consignments.
4. Where direct inspection is to be undertaken by Biosecurity SA,
   a) complete a "Direct Inspection Request" form (available at https://www.pir.sa.gov.au/forms) and return to PIRSA.PlantHealthMarketAccess@sa.gov.au indicating requested time and date for the inspection (meeting a request is subject to availability of a PIRSA Inspector) and -
   b) send manifest details by email PIRSA.PlantHealthManifest@sa.gov.au or fax (08) 8124 1467, including: a clear description of the produce type, quantity, carrier details, name and address of the sender, name and address of the receiver, consignment note number and estimated date and time of arrival.

1. GRAPEVINE MATERIAL (INCLUDING FOR PLANTING AND/OR PROPAGATION)

Any grapevine material, including for planting and/or propagation, must not enter South Australia unless all steps have been undertaken as outlined below.

For entry conditions relating to grapes and grape-related material – refer Clause 4 and for grapevine diagnostic samples and vineyard soils – refer Clause 5.

1.1 Prohibited Entry

(1) From a PRZ/PIZ/PIBZ

a) All grapevines in the form of whole grapevines or part thereof, cuttings, rootlings, potted vines and other propagules, but excluding grapevine tissue cultures (refer 1.2 (2)).

(2) From a PEZ

a) All grapevines in the form of whole grapevines or part thereof, potted vines and other propagules, excluding dormant rootlings, lignified cuttings and grapevine tissue cultures (refer 1.2 (2)).

1.2 Conditional Entry

(1) Lignified cuttings and dormant rootlings from a PEZ

a) Sterilise by hot water treatment within 24 hours prior to dispatch to South Australia:

i. Completely immerse and maintain bundles at a minimum of 50°C ± 1°C for 30 minutes OR 54°C ± 1°C for 5 minutes.

ii. A minimum of three sensors must be used for each hot water treatment vessel. One sensor should be located at a depth of 100mm from the base of the vessel, another at 100mm from the surface and the other inserted into the centre of the load mass.
Note: Lignified cuttings and dormant rootlings must be washed free of all soil and excess organic matter before sterilisation. If bundled, no more than approximately 100 lignified cuttings in a bundle or approximately 50 dormant rootlings in a bundle.
Note: Some plant material may be damaged by hot water treatment. A trial treatment is recommended unless the response of the plant material to this treatment is known.

b) Handle post-sterilisation so as to prevent contamination/infestation after treatment.

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) or Plant Health Assurance Certificate (PHAC) under ICA-37.

(2) Grapevine Tissue Culture

a) Must not enter South Australia without prior written approval from the Chief Inspector or delegate, providing:

i. Details of the place or places of origin of each culture.

ii. Details of the grape varieties of each culture.

b) Must be produced in accordance with SECTION 8 – Appendix 2 of South Australia's Plant Quarantine Standard as evidenced in PHIC.

Proof: Consignment to be accompanied by a Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC).

(3) Grapevines entering SA after overseas import

a) Grapevines that have been quarantined at a Commonwealth post-entry quarantine facility will be allowed entry as cuttings, rootlings or potted plants without additional treatment provided they are sent directly from that quarantine facility to South Australia with certification. Refer to Section 6 of this standard for further detail.

2. MACHINERY PREVIOUSLY USED IN GRAPE PRODUCTION

Applies to any machinery previously used in the production and manipulation of grapes, grapevines and/or used on vineyard soil. A machine is a device that uses energy to perform some activity and is defined as a collection of machines that operate together to perform a task. A machine is generally large, complex and can't be easily cleaned. Machinery includes but is not restricted to, tractors, spray equipment, pruning machines, mechanical grape harvesters, winery crushing and processing machinery, post knockers, post-hole diggers, mechanical augers, trenchers, slashers, forklifts, backhoes, excavators, tillers, seeders and vineyard vehicles used to drive down vine rows. For equipment requirements, refer Clause 3.

Any machinery previously used in grape production must not enter South Australia unless all steps have been undertaken as outlined in 2.1 and 2.2. Refer 2.3 for machinery that requires re-entry into SA after servicing only in an interstate PEZ.

2.1 Used grape harvesters

(1) A used grape harvester must not enter South Australia without prior written approval from the Chief Inspector or delegate and unless:

a) Cleaned

i. Remove any parts of the harvester which may hold and hide vineyard soil and plant material. This includes all harvester belts (discharge, cross feed, transfer, pick up and elevator belts) and covers or guards that have been designed to open or completely detach from the harvester frame (termed "dismantled parts").

ii. Thoroughly clean the harvester and all dismantled parts with a steam cleaner, pressure washer or air hose to ensure all vineyard soil and plant material is completely removed. Clean the inside, outside, top of the harvester and cabin (where present). Start cleaning at the top of the harvester so that all vineyard soil and plant material does not wash back over areas that have already been cleaned. Pay particular attention to areas where material can get caught or carried inside the machine – including fans, conveyor belts, baskets (buckets), bow rods/beaters, fish plates, onboard deleafers, destemmers, hoppers and sorting tables.

AND EITHER

b) Sterilised using Dry Heat

i. Place the harvester and dismantled parts (as specified in 2.1.(1)) a) in a suitable room, shed or container that can be heated up to the required temperature; and

ii. Apply temperature probes to the harvester and measure the surface temperature and preferably some internal parts of the harvester; and

iii. Heat up the room until the probes indicate the required temperature has been reached and hold the harvester at the required temperature for the required time: EITHER 45°C for 90 minutes (1½ hours) OR 40°C for 180 minutes (3 hours).

OR

c) If currently located in a PEZ and has been in a PRZ/PIZ/PIBZ in the previous 6 months, evidenced as sterilised using Dry Heat as per 2.1(1)(b) prior to exiting the PRZ/PIZ/PIBZ.

Proof: Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC)

OR

d) If currently located in a PEZ declared as not having been in a PRZ/PIZ/PIBZ in the previous 6-months.

Proof: Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC) and Declaration (Appendix 13)

2.2 Other used machinery excluding grape harvesters

(1) Other machinery must not enter South Australia without prior written approval from the Chief Inspector or delegate and unless:

a) Cleaned

i. Remove any parts of the machinery which may hold and hide vineyard soil and plant material. This includes covers or guards that have been designed to come off or open.

ii. Thoroughly clean the machinery and all parts removed with a steam cleaner, pressure washer or air hose to ensure all vineyard soil and plant material is completely removed. Clean from the top down to avoid contaminating areas already cleaned.

AND EITHER

b) Sterilised by one of the following methods:

i. Dry Heat (as specified in 2.1 (1) b))

ii. Hot Water

- Fully immerse the machinery in water.
- Once the water temperature has stabilised at 60°C or higher, hold the machinery in the water for at least 90 seconds (1½ minutes).

OR

c) If currently located in a PEZ and has been in a PRZ/PIZ/PIBZ in the previous 6 months, evidenced as sterilised using Dry Heat as per 2.1(1) b) or Hot Water as per 2.2 (1) b) ii. prior to exiting the PRZ/PIZ/PIBZ

Proof: Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC)

OR

d) If currently located in a PEZ declared as not having been in a PRZ/PIZ/PIBZ in the previous 6-months.

Proof: Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC) and Declaration (Appendix 13)

2.3 Used machinery including grape harvesters sent from South Australia to a service provider located in an interstate PEZ, for servicing only

(1) The following steps can be undertaken to negate the need for Dry Heat or Hot Water treatment or obtaining a Plant Health Certificate (PHC) prior to re-entry into South Australia:

a) The South Australian consigning business must ensure that the machine has been cleaned thoroughly (including removing any belts, covers etc.) to remove all vineyard soil and plant material prior to leaving South Australia.
b) When the machinery to be serviced is in transit outside of South Australia, it must not be backloaded with any other grape-related machinery or equipment.
c) The route of travel must be the most direct to and from the service provider and not through a PRZ/PIZ/PIBZ.

Proof: Consignment to be accompanied by a Plant Health Import Certificate (PHIC) and a Declaration (refer Appendix 15) issued by the service centre and sent to Biosecurity SA prior to departure from the service centre.

Note: *Any used machinery including grape harvesters sent from South Australia to a service provider located in an interstate PRZ/PIZ/PIBZ for servicing, must abide by all requirements in 2.1 and 2.2.*

3. EQUIPMENT PREVIOUSLY USED IN GRAPE PRODUCTION

Applies to any equipment previously used in the production and manipulation of grapes, grapevines and/or used on vineyard soil. Equipment is defined as items required to do a given task (excluding machinery) and includes but it is not limited to, any vessel that has held grapes (including grape picking bins, picking buckets, bulk tippers), hand tools (including pruning snips - pneumatic/hydraulic and electric shears, picking snips, shovels, soil corers, dig sticks, technical equipment), trellis posts used in vineyard soil, netting, wire, dripper tube, clips and vine guards. For machinery requirements, refer Clause 2.

Any equipment previously used in grape production must not enter South Australia unless all steps have been undertaken as outlined in 3.1 and 3.2. Refer 3.3 for equipment that requires re-entry into SA after servicing only in an interstate PEZ.

3.1 From a PEZ

(1) Used netting, trellis posts, vine guards, dripper tube, wire, clips – **prohibited entry into South Australia**

(2) All other used equipment must be clean thoroughly with a steam cleaner, pressure washer or air hose to ensure all vineyard soil and plant material is completely removed.

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) or Plant Health Assurance Certificate (PHAC) under a Compliance Arrangement for used vessels that have held grapes only.

3.2 From a PRZ/PIZ/PIBZ

(1) Used netting, trellis posts, vine guards, dripper tube, wire, clips – **prohibited entry into South Australia**

(2) For any used vessel that held grapes (including grape picking bins, picking buckets, bulk tippers) and used hand tools (including technical equipment):

a) Clean thoroughly with a steam cleaner, pressure washer or air hose to ensure all vineyard soil and plant material is completely removed; **and**

b) Sterilise by one of the approved methods indicated in the table below:

Sterilisation method	Used vessel that has held grapes	Used hand tools
Dry Heat i. As specified in 2.1 (1) b).	Yes	Yes
Hot Water i. As specified in 2.2 (1) b) ii.	Yes	Yes
Sodium hypochlorite (bleach) i. Mix a 2% sodium hypochlorite solution in a tub in sufficient volume to cover the top of the equipment (if using a 4% sodium hypochlorite product, mix 1-part water to 1-part product); and ii. Completely immerse the equipment for a minimum of 60 seconds. Do not rinse with water after immersion.	No	Yes

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) on the provision of data logger evidence of the time/temperature sterilisation for Dry Heat and Hot Water only and where required by the source state jurisdiction, a Permit for movement out of the origin PRZ/PIZ/PIBZ.

3.3 Used equipment sent from South Australia to a service provider located in an interstate PEZ, for servicing only

(1) The following steps can be undertaken to negate the need for obtaining a Plant Health Certificate (PHC) prior to re-entry into South Australia:

a) The South Australian consigning business must ensure that the equipment has been cleaned thoroughly to remove all vineyard soil and plant material and is securely packaged prior to leaving South Australia; and

b) When the equipment to be serviced is in transit outside of South Australia, it must not be backloaded with any other grape-related equipment or machinery; and

c) The route of travel must be the most direct to and from the service provider and not through a PRZ/PIZ/PIBZ.

Proof: Consignment to be accompanied by Declaration (refer Appendix 15) issued by the service centre and sent to Biosecurity SA prior to departure from the service centre.

Note: *Any previously used equipment sent from South Australia to a service provider located in an interstate PRZ/PIZ/PIBZ for servicing, must abide by all requirements in 3.2.*

4. GRAPES AND GRAPE-RELATED MATERIALS

Applies to table grapes, winegrapes, crushed fresh grapes (must) and unfiltered (fresh) juice, filtered juice, wine, grape marc and destemmer waste from fresh grapes.

Note: *Refer also to Conditions 12E and 12F for fruit fly requirements.*

Any grapes and grape-related materials must not enter South Australia unless all steps have been undertaken as outlined below for each grape or grape-related material type:

4.1 Table grapes

(1) From a PEZ
Permitted entry, subject to proof of origin.

Proof: Consignment to be accompanied by a Plant Health Assurance Certificate (PHAC) or Plant Health Certificate (PHC).

(2) From a PRZ
Permitted entry if free of all vineyard soil and leaf matter and after sterilisation by one of the following methods:

a) Fumigation with methyl bromide by a licensed fumigator at either of the following rates based on flesh temperature -
   i. 17°C - 20.9°C @ 40 g/m3 for 2 hrs; or
   ii. 21°C - 31.9°C @ 32 g/m3 for 2 hrs.

Note*: Fumigant loading rates for table grapes must not be less than 30% or more than 50% of the volume of the chamber when empty. The fumigator must ensure that table grapes enclosed or covered with impervious materials (such as plastic bags, stacked plastic punnets or waxed paper), are opened, cut or removed to allow adequate penetration of the gas unless packaging has not less than four unobstructed perforations of 6mm diameter per 100cm^2, or five unobstructed perforations of 5mm diameter per 100cm^2, or numerous pinholes (at least six holes per cm^2).*

OR

b) Fumigation treatment with a mixture of 1% sulphur dioxide (SO_2) and 6% carbon dioxide (CO_2) for 30 minutes.

Note: *Packaging of grapes for fumigation must allow for penetration and subsequent aeration of the fumigants.*

OR

c) Sulphur pads.
The inclusion of sulphur pads (a registered product containing a minimum of 970g/kg anhydrous sodium metabisulphite at the rate specified on the label).

Note: *This method is only valid for packed table grapes.*

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) or Plant Health Assurance Certificate (PHAC) under ICA-04 for methyl bromide fumigation only.

(3) From a PIZ/PIBZ
Permitted entry if free of all vineyard soil and leaf matter, and after sterilisation by either the method as specified in 4.1(2)a) or 4.1(2)b).

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) or Plant Health Assurance Certificate (PHAC) under ICA-04 for methyl bromide fumigation only.

4.2 Winegrapes

(1) From a PRZ/PIZ/PIBZ - **prohibited entry into South Australia**

(2) From a PEZ
Permitted entry subject to proof of origin.

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC) or Plant Health Assurance Certificate (PHAC) under ICA-33.

4.3 Crushed Fresh Grapes (Must) and Unfiltered (Fresh) Juice

(1) Produced from grapes grown in a PEZ
Permitted entry subject to proof of origin.

Proof: Consignment to be accompanied by a Plant Health Certificate (PHC).

(2) Produced from grapes grown in a PRZ/PIZ/PIBZ and moved under an approved Interstate Certification Assurance (ICA) Arrangement (ICA22).

Proof: Consignment to be accompanied by a Product Movement Declaration under ICA-22 or Plant Health Certificate (PHC).

4.4 Filtered Juice

That has been processed (filtered, centrifuged, cold settled or other) to a 50-micron filtration rating (or tighter), may enter unrestricted.

4.5 Wine

May enter unrestricted.

4.6 Grape marc and destemmer waste from fresh grapes

(1) Produced from grapes grown in a PEZ
Permitted entry subject to proof of origin.

Proof: Consignment to be accompanied by a Declaration indicating PEZ origin (refer Appendix 13).

(2) Produced from grapes grown in a PRZ/PIZ/PIBZ - **prohibited entry into South Australia.**

5. GRAPEVINE DIAGNOSTIC SAMPLES AND VINEYARD SOILS

Grapevine diagnostic samples and vineyard soil samples imported into South Australia for analysis must only be handled in laboratories in South Australia that are accredited or approved by Biosecurity SA for this purpose, unless otherwise specified. The laboratory accreditation scheme is CA12 (Laboratory Accreditation for Importation of Grapevine, Soil and Plant Diagnostic Material) which covers the importation, security, receival, storage, handling and disposal of received material.

Notes:
If you require information on which laboratories are accredited to receive grapevine, soil and plant diagnostic material within South Australia please contact PIRSA on 08 8207 7814.
Wherever possible, diagnostic analysis should be preferentially carried out within the originating Phylloxera Management Zone.

Diagnostic samples of any part of a grapevine and vineyard soils, must not enter South Australia unless all below steps have been undertaken as outlined:

5.1 Sourced from a grapevine or vineyard in a PEZ

(1) Sending to a CA12 accredited laboratory
Securely package the sample in a double ziploc or sealed bag, inside a cooler box (or similar hard structure). Place the cooler box in an overnight courier bag, express post pack or similar for transport or personal carriage.

Proof: Consignment to be accompanied by CA12 accredited laboratory documentation.

(2) Sending to an approved laboratory
Diagnostic samples must not enter South Australia:
a) Without prior written approval from the Chief Inspector or delegate, and
b) Unless they have been securely package as specified in 5.1 (1).

Proof: Consignment to be accompanied by a Plant Health Import Certificate (PHIC) to be organised by the approved laboratory through Biosecurity SA and a Plant Health Certificate (PHC).

5.2 Sourced from a grapevine or vineyard in a PRZ/PIZ/PIBZ

(1) Sending to a CA12 accredited laboratory
a) Unless 3) below applies, samples to be disinfested by one of the following methods and securely packaged prior to moving out of the PRZ/PIZ/PIBZ:
i. Freezing and then being held at -18ºC for 24 hours and packed with an ice pack for transport.
ii. Freezing and transfer under liquid nitrogen at -196ºC.
iii. Freeze drying.
iv. Oven drying at 45ºC for a minimum of 120 minutes.
Note: Probes must be used with large samples to ensure middle of sample has reached the required temperature for the required time. Bulky samples must be spread out on trays prior to placing in oven to increase surface area exposed to the heat.
v. Hot water treatment at 54ºC ± 1ºC for 5 minutes, or 50ºC ± 1ºC for 30 minutes.
vi. Fixative – devitalisation using formalin/acetic acid, glutaraldehyde, or 70% ethanol.
vii. Gamma irradiation at 50 grays in an approved facility.
viii. For juice samples, either:

- Filter, centrifuge or cold-settle to ensure remaining particles are less than 50 microns in size; or
- Freezing and then being held at -18ºC for 24 hours and packed with an ice pack for transport; and
- Seal in an unbreakable vessel prior to sending.

b) Securely package as specified in 5.1 (1).

Proof: CA12 accredited laboratory documentation and where required by the source state jurisdiction, a Permit for movement out of the origin PRZ/PIZ/PIBZ.

(2) Sending to an approved laboratory
Diagnostic samples must not enter South Australia without prior written approval from the Chief Inspector or delegate and unless they have been:
a) Unless 3) below applies, disinfested prior to moving out of the PRZ/PIZ/PIBZ as specified in 5.2 (1) a).
b) Securely package as specified in 5.1 (1).

Proof: Consignment to be accompanied by a Plant Health Import Certificate (PHIC) to be organised by the approved laboratory through Biosecurity SA and a Plant Health Certificate (PHC)

(3) Where disinfestation prior to moving out of the PRZ/PIZ/PIBZ has been proven to compromise a specific diagnostic test, diagnostic samples must not enter South Australia:
a) Without prior written approval from the Chief Inspector or delegate, and
b) Unless they have been securely packaged as specified in 5.1 (1).

Proof: Consignment to be accompanied by a Plant Health Import Certificate (PHIC) and Plant Health Certificate (PHC).

6. INTERPRETATIONS:

For interpretations that apply to all Conditions, refer to Section 3.
Additional interpretations for words/terms used only in Condition 7 are as listed below:

WORD/TERM	DEFINITION
Crushed fresh grapes (must)	Crushed fresh grapes (must) is the total product of crushing grape berries and includes unclarified juice, skins, seeds, pulp and possibly some stems and leaves.
Destemmer waste from fresh grapes	Also known as ‘stalks and stems’, this is a winery waste of grape bunch stalks (rachis). Commonly a separate waste stream from grape marc where it has arisen from handpicked grapes that are destemmed prior to crushing and/or pressing.
Diagnostic samples	Non-commercial volume of grapes, grapevine material or vineyard soil collected for specific analyses undertaken in a Biosecurity SA approved or accredited laboratory.
Dismantled parts	A term used in association with used grape harvesters to describe all belts (discharge, cross feed, transfer, pick up and elevator belts) and covers or guards that have been designed to completely detach from the frame of the harvester.
Equipment	Equipment is defined as items required to do a given task (excluding machinery) and includes but it is not limited to, any vessel that has held grapes (including grape picking bins, picking buckets, bulk tippers), hand tools (including pruning snips - pneumatic/hydraulic and electric shears, picking snips, shovels, soil corers, dig sticks, technical equipment), trellis posts used in

	vineyard soil, netting, wire, dripper tube, clips and vine guards.
Filtered (processed) juice	Juice that has been processed (filtered, centrifuged, cold settled or other) to a 50-micron filtration rating (or tighter).
Grape marc	Grape material discarded after juice is extracted through pressing of white, rose and sparkling wine styles, and after wine is extracted through pressing of must fermented for at least four days on skins. Consists of grape skins/pulp, seeds, stems (bunch and berry stalks) and unfermented grape juice or wine.
Grape-related materials	Grape-derived materials other than table or wine grapes, including crushed fresh grapes (must) and unfiltered (fresh) juice, filtered juice, wine, grape marc and destemmer waste from fresh grapes.
Lignified	Woody as a result of the deposition of lignin in the cell walls.
Machinery	Machinery is a device that uses energy to perform some activity and is defined as a collection of machines that operate together to perform a task. A machine is generally large, complex and can't be easily cleaned. Machinery includes but is not restricted to, tractors, spray equipment, pruning machines, mechanical grape harvesters, winery crushing and processing machinery, post knockers, post-hole diggers, mechanical augers, trenchers, slashers, forklifts, backhoes, excavators, tillers, seeders and vineyard vehicles used to drive down vine rows.
Phylloxera Management Zone (PMZ)	According to the National Phylloxera Management Protocol, Australian wine regions are classified into three zones for policy, regulatory and management purposes, according to evidence of grape phylloxera presence, absence or unknown (untested) status. These three zones are PEZ or state free of grape phylloxera, PRZ or PIZ. The new PIBZ is now included as a PMZ by South Australia.
Potted vine	Often termed 'green potted vine' or 'spring banded vine' it is a vine that is grown in soil-less media inside a biodegradable paper plant band, peat pot or plastic pot. Typically grown in a greenhouse and supplied as an actively growing plant it can be own-rooted or grafted.
Product (produce) Movement Declaration	Means a declaration form used to verify the details of origin of the consignment of product from a PIZ or PRZ to a PEZ under ICA22 which must accompany the consignment and be provided to the Transport Controller on arrival at the destination winery.
Rootlings	Grapevine plants that have been grown in a nursery so as to develop roots (including callus) and includes grafted rootlings.
Unfiltered (fresh) juice	The liquid fraction from must, excluding skins, seeds and other large solids, but may contain some suspended solids (particle size is greater than 50 microns). Also includes clarified juice not filtered to 50 microns.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 7A: VACANT

CONDITION 8: VACANT

CONDITION 8A: VACANT

TABLE 2 – HOST FRUITS OF MEDITERRANEAN AND QUEENSLAND FRUIT FLIES[1]

A variety of entry criteria apply to such fruits. Those criteria appear after Table 2, which lists the fruits currently, rated as hosts of Mediterranean and Queensland fruit flies:

Plant Common Name	Plant Scientific Name	Mediterranean Fruit Fly	Queensland Fruit Fly
Abiu	*Pouteria caimito*	yes	yes
Acerola	*Malpighia glabra*	yes	yes
Achachairu	*Garcinia humilis*	yes	yes
Apple	*Malus domestica*	yes	yes
Apricot	*Prunus armeniaca*	yes	yes
Avocado	*Persea americana*	yes	yes
Babaco	*Carica pentagona*	yes	yes
Banana	*Musa acuminata*	yes	yes
Blackberry	*Rubus fruiticosus*	yes	yes
Black Sapote	*Diospyros ebenum*	yes	yes
Blueberry	*Vaccinium corymbosum*	yes	yes
Brazil Cherry	*Eugenia uniflora*	yes	yes
Breadfruit	*Artocarpus altilis*	yes	no
Caimito / Star Apple	*Chrysophyllum cainito*	yes	yes
Cape Gooseberry	*Physalis peruviana*	yes	yes
Capsicum	*Capsicum annuum var. grossum*	yes	yes
Carambola / Star Fruit	*Averrhoa carambola*	yes	yes
Cashew Apple	*Anacardium occidentale*	yes	yes
Casimiroa	*Casimiroa edulis*	yes	yes
Cherimoya	*Annona cherimolia*	yes	yes
Cherry	*Prunus avium*	yes	yes
Chilli	*Capsicum annuum var. acuminatum*	yes	yes
Citron	*Citrus medica*	yes	yes
Coffee berry	*Coffea* species	yes	yes
Custard Apple	*Annona squamosa*	yes	yes
Date (fresh)	*Phoenix dactylifera*	yes	yes
Dragon Fruit	*Hyloscereus undatus*	yes	yes
Durian	*Durio zibethinus*	yes	yes
Eggplant	*Solanum melongena*	yes	yes
Feijoa	*Feijoa sellowiana*	yes	yes
Fig	*Ficus carica*	yes	yes
Gourd, Bitter / Bitter Melon	*Momordica charantia*	yes	yes
Gourd, Bottle / Long Melon	*Langenaria siceraria*	yes	yes
Granadilla	*Passiflora quadrangularis*	yes	yes
Grapefruit	*Citrus paradisi*	yes	yes
Grapes	*Vitis* species	yes	yes
Grumichama / Brazil Cherry	*Eugenia braziliensis*	yes	yes
Guava	*Psidium* species	yes	yes
Hog Plum	*Spondias mombin*	yes	yes
Jaboticaba	*Myrciaria cauliflora*	yes	yes
Jackfruit	*Artocarpus heterophyllus*	yes	yes
Jambu	*Syzygium cumini*	yes	no
JuJube	*Ziziphus* spp	yes	yes
Kiwifruit	*Actinidia deliciosa*	yes	yes
Kumquat	*Fortunella japonica*	yes	yes

[1] Host fruits of fruit flies are specified in the Ministerial Notice pursuant to Section 7 of the *Plant Health Act, 2009* reproduced here for ease of access.

Plant Common Name	Plant Scientific Name	Mediterranean Fruit Fly	Queensland Fruit Fly
Lemon	*Citrus meyeri (Also Citrus limon x citrus chinese)*	yes	yes
Lime - West Indian Lime	*Citrus aurantiifolia*	yes	yes
Lime - Tahitian Lime	*Citrus latifolia*	yes	yes
Lime - Rangpur Lime	*Citrus reticulata var. austera*	yes	yes
Lime – Finger Lime	*Citrus australasica*	yes	yes
Loganberry	*Rubus loganobaccus*	yes	yes
Loofa, Smooth	*Luffa cylindrica*	yes	no
Loofa, Angled / Ridged / Sinquar	*Luffa acutangula*	yes	no
Loquat	*Eriobotrya japonica*	yes	yes
Longan	*Euphoria longan*	yes	yes
Lychee	*Litchii chinensis*	yes	yes
Mandarin	*Citrus reticulata*	yes	yes
Mango	*Mangifera indica*	yes	yes
Mangosteen	*Garcinia mangostana*	yes	yes
Medlar	*Mespilus germanica*		
Mulberry	*Morus nigra*	yes	yes
Nashi	*Pyrus pyrifolia var. culta*	yes	yes
Nectarine	*Prunus persicae var. nectarina*	yes	yes
Olive	*Olea europaea*	yes	yes
Orange	*Citrus aurantium, Citrus sinensis*	yes	yes
Passionfruit	*Passiflora spp.*	yes	yes
Papaw	*Carica papaya*	yes	yes
Peach	*Prunus persica*	yes	yes
Peacharine	*Prunus nucipersica*	yes	yes
Pear	*Pyrus communis*	yes	yes
Pepino / Melon Pear	*Solanum muricatum*	yes	yes
Persimmon	*Diospyros kaki*	yes	yes
Plum	*Prunus domestica*	yes	yes
Plumcot	*Prunus domestica x Prunus armeniaca*	yes	yes
Pomegranate	*Punica granatum*	yes	yes
Prickly Pear	*Opuntia stricta or O. ficus indica*	yes	yes
Pummelo	*Citrus grandis*	yes	yes
Quandong	*Santalum acuminatum*	yes	yes
Quince	*Cydonia oblonga*	yes	yes
Rambutan	*Nephelium lappaceum*	yes	yes
Raspberry	*Rubus idaeus*	yes	yes
Rollinia	*Rollinia deliciosa*	yes	yes
Rose Apple / Wax Jambu	*Syzygium jambos*	yes	yes
Santol	*Sandoricum indicum*	yes	yes
Sapodilla	*Manilkara zapota*	yes	yes
Sapote	*Sapote*	yes	yes
Soursop	*Annona muricata*	yes	yes
Star Fruit	*Averrhoa carambola*	yes	yes
Strawberry	*Fragaria ananassa*	no	yes
Sweetsop	*Annona squamosa*	yes	yes
Tamarillo	*Cyphomandra betacea*	yes	yes
Tangelo	*Citrus reticulata x C. paradisi*	yes	yes
Tangor	*Citrus reticulata × C. sinensis*	yes	yes
Tomato	*Lycopersicon esculentum*	yes	yes
Wax jambu / Water Apple	*Syzygium samarangense*	yes	yes
Winter Melon / Hairy Melon, Winter Gourd, White Gourd,	*Benincasa hispida*	yes	yes

Yes = is a host of either Mediterranean or Queensland fruit fly and requires certification
No = not a host of either Mediterranean or Queensland fruit fly fruit fly.

CONDITION 9: AREA FREEDOM FROM FRUIT FLIES / SECURE TRANSPORTATION

Note: Produce certified under the below condition is accepted for movement into the Riverland Pest Free Area.

1. Fruit fly host fruit listed in the Ministerial Notice (Annex 2) from a State declared free from fruit flies and having a current valid State Freedom certificate for fruit fly may enter South Australia uncertified for fruit fly provided it also meets the following;.

1.1 Fruit fly host produce (other than wine grapes) that passes through areas not declared free from fruit fly must transit in secure conditions as follows;

(1) Enclosed within a vehicle, container etc., or

(2) If not enclosed, in fly-proof packaging, shrink-wrapped or covered (lids or tarpaulins) that will prevent entry of fruit fly.

(3) Fruit fly host produce from a fruit fly free area must be kept separated from any produce from an area not declared fruit fly free.

Proof: Current State Freedom Certificate (available on DCWG share-point) or accompanied by a Plant Health Assurance Certificate (ICA23) or a Plant Health Certificate.

2. Fruit fly host fruit grown andr packed in States without State Freedom but in an area declared free from fruit flies must comply with 1.1 above and provide certification verifying property or area freedom.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA23).

3. Fruit fly hosts not able to meet 1 or 2 above must be certified to meet other fruit fly entry requirements of this standard.

4. Fruit fly hosts certified under an approved condition for entry into South Australia and either repacked after treatment or re-consigned into the State must be managed under secure conditions.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA17 or ICA57).

Note:

Area free status is determined in accordance with Australia's national fruit fly management agreements.

In accordance with the same agreements area freedom will be lost following the declaration or commencement of a fruit fly outbreak.

If area freedom cannot be verified, the host produce must comply with the procedures outlined in Conditions 10 to 14 below before it can be brought into the State.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 10: HARD GREEN OR SIMILAR CONDITION FOR FRUIT FLY

Note: For the purpose of excluding fruit flies from the Riverland Pest Free Area, only produce listed in clause 1 below are accepted for the entry into the Riverland Pest Free Area.

Produce defined under clause 2 of this condition are **strictly prohibited** from entering the Riverland Pest Free Area under this condition.

This provision recognises that certain fruits are susceptible to fruit fly attack when past a certain stage of maturity and/or their surface has been damaged. Fruits entering under this requirement must have been certified by a departmental inspector or by an authorised signatory operating under an approved Interstate Certification Assurance Arrangement at the time of packing.

This procedure is necessary to ensure that fruit is at a stage of maturity and / or free from damage to ensure that the risk of fruit fly attack is unlikely. Secure transportation requirements apply – see **Condition 9** (1.1)

1. The following fruits are acceptable for the movement into South Australia including the Riverland Pest Free Area:

1.1 Avocados –
For **Queensland fruit fly**; the varieties **Hass and Lamb Hass and**
For **Mediterranean fruit fly; the varieties Fuerte, Hass, Lamb Hass, Reed and Sharwil;** must have been harvested in a hard condition and have been stored in secured conditions within 48 hours of harvest (ICA30).

1.2 **Babaco** must be hard **and** may show no more than 25% of colour over their surface at the time of inspection and packaging (ICA08).

1.3 **Bananas** - must be mature green with unbroken skin at the time of inspection and packaging (ICA06/ICA16).

1.4 **Black Sapote** (Queensland fruit fly only) must be green (skin free of any black colouring) with unbroken skin at the time of inspection and packaging (ICA15).

1.5 **Durians, Jaboticaba, Jackfruit, Longans, Lychees, Mangosteens, Pomegranates and Rambutans** (Queensland fruit fly only) must be firm with unbroken skin at the time of inspection and packaging (ICA13).

1.6 **Tahitian limes** (Queensland fruit fly only) must be in a mature green condition (free of any yellow colouring) with unbroken skin at the time of inspection and packaging (ICA15).

Note: Unbroken Skin means the skin has no pre-harvest crack, puncture, pulled stem or other break that penetrates through to the flesh and has not healed with callus tissue.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate

2. The following fruit are accepted for entry into South Australia, however not accepted for entry into the Riverland Pest Free Area:

2.1 **Achachairu** (Queensland fruit fly only) must be firm with unbroken skin at the time of inspection and packaging (ICA13).

2.2 **Papaws (non-defective flowering type)** must be hard **and** may show no more than 25% of colour over their surface at the time of inspection and packaging (ICA08).
Where the papaw is non-defective flowering type, the words “Non-defective Flower Type” must appear clearly on the certification.

2.3 **Papaws (defective flowering type)** must be hard, may show no more than 25% of colour over their surface at the time of inspection and packaging **and be fumigated** (ICA08).
Where the papaw is defective flowering type, the words, “Defective Flower Type” must appear clearly on the certification.

2.4 **Passionfruit (purple types only /** (Queensland fruit fly only) must be unwrinkled with unbroken skin at the time inspection and packaging (ICA15).

2.5 **Tomatoes** (Mediterranean fruit fly only) must be in a mature green condition with no more than a 2 cm diameter of pink colouring at the stylar end ("breaker" stage) and no unbroken skin at the time of inspection and packaging (ICA15).

Note: Unbroken Skin means the skin has no pre-harvest crack, puncture, pulled stem or other break that penetrates through to the flesh and has not healed with callus tissue.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate

Secure transportation requirements apply – see **Condition 9** (1.1).

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 11: DISINFESTATION BY COLD STORAGE

Note: Produce treated under the below treatment method is accepted for movement into the Riverland Pest Free Area.

1. Queensland Fruit Fly

Applicable fruits are:

Kiwifruit, citrus fruit, pome fruits, stone fruits, blueberries and any other fruits that are unaffected by the treatment.

These must have been held under one of the following ranges and duration in terms of centre core flesh temperature:

1.1 0.0°C ± 0.5°C for at least 14 days or

1.2 1.0°C to 3.0°C ± 0.5°C for at least 16 days (lemons 14 days)

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA07).

2. Mediterranean Fruit Fly

Applicable fruits are:

Kiwifruit, pome fruits and stone fruits, and other fruits including all citrus, which are not affected by these temperature/time regimes.

These must have been held under one of the following ranges and duration in terms of centre core flesh temperature:

2.1 0.0°C ± 0.5°C for at least 14 days or

2.2 1.0°C ± 0.5°C for at least 16 days (lemons at least 14 days) or

2.3 2.0°C ± 0.5°C for at least 18 days (lemons at least 16 days) or

2.4 3.0°C ± 0.5°C for at least 20 days (lemons at least 18 days)

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA07).

Notes:

Some fruits may be damaged by this treatment. A trial treatment is recommended unless the response of the fruit to this treatment is known.

A minimum of three sensors/probes, two for centre core flesh and one for air temperature are to be used for the first 250 cubic metres of fruit or less. For each additional 250 cubic metres or part thereof, one additional centre core flesh sensor is to be used.

In all instances the cold storage chamber must be capable of sustaining the stated temperatures throughout the prescribed periods and records must be available to the supervising Department to ensure that the temperatures and times requirements have been met.

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12: DISINFESTATION USING DIMETHOATE - QUEENSLAND FRUIT FLY

Note: Produce treated under the below treatment method is accepted for movement into the Riverland Pest Free Area.

Fruit fly host produce may be treated in accordance with one or more of the following;

1. Application by Dipping

1.1 **Dimethoate:** All host fruits specified by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for post-harvest dip treatment and used in accordance with label instructions or APVMA permits for minor use for Queensland fruit fly.

Note; Mangoes treated under this condition must also meet the treatment and inspection requirements stipulated under clause 3 below.

Note; Custard Apples treated under this condition must also meet the treatment and inspection requirements stipulated under clause 4 below).

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA01)

2. Application by Flood Spraying

2.1 **Dimethoate:** All host fruits specified by the APVMA for post-harvest flood spray treatment and used in accordance with label instructions or APVMA permits for minor use for Queensland fruit fly.

Note; Mangoes treated under this condition must also meet the treatment and inspection requirements stipulated under clause 3 below.

Note; Custard Apples treated under this condition must also meet the treatment and inspection requirements stipulated under clause 4 below).

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA02)

Note: Dipping or spraying should be the last treatment before packing except where a non-recovery gloss coating (wax) is applied to citrus. This treatment must be applied not less than 60 seconds after treatment.

3. Mangoes – Systems Approach – CTM01

All cultivars of mangoes are required to be class one quality fruit subject to the below conditions of an approved ICA/CA arrangement (CTM01), which utilises a systems approach to provide an adequate level of security against Queensland fruit fly:

3.1 Harvested in a hard mature condition (unripe / ripeness stage 0 – Hard with ‘no give’ when held in hand and firm pressure is applied with the ball of thumb - see picture below) consistent with the mango industry standard,

AND

3.2 an approved post-harvest treatment,

AND

3.3 inspection to verify hard mature condition, class one quality and freedom from fruit fly.

These requirements can also be met through a systems approach ICA/CA arrangement approved by Biosecurity SA. See condition 12A.

How to Test Ripeness of Mango
0 Ripeness = “No Give” / Flesh doesn’t give at all to firm pressure applied by thumb.

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate (CTM01)

4. Custard apples and Other Annona SPP – Systems Approach – ICA18

4.1 **Custard apples and other *Annona* spp** are required to be subject to the conditions of an approved ICA arrangement, which utilises a systems approach to provide an adequate level of security against Queensland fruit fly. This involves a combination of pre-harvest treatment, post-harvest inspection and post-harvest treatment.

Proof: Accompanied by a Plant Health Certificate Assurance Certificate (ICA18)

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12A: MANGOES – PRE-HARVEST SYSTEMS APPROACH - MANGOES

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. Mangoes – Systems Approach – CTM01

All cultivars of mangoes are required to be class one quality fruit subject to the below conditions of an approved ICA/CA arrangement (CTM01), which utilises a systems approach to provide an adequate level of security against Queensland fruit fly:

1.1 Harvested in a hard mature condition (unripe / ripeness stage 0 – Hard with 'no give' when held in hand and firm pressure is applied with the ball of thumb - see picture below) consistent with the mango industry standard,

AND

1.2 an approved pre-harvest treatment

All other Cultivars – approved pre-harvest treatment.

AND

1.3 inspection to verify hard mature condition, class one quality and freedom from fruit fly.

These requirements can also be met through a systems approach ICA/CA arrangement approved by Biosecurity SA.

How to Test Ripeness of Mango
0 Ripeness = "No Give" / Flesh doesn't give at all to firm pressure applied by thumb.

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate (CTM01)

Secure transportation requirements apply – see **Condition 9** (1.1).

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12B: PRE HARVEST FIELD CONTROL AND INSPECTION OF STRAWBERRIES

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. Strawberry fruit are required to be subjected to the conditions of an approved ICA Arrangement (ICA34), which utilises a systems approach of a specified combination of pre-harvest field treatment and post-harvest inspection to provide an adequate level of security against Queensland fruit fly.

2. The provisions of ICA34 apply only to the South East Queensland* region for in-ground strawberry production. It provides for a pre-harvest bait spraying treatment for fruit harvested up to 10 August and a pre-harvest cover spray treatment after 10 August each year, and

3. South East Queensland are those parts of Queensland South of Pomona to the state border with NSW i.e. south of latitude 26.349° and east of longitude -152.283°.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA34).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12C: VACANT

Vacant

CONDITION 12D: PRE-HARVEST TREATMENT AND INSPECTION OF POME FRUIT, PERSIMMON AND BLUEBERRY FRUIT – SYSTEMS APPROACH

Notes:

- For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under this Condition is **strictly prohibited** from entry into the Riverland Pest Free Area.
- This Condition and associated assurance scheme, ICA21, is not accepted for the treatment and certification of **stone fruit**

1. To provide an adequate level of security against Queensland fruit fly pome fruit, persimmon and blueberry fruit must receive a specific combination of pre-harvest treatment and post-harvest inspection utilising a systems approach.

2. The required treatments and inspections will be the conditions of an approved ICA Arrangement (ICA21).

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA21).

Secure transportation requirements apply- see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12E: WINE GRAPES SECURE TRANSPORTATION – SYSTEMS APPROACH

Note: The below condition is recognised as an approved processing system for movement into the Riverland Pest Free Area.

Wine grapes – all varieties are required to be subjected to the conditions of an approved ICA Arrangement (ICA33) which utilises a systems approach to provide an adequate level of security against Queensland fruit fly and Mediterranean fruit fly. This involves a combination of spillage prevention whilst in transport and processing within 24 hours upon arrival at the designated winery.

1. All wine grape varieties which have originated from a fruit fly endemic area or from within a fruit fly suspension area must be certified stating their origin; **and**

2. The wine grapes must be dispatched to South Australia under conditions that prevent spillage during transportation (see note below).

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA33).

Note: *The wine grapes have been contained with covers applied or loaded to a level that must prevent any spillage during transport to the designated winery.*

For grapes that originate from a fruit fly endemic area, within a fruit fly outbreak area or fruit fly suspension area, the receiving winery must be both accredited as an importer and under the Import Verification Compliance Arrangements (IVCA), and have in place a system for the management of any spillage and waste generated during the crushing processes.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12F: PRE-HARVEST TREATMENT AND POST-HARVEST INSPECTION OF TABLE GRAPES – SYSTEMS APPROACH

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. Table grapes are required to be subjected to the conditions of an approved ICA Arrangement (ICA20), which utilises a systems approach to provide an adequate level of security against Queensland fruit fly. This involves a specified combination of pre-harvest treatment and post harvest inspection.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA20).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12G: PRE-HARVEST TREATMENT AND POST-HARVEST INSPECTION OF TOMATOES (MEDITERRANEAN FRUIT FLY AND QUEENSLAND FRUIT FLY), CAPSICUMS, CHILLIES AND EGGPLANT (QUEENSLAND FRUIT FLY) –SYSTEMS APPROACH

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. To provide an adequate level of security against Queensland fruit fly Tomatoes, Capsicums, Chillies and Eggplant are required to be subjected to the conditions of an approved ICA Arrangement (ICA26), which utilises a systems approach involving a specified combination of pre-harvest treatment and post harvest inspection.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA26).

2. To provide an adequate level of security against Mediterranean fruit fly Tomatoes are required to be subjected to the conditions of an approved ICA Arrangement (ICA26), which utilises a systems approach involving a specified combination of pre-harvest treatment and post harvest inspection.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA26).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12H: PRE-HARVEST TREATMENT AND INSPECTION OF CITRUS – SYSTEMS APPROACH

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. To provide an adequate level of security against Queensland fruit fly Citrus fruit (Eureka and other true lemon varieties except Meyer all cultivars of mandarins, tangors, oranges, limes and grapefruit) are required to be subjected to;

1.1 a specified combination of pre-harvest bait spraying treatment and post harvest inspection provided by the conditions of an approved ICA Arrangement (ICA28) utilising a systems approach, and

1.2 This provision applies only to the Central Burnett area of Queensland for citrus fruit harvested from 1 March to 25 August.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA28).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12I: VACANT

Vacant

CONDITION 12J: SYSTEM APPROACHES FOR PEST FREE PLACE OF PRODUCTION - QUEENSLAND FRUIT FLY (CA14 / CA01 - NSW), (PS37 / PS38 - VIC)

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

Host produce grown within a Pest Free Place of Production (PFPP) are required to be subjected to the conditions of an approved ICA Arrangement (ICA) or Compliance Arrangement (CA), whereby an accredited business utilises a systems approach to provide an adequate level of security against Queensland fruit fly and must be approved by the Chief Inspector. The following are approved arrangements;

1. CA01 is such an approved scheme involving a specified combination of monitoring and inspection and the procedure only applies for the following Biosecurity SA approved NSW properties:

- Tomatoes only from the business named within CA01 - Guyra Procedure

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (CA01).

2. CA14 is such an approved scheme involving a specified combination of monitoring and inspection and the procedure only applies for the following Biosecurity SA approved NSW properties:

- Blueberries only from the business named within CA14 - Tumbarumba Procedure

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (CA14).

3. PS37 is such an approved scheme involving a specified combination of monitoring and inspection and the procedure only applies for the following Biosecurity SA approved Victorian properties:

- Host produce from a PS37 accredited business within the Yarra Valley

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (PS37).

4. PS38 is such an approved scheme involving a specified combination of monitoring and inspection and the procedure only applies for the following Biosecurity SA approved Victorian properties:

- Tomatoes only from a PS38 accredited business – Flavorite
- Strawberries only from a PS38 accredited Portland business – Portland Strawberries
- Blueberries only from a PS38 accredited Gellibrand business – Otway Blueberries

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (PS38).

5. A systems approach approved by the Chief Inspector for the purpose of contributing to the development of phytosanitary market access systems for the interstate trade of plants and plant products.

Proof: Written approval from the Chief Inspector or delegate and accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12K: SYSTEM APPROACHES FOR SPECIFIED REGIONS OF PRODUCTION

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce treated and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area.

1. To provide an adequate level of security against Queensland fruit fly Tomatoes and capsicums grown within a Specified Region of Production are required to be subjected to the conditions of an approved ICA Arrangement (ICA) or Compliance Arrangement (CA), whereby an accredited business utilises a systems approach and must be approved by the Chief Inspector.

2. ICA48 is such an approved scheme involving a specified combination of pre-harvest treatment and inspection and the procedure only applies for properties approved for the following:

2.1 Tomatoes and capsicums only from an ICA48 accredited business within the approved Bowen Gumlu region of Queensland.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate ICA48).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 12L: SPECIFIED PRODUCTION SYSTEMS

Note: For the purposes of excluding fruit flies from the Riverland Pest Free Area, produce handled and certified under the below condition is **strictly prohibited** from entry into the Riverland Pest Free Area without written approval from the Chief Inspector.

Diced or prepacked host fruits prepared in a manner where the process follows specified production systems or approved quality assurance programs providing an adequate level of security against Queensland or Mediterranean fruit fly.

1. Hosts may be subject to the conditions of Specified Production Systems under Compliance Arrangement (CA) or ICA Arrangement; or

2. Specified production systems approved by the Chief Inspector.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 13: DISINFESTATION BY METHYL BROMIDE FUMIGATION

Note: Produce treated under the below treatment method is accepted for movement into the Riverland Pest Free Area.

Mangoes and plums are no longer allowed entry into South Australia under this condition if being treated for Queensland fruit fly (QFF).

This Condition applies to all Queensland fruit fly (QFF) host material and all Mediterranean fruit fly (MFF) host material for which Methyl Bromide is an accepted treatment, as specified in the Index of Conditions of Entry / Regulated Movement in Section 4 of this Standard.

1. Fruit fly host material may be fumigated by a licensed fumigator at the following pulp temperatures and rates:

1.1 To treat for Queensland fruit fly:

(1) 17°C – 20.9°C @ 40 g/m3 for 2 hrs; or

(2) 21°C - 31.9°C @ 32 g/m3 for 2 hrs;

1.2 To treat for Mediterranean fruit fly:

(1) 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

(2) 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

(3) 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

(4) 21°C - 31.9°C @ 32 g/m3 for 2 hrs.

And

2. Fruit core temperature must be verified in accordance with the following:

2.1 The temperature must be measured by placing the tip of the temperature probe into the centre of a piece of fruit located in the middle of a carton;

2.2 At least three temperature readings must be taken from each bin or pallet or lot on each pallet.

(1) Where the lot is on a pallet, at least three different cartons in a lot must be inspected, including samples taken from:

a) One from the top of the pallet;

b) One from the centre/inside/middle of the pallet; ***and***

(2) Where the lot is in a bin, at least three different samples readings must be taken from each bin, including samples taken from:

a) One from the top of the bin;

b) One from the centre/inside/middle of the bin; ***and***

2.3 In addition to three readings specified in 2.2 above, a further three readings must be taken for each commodity in the pallet, lot on a pallet or bin that is either a different fruit variety or supplied by a different grower and/or packer.

And

3. Fumigant loading rates for fruits and vegetables are not less than 30%, nor more than 50%, of the volume of the chamber when empty and the total load of produce being treated in the chamber (including anything else in the chamber contributing to the total load) must be specified in cubic metres on the plant health certification,

And

4. The fumigator ensures produce packaged or covered with impervious materials (such as plastic bags, stacked plastic punnets or waxed paper), are opened, cut or removed to allow adequate penetration of the gas unless impervious materials contain:

4.1 not less than four unobstructed perforations of 6mm diameter per 100cm²; or

4.2 five unobstructed perforations of 5mm diameter per 100cm²; or

4.3 numerous pinholes (at least 6 holes per square centimetre).

And

5. If treating for Queensland fruit fly, a pre-treatment fruit fly inspection must occur per chamber load for high-risk commodities as identified below:

5.1 The inspection must be undertaken by an Authorised Inspection Person trained and with proven competence in the identification of fruit fly damage, eggs and larvae; ***and***

5.2 Where citrus fruits are present in the chamber load, a 600 piece inspection must be completed ensuring an even distribution of fruit is inspected proportionate across all varieties and growers and/or packers represented in the chamber load; ***and***

5.3 Where stone fruits (other than plums) are present in the chamber load, a 600 piece inspection must be completed ensuring an even distribution of fruit is inspected proportionate across all varieties and growers and/or packers represented in the chamber load; ***and***

5.4 Where chillies are present in the chamber load, a 600 piece inspection must be completed ensuring an even distribution of fruit is inspected proportionate across all varieties and growers and/or packers represented in the chamber load; ***and***

5.5 Any fruit showing signs of fruit fly infestation must be cut and examined for presence of fruit fly; ***and***

5.6 The Authorised Inspection Person endorses that the fruit is free of live fruit fly; ***and***

5.7 All fruit of the same variety, sourced from the same grower and/or packer as one confirmed to have fruit fly damage does not qualify for treatment and those packages must be rejected; ***and***

5.8 All other produce from the same grower and/or packer of the non-conforming lot must be rejected for treatment for that day, regardless of variety, but excluding already treated produce.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA04).

Note: *Some fruits may be damaged by this treatment. A trial treatment is recommended unless the response of fruits to this treatment is known.*

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 14: DISINFESTATION BY IRRADIATION

Note: Produce treated under the below treatment method is accepted for movement into the Riverland Pest Free Area.

Applies to fruit and vegetables for which Food Standards Australia New Zealand (FSANZ) has approved the use of irradiation. For further information consult the FSANZ website http://www.foodstandards.gov.au

1. For fruit fly host material applicable fruits to be treated to achieve a minimum absorbed dose of 150 gray.

2. For all plant pests of the class *Insecta* except pupae and adults of the order Lepidoptera to be treated to achieve a minimum absorbed dose of 400 gray.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA55).

Secure transportation requirements apply – see **Condition 9** (1.1)

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 15: MAIZE SEED (INCLUDES POPCORN AND SWEET CORN VARIETIES FOR SOWING)

Viable seed of *Zea spp.* produced in States where Boil Smut of maize has been detected must not enter South Australia unless it has been:

Either

1. Grown in an area where *Ustilago maydis* (boil smut of maize) is not known to occur and the crop was inspected prior to harvest and found to be free of the disease; **and**

2. Cleaned, graded and packed in premises that have not been used for processing seed affected with the disease;

Or

3. Treated with Vitavax 200FF fungicide or equivalent in accordance with the manufacturer's instructions.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 16: MELONS AND OTHER HOSTS OF MELON THRIPS (*THRIPS PALMI)*

1. Melon thrips host produce grown or packed in Northern Territory, Queensland, Western Australia and certain parts of north eastern New South Wales that are within 100km radius of a known infestation of melon thrips must not enter South Australia unless:

1.1 from a property granted freedom from Thrips palmi status through an approved monitoring system as set out below in part 6.1 or 6.2 of the Protocol for Melon thrips; or

1.2 Inspected at the approved sampling rate as set out in part 6.4 of the Protocol for Melon thrips **(ICA38)**; or

1.3 The produce has been fumigated with methyl bromide at rates given in part 6.5 of the Protocol for Melon thrips **(ICA04)**; or

1.4 The produce has been post-harvest washed as required in part 6.6 of the Protocol for Melon thrips.

2. Produce grown or packed in New South Wales, Northern Territory, Queensland and Western Australia greater than 100 km radius of known infested areas can enter South Australia subject to proof of origin certification indicating where the produce was grown.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA 38)

3. Produce grown greater than 100 km radius of known infested area and the area has a valid Area Freedom Certificate issued by an officer of the relevant jurisdiction as result of ongoing surveillance, can enter South Australia accompanied by a Melon Thrips Declaration of Source (see Appendix 14).

Proof: Accompanied by a Melon Thrips Declaration of Source (Appendix 14).

Note: *Melon thrips is known to occur in parts of Northern Territory, Queensland, and Western Australia. Some production areas in north eastern New South Wales are within 100 km radius of areas in Queensland where melon thrips is known to occur.*

Melon thrips host produce subject to entry restrictions are melons, beans, capsicum, chilli, cucurbits, choko, cucumber, dragon fruit, eggplant, okra, peas, pumpkin, silver beet, squash, tobacco, tomato and zucchini.

PROTOCOL FOR MELON THRIPS

4. Locations Subject to Restrictions

4.1 Produce grown or packed in Northern Territory, Queensland, Western Australia and certain parts of north eastern New South Wales and are within 100 km of a known infestation of melon thrips are subject to the restrictions in this protocol.

4.2 Checks for new infestations must be continued by:

(1) Examining badly blemished and distorted produce at markets.

(2) Investigating suspect infestations reported by growers.

(3) Monitoring the margins of infested areas to detect spread.

(4) Checking major production areas of cucurbits, eggplant and capsicums for symptoms of melon thrips.

4.3 A property that has been infested is considered to be no longer infested if it has been found free of melon thrips for 6 months prior to export to South Australia using the

monitoring procedure in 7.2 for "50km property freedom". The crop previously planted will determine the number and location of traps, and the traps read one week in each month.

5. Produce Subject to Entry Restrictions

Beans, capsicums, chilli, cucurbits, choko, cucumber, dragon fruit, eggplant, melons, okra, peas, pumpkin, silver beet, squash, tobacco, tomato and zucchini.

6. Entry Restrictions

6.1 Area Freedom

Produce grown and packed in an area free of melon thrips as demonstrated by monitoring performed by the Department of the exporting State:

(1) The area is to be monitored with a minimum of 20 traps spread over a minimum of 5 properties for an area of 100 km radius. Smaller areas can be monitored with a proportional number of traps down to a minimum of 10 traps spread over a minimum of 2 properties for a 50 km radius area.

(2) Each monitored property is initially inspected at 10 or more sites examining crop or weed hosts with a hand lens or by beating leaf samples to separate out thrips.

(3) Initial monitoring is for one week to confirm freedom. Monitoring is continued at the following frequencies during the harvest period to maintain melon thrips free status –

a) **Field Production**

Tropical areas: fortnightly, for all months of the year
Temperate areas: monthly from 1 March to 31 August and fortnightly from 1 September to 28 February.

b) **Glasshouse or greenhouse with temperature above ambient in winter**

All areas: fortnightly for all months of the year.

(4) Trapping involves the use of flat, sticky traps, with an area of 250-300 square centimetres, coloured royal blue, and located within, or at the margins of a host crop or weed area, facing into the prevailing wind.

(5) All exporting properties in the area are within 50km of a monitored property.

(6) No properties in the area are within 50km of a known infestation.

6.2 50km Property Freedom

Produce grown on a property free of melon thrips as demonstrated by:

(1) The property is more than 50km from a known infestation.

(2) The property is initially inspected by the Department in the exporting state at 10 or more sites by examining crop or weed hosts with a hand lens or by beating leaf samples to separate out thrips.

(3) The property is then monitored by the Department in the exporting state with one trap per 200m length of exposure of susceptible crop to the prevailing wind to a maximum of 4 traps.

(NT and Queensland consider that one trap per property is sufficient for 50km freedom. NT will provide data when available).

(4) Initial monitoring is for two weeks to confirm freedom. Monitoring is continued during the harvest period at the following frequencies.

a) **Field Production**

Tropical areas: weekly for all months of the year.
Temperate areas: fortnightly from 1 March to 31 August and weekly from 1 September to 28 February.

b) **Glasshouse or greenhouse with temperature above ambient in winter**

All areas: weekly for all months of the year.

Note: *This condition is needed to allow produce to be moved interstate from isolated properties where monitoring of five properties within a 100km radius area is not practicable. Also, under the fees system operating in Queensland, individual properties need to be able to pay for monitoring on their own properties without being dependent on the same thing being in place for other properties within in the same district. Monitoring on the actual property on which produce is grown is a much more precise indicator of freedom than monitoring on properties up to 50km away as permitted under Area Freedom.*

6.3 5km Property Freedom

Not accepted.

6.4 Inspected and found Free

(1) Hosts that that have been inspected at the international sampling rate **(600 piece or 2%)** under ICA38 or by a Departmental inspector and found free of melon thrips. Inspections can be made during sizing and packing or on packed lots; **or**

(2) Melons and pumpkins from blocks that have been inspected by the Department prior to harvest. Inspections are made at a minimum of 50 sites at random per 5 ha. At each site a young leaf that has just recently reached full size is inspected. Certificates issued are valid for produce loaded that day or the following day.

6.5 Methyl Bromide Fumigation

(1) Produce or plants that have been fumigated with methyl bromide for two hours at a fumigation rate and temperature specified below. There should be an 80% retention of the methyl bromide concentration at the end of the fumigation period.

Fumigation temperature (°C)	Methyl bromide concentration (grams per cubic metre)
11-15	48
16-20	40
21-25	32
26-30	24
31 or over	16

6.6 Post-harvest Washed

(1) Produce that has been dipped or flood sprayed in an approved manner to remove and/or kill thrips. Approvals to date are:

a) Tomatoes with the calyx removed that have been flood sprayed on rotating brushes during an approved fruit fly treatment.

b) Tomatoes, beans, chillies, cucumbers, zucchini, squashes, pumpkins, smooth skinned or champagne melons and rockmelons that have been

washed by hand in water plus detergent* or if calyx removed wash-treated by rolling brushes^ in water applied by flood spraying so that the entire surface of each fruit is thoroughly wetted, brushed and rinsed in clear water.

Proof: Plant Health Certificate or a Plant Health Assurance Certificate.

Note * A detergent or wetting agent suitable for use on food produce.
^ Rolling brushes shall equate to either flood spraying at 16L/min, heavily agitated water or commercial produce scrubbers

Note: – *Interstate Certification Assurance*

The manager or an authorised person of a business approved by the Department in the exporting State on the basis that the business:

1. *Has property or area freedom from melon thrips*
2. *Maintains an Interstate Certification Assurance System covering the entry conditions and crops affected by this melon thrips protocol that is regularly audited by the Department and found acceptable.*
3. *Is acceptable to the Chief Inspector, South Australia*

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 17: TOMATO POTATO PSYLLID (TPP) (*BACTERICERA COCKERELLI*) AND ZEBRA CHIP (CLSO) (*CANDIDATUS LIBERIBACTER SOLANACEARUM*)

With the exception of dried plants, seed (other than potato), mulch, timber, chaff and hay the entry into South Australia of the following:

- Category 1
  all *Solanaceous* and *Convolvulaceae* plants, plant material (including fruit and vegetables for consumption), cut flowers and potatoes (seed and ware),
- Category 2
  All other plants and plant material (including fruit and vegetables for consumption) and cut flowers but excludes dormant trees without foliage/fruit and excludes fresh fruit/vegetables without leaves, green calyx or other attached green material,
- Machinery and equipment used in association with the production or manipulation of category 1 or category 2 plants and plant material,

is prohibited unless in compliance with one of the following requirements:

1. The plants or plant material were grown on or sourced from a property (or for machinery or equipment continuously located on the property for the past 12 months) located in a State or Territory for which an area freedom certificate, approved by the Chief Inspector and issued by an officer responsible for agriculture for the State or Territory where the plants or plant material were grown or sourced, is currently in force certifying that all of the State or Territory is known to be free from

1.1 Tomato potato psyllid and Candidatus Liberibacter solanacearum OR

1.2 Candidatus Liberibacter solanacearum only, in the case of potato (*Solanum tuberosum*) tubers free of shoots, stems, leaves, stalks or any other green plant material and TPP (refer 3.3 below)

Proof: No certification; however documentation that verifies origin may be requested on entry.

2. The plants or plant material were grown on or sourced from a property (or for machinery or equipment continuously located on the property for the past 12 months) located in a part of a State or Territory for which an area freedom certificate, approved by the Chief Inspector and issued by an officer responsible for agriculture for the State or Territory where the plants or plant material were grown or sourced, is currently in force certifying that part of the State or Territory is known to be free from Tomato potato psyllid and Candidatus Liberibacter solanacearum,

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate or the Biosecurity SA Tomato potato psyllid Declaration of Source (Appendix 11).
The Biosecurity SA Tomato potato psyllid Declaration is shown in Appendix 11 or available at www.pir.sa.gov.au/forms

3. Treatment and Inspection

3.1 Nursery Stock / Plants / Cut Flowers (also see 3.4)

(1) Category 1

Cannot be treated or inspected and can only enter under 1 or 2 above, or 3.5 or 5 below

(2) Category 2

a) Apply one of following pesticide treatments effective against adult tomato-potato psyllid only in accordance to the label or APVMA permit, ensuring;

- They make contact with the underside of the leaf, and,

- Are not rinsed off, and
- Are followed prior to dispatch by a 2% / 600-piece inspection and found to be free of tomato-potato psyllid, and
- Are packed in an approved manner to prevent infestation with tomato-potato psyllid;

i. **Abamectin** within 3 days prior to dispatch;

(A) with active ingredient of 18g/L at rate of 90mL/100L or 450ml/ha, plus 500mls of Summer Spray Oil, or

(B) with active ingredient of 36g/L at rate of 45mL/100L or 225ml/ha, plus 500mls of Summer Spray Oil, or

ii. **Bifenthrin** within 3 days prior to dispatch;

(A) with active ingredient of 100g/L at rate of 80mL/100L, or

(B) with active ingredient of 250g/L at rate of 32mL/100L, or

iii. **Methomyl** within 3 days prior to dispatch;

(A) with active ingredient of 225g/L at rate of 200ml/100L,

OR

(3) Fumigated with methyl bromide

a) By a licensed fumigator prior to dispatch at one of the following temperatures and rates for 2 hours

i. 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

ii. 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

iii. 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

iv. 21°C - 31.9°C @ 32 g/m3 for 2 hrs, and

b) Packed in an approved manner to prevent infestation with tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA04).

3.2 Fruit and Vegetables for Consumption (excluding tubers – see 3.3)

(1) Category 1 - Fresh fruit and vegetables with calyx but no leaves or other attached green material

a) Treated with an insecticide effective against **all** life stages of the psyllid and registered for the control of tomato-potato psyllid at rates specified on the label (or in accordance with an approved APVMA minor use permit), and

b) Packed in an approved manner to prevent infestation with tomato-potato psyllid, and

c) 2% / 600-piece inspected prior to dispatch and found to be free of tomato-potato psyllid,

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate.

OR

d) Fumigated by a licensed fumigator with methyl bromide prior to dispatch at the following pulp temperatures and rates for 2 hours

i. 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

ii. 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

iii. 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

iv. 21°C - 31.9°C @ 32 g/m3 for 2 hrs, and

e) Packed in an approved manner to prevent infestation with tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA04).

(2) Category 2 – Fresh fruit and vegetables with leaves, green calyx or other attached green material

a) Apply one of following pesticide treatments effective against adult tomato-potato psyllid, ensuring;

- They make contact with the underside of the leaf, and,
- Are not rinsed off, and
- Followed prior to dispatch by a 2% / 600-piece inspection and found to be free of tomato-potato psyllid, and
- Packed in an approved manner to prevent infestation with tomato-potato psyllid;

i. **Abamectin** within 4 days of harvest and packed in an approved manner pending dispatch**;**

(A) with active ingredient of 18g/L at rate of 90mL/100L or 450ml/ha, or

(B) with active ingredient of 36g/L at rate of 45mL/100L or 225ml/ha, or

ii. **Bifenthrin** within 4 days of harvest and packed in an approved manner pending dispatch;

(A) with active ingredient of 100g/L at rate of 80mL/100L, or

(B) with active ingredient of 250g/L at rate of 32mL/100L, or

iii. **Methomyl** within 4 days of harvest and packed in an approved manner pending dispatch;

(A) with active ingredient of 225g/L at rate of 200ml/100L,

OR

b) Treated with an insecticide known to be effective against the adult life stage of the psyllid and registered for the control of tomato-potato psyllid at rates specified on the label (or in accordance with an approved APVMA minor use permit), and

i. Packed in an approved manner to prevent infestation with tomato-potato psyllid, and

ii. 2% / 600-piece inspected prior to dispatch and found to be free of tomato-potato psyllid,

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA64).

OR

c) Fumigated by a licensed fumigator with methyl bromide prior to dispatch at the following pulp temperatures and rates for 2 hours

i. 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

ii. 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

iii. 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

iv. 21°C - 31.9°C @ 32 g/m3 for 2 hrs, and

v. Packed in an approved manner to prevent infestation with tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA04).

(3) Category 1 – Pack-house prepared fruit and vegetables with NO leaves, calyx or other attached green material, or

Category 2 – Pack-house prepared fruit and vegetables with leaves, green calyx or other attached green material

a) Washed/drenched/sprayed in accordance with one of the following Biosecurity SA approved methods and following equipment manufacturer's instructions to effectively remove adult tomato-potato psyllid,

i. Hydro-cooled with continuously circulated water for a period of not less than 20 minutes a minimum flow rate of 200 litres per minute per square metre, or

ii. Immersed in water and produce remaining submerged and continuously agitated for a period of not less than 3 minutes with adequate circulation of the water over and around the produce, or

iii. High pressure spray washed by water in a single layer to ensure complete coverage of the produce passing through the spray at pressure of 200kpa for not less than 20 seconds, or

iv. Moved in a single layer along on roller brushes for at least thirty (30) seconds receiving sprayed water to all surfaces at a minimum of 16L/min.

And

b) Packed in an approved manner to prevent infestation with tomato-potato psyllid, and

c) 2% / 600-piece inspected prior to dispatch and found to be free of tomato-potato psyllid.

Proof – Category 1: Accompanied by Plant Health Assurance Certificate (CA15) or Plant Health Certificate

Proof – Category 2: Accompanied by Plant Health Assurance Certificate (ICA61) or Plant Health Certificate.

OR

d) Treated with an insecticide known to be effective against the adult life stage of the psyllid and registered for the control of tomato-potato psyllid at rates specified on the label (or in accordance with an approved APVMA minor use permit), and

e) Packed in an approved manner to prevent infestation with tomato-potato psyllid, and

f) 2% / 600-piece inspected prior to dispatch and found to be free of tomato-potato psyllid,

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA).

OR

g) Fumigated by a licensed fumigator with methyl bromide prior to dispatch at the following pulp temperatures and rates for 2 hours

i. 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

ii. 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

iii. 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

iv. 21°C - 31.9°C @ 32 g/m3 for 2 hrs, and

h) Packed in an approved manner to prevent infestation with tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA04).

(4) Strawberry fruit.

a) 2% / 600-piece inspected prior to dispatch and found to be free of tomato-potato psyllid, and

b) Packed in an approved manner to prevent infestation with tomato-potato psyllid

Proof: Accompanied by Plant Health Assurance Certificate or Plant Health Certificate (ICA60).

3.3 Tubers

(1) Category 1

a) Unwashed or unbrushed ware potato (*Solanum* tuberosum) tubers and potatoes (*Solanum tuberosum*) for propagation that meet 1.2 above

i. Must be subjected to a 2% or 600 unit inspection prior to dispatch and found free of shoots, stems, leaves, stalks or any other green plant material and TPP.

b) Unwashed or unbrushed sweet potato (*Ipomea batatas*) or other tubers in the Families Convolvulaceae or Lamiaceae

i. No restrictions for CLso

ii. Must be subjected to a 2% or 600 unit inspection prior to dispatch and found to be free of shoots, stems, leaves, stalks or any other green plant material and TPP

c) Brushed or washed ware potato (*Solanum tuberosum)* tubers and sweet potato (*Ipomea batatas*) or other tubers in the Families Convolvulaceae and Lamiaceae

i. Must be free of shoots, stems, leave stalks or any other green plant material and TPP

Proof: a Declaration (Appendix 13)

(2) Category 2

a) No restrictions for CLso.

b) Restrictions for TPP

i. Must have been subject to a 2% or 600 unit inspection prior to dispatch and found to be free of shoots, stems, leaves, stalks or any other green plant material and TPP

Proof: No certification required.

3.4 Cut Flowers

(1) Category 1, Category 2 (also see 3.1)

a) Fumigated in a manner that doesn't restrict gas permeation with ethyl formate gas (166.7g/kg – ie. Vapormate) at 25g/m3 plus 833.3gm/Kg CO2 for minimum of 1 hour at a minimum of 15°C in accordance with label or APVMA permit, then packed in an approved manner to prevent infestation with tomato-potato psyllid

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA65).

OR

b) Submerged, in a manner that doesn't restrict solution permeating foliage, in a solution of Deltamethrin (active ingredient 25g/L) at rate of 100m/100L for in accordance with label or APVMA permit for a minimum of 3 minutes then left to dry naturally for 2 hours, then packed in an approved manner to prevent infestation with tomato potato psyllid

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA64)

OR

c) Fumigated in a manner that doesn't restrict gas permeation by a licensed fumigator with methyl bromide prior to dispatch at the following temperatures and rates for 2 hours

i. 10°C - 10.9°C @ 56 g/m3 for 2 hrs; or

ii. 11°C - 15.9°C @ 48 g/m3 for 2 hrs; or

iii. 16°C - 20.9°C @ 40 g/m3 for 2 hrs; or

iv. 21°C - 31.9°C @ 32 g/m3 for 2 hrs,

then packed in an approved manner to prevent infestation with tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate (ICA04)

3.5 Alternative Treatment / Handling

(1) Category 1

a) Host seedlings (other than potato) grown and prepared in a Pest Free Place of Production may enter to an Approved TPP Facility in South Australia, provided;

i. They were grown and prepared in a PFPP facility approved by the Chief Inspector, and

ii. They travel under secure conditions directly to an Approved TPP Facility accredited by Biosecurity SA for planting and management under accreditation conditions.

Proof: Accompanied by Plant Health Certificate (CA14)

(2) Category 1, Category 2

a) Treated under conditions effective against all life stages of the psyllid otherwise permitted by the Chief Inspector

And 2% / 600-piece inspected prior to dispatch by a Biosecurity officer and found to be free of tomato-potato psyllid.

Proof: Accompanied by Plant Health Certificate, Plant Health Assurance Certificate. or Plant Health Import Certificate

4. All machinery and equipment used in the production or manipulation of all categories of plants or plant material must be

4.1 Washed free of plant material and soil with high pressure hot water, and

4.2 Inspected prior to dispatch by a Biosecurity officer and found to be free of tomato-potato psyllid, plant material and soil.

Proof: Accompanied by a Plant Health Certificate and Plant Health Import Certificate or Plant Health Assurance Certificate (ICA66)

5. The material has been consigned under other conditions permitted by the Chief Inspector that ensures it is incapable of introducing TPP or CLso into the State.

Proof: Accompanied by a Plant Health Import Certificate and a Plant Health Certificate or Plant Health Assurance Certificate.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 18: POTATOES AND SOLANACEOUS HOSTS - POTATO CYST NEMATODE (PCN) *(GLOBODERA PALLIDA* AND *G. ROSTOCHIENSIS)*

The plant is a host of the serious pests *Globodera pallida* and *G. rostochiensis* Potato Cyst Nematode (PCN).

Tissue culture grown in an approved facility does not require certification but must be accompanied by documentary proof it came from an approved facility.

Potatoes and PCN host plants entering South Australia (other than Kangaroo Island – see condition 18.10.) must meet the following requirements;

1. The following are prohibited entry into South Australia:

1.1 Potatoes grown on a property known to be infested with PCN,

1.2 Nursery produce grown 'in-ground' on infested properties.

1.3 The whole of Kangaroo Island was declared the 'Kangaroo Island Protected Production Area' in August 2000 and special provisions apply - see condition 18.10.

2. Potatoes for propagation/planting may enter provided they have been washed or brushed[2] (see definition) free of soil and unless from a state with a recognised Area Freedom Certificate, have been PCN tested[2], and

2.1 In the case of generation zero (G0) seed covered under the specifications of a national certified seed scheme in which case will not require PCN testing when produced in an approved facility and consignments are accompanied with an approved black label certified seed tag, or

2.2 Produced under the requirements of a national certified seed scheme that includes mandatory PCN testing conducted by or under on-site supervision of a certification officer or quarantine inspector and accompanied with an attached approved nationally recognised certified seed tag, or

Proof: The appropriate National Certified Seed Label/Tag (as approved by the Australian Potato Industry Council) attached to individual containers or a Plant Health Certificate.

2.3 Produced under the following requirements;

(1) Under an approved certified seed scheme that meets the Australian National Standard, and

(2) During the current growing season the crop was PCN soil tested by or under on-site supervision of a certification officer or quarantine inspector and found negative, and

(3) Accompanied with an attached approved nationally recognised certified seed tag endorsed with "Crop soil tested and found free of PCN" and the signature of an authorised Senior Seed Certification Officer or a Plant Health Certificate, or

Proof: The appropriate nationally recognised Certified Seed Label/Tag endorsed with "Crop soil tested and found free of PCN" and signature and stamp of a senior seed certification officer attached to individual containers or a Plant Health Certificate.

2.4 In the case of one-off seed (smalls) or potatoes for propagation/planting that do not meet 2.2, 2.3 or 2.5, the crop tested and found free of potato cyst nematode during the current growing season by or under on-site supervision of a certification officer or quarantine inspector and accompanied with a plant health certificate and test results.

Proof: Plant Health Certificate and copy of the PCN test results.

[2] 'Australian National Standard - Certification of Seed Potatoes', published and released in August 2007.

2.5 Potatoes for propagation/planting including one-off seed (smalls) from a crop grown in a state with a current and recognised freedom certificate for potato cyst nematode must be accompanied by documentation that verifies the origin of the crop e.g. Certified or Registered Seed Label/Tag attached to individual containers or documentation that verifies origin of the potatoes.

Proof: Documentary proof of origin e.g. Certified/Registered Seed Label/Tag attached to individual containers or documentation that verifies origin.

3. Ware potatoes and potatoes for processing may enter unrestricted provided they are brushed[2] (see definition) and were grown on or sourced from a property not infested with potato cyst nematode or linked to a property that has had a detection of potato cyst nematode.

Proof: No certification; however, documentation that verifies origin may be requested on entry.

4. Potatoes (ware and processing), root vegetables and bulbs grown on linked land may only enter if certified as meeting the requirements of an approved accreditation program

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate. (ICA44*)*

5. Agricultural equipment used in the production of potatoes may only enter provided;

5.1 It is cleaned free of soil and plant material (see condition 27); and

5.2 If used on linked land or land infected with PCN has also been sprayed with steam or high-pressure hot water in all accessible areas to further ensure cleanliness from soil and organic matter and decontamination from PCN, or

5.3 It meets any other treatment approved by the Chief Inspector, Biosecurity SA - Plant Health.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Import Certificate from the Chief Inspector, Biosecurity SA - Plant Health or CA12 Laboratory documentation.

6. Nursery Stock may enter unrestricted provided it was not grown on or sourced from a property infested with potato cyst nematode or linked to a property that has had a detection of potato cyst nematode and is not restricted by any other condition in this standard.

Proof: No certification; however documentation that verifies origin may be requested on entry.

7. Nursery stock grown on PCN infested land may only enter provided it was;

7.1 produced in strict accordance with an approved accreditation program (PS27) and

7.2 grown in soil-free media, with the plants, pots and potting mix not having been in any contact with soil, and

7.3 **not** grown in-ground. (Produce grown in-ground on infected land is prohibited entry to South Australia).

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate (PS27)

8. Nursery stock grown on linked land may enter provided it;

8.1 was produced in strict accordance with an approved accreditation program (PS27), or

8.2 is bare rooted, washed visually free of soil; or

8.3 was grown in soil-free media, with the plants, pots and potting mix not having been in contact with soil.

Proof: Accompanied by a Plant Health Certificate or Plant Health Assurance Certificate.

9. PCN diagnostic / agronomic sample (plant material / soil) for chemical / biological analysis may enter if sent directly to an approved diagnostic laboratory and meets the following provisions;

9.1 packaged in a quarantine secure manner; and

9.2 the package is clearly and legibly marked on the outside with the name of the collector, the place of collection, the name and address of the recipient; and

9.3 the receiving laboratory is notified of the impending arrival of the sample prior to it being dispatched and that the sample must be denatured by autoclaving at the completion of testing and before disposal into the municipal waste stream.

Proof: Accompanied by a Plant Health Import Certificate

OR

9.4 to a CA12 Accredited Laboratory in accordance with their prescribed dispatch and receival procedures and accompanied by a CA12 Diagnostic Sample Declaration Form.

Proof: Accompanied by a CA12 Diagnostic Sample Declaration Form to the CA12 Accredited Laboratory.

10. Movements of potatoes, related equipment, harvesters, plastic/wooden bins and used packaging (plant material / soil) are restricted entry to Kangaroo Island Protected Production Area and must meet the following special provisions;

10.1 Potatoes for propagation/planting may enter only minitubers/plantlets from accredited laboratories, as generation zero (G0) seed as outlined in 2.1 (and thereafter can only be re-sown from G1, G2, G3 and G4 stock grown within the Kangaroo Island Protected Protection Area);

10.2 Ware potatoes may only enter washed or brushed and in new packaging;

10.3 Machinery and equipment used in production of any potatoes must be witnessed and certified as having been treated in accordance with 5.2 and disinfested with a 2% (±1%) sodium hypochlorite solution and not rinsed for 10 minutes after completion;

10.4 Containers used to transport potatoes must be plastic and if used must be treated as outlined in 10.3
Note: Other containers used in the manipulation or storage of potatoes (e.g. wooden bins, bulker bags, jute bags etc) are prohibited from entry to Kangaroo Island.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Import Certificate

Definitions

"**approved accreditation program**" means the Victorian DEPI Nursery Accreditation Scheme (PS27)

"**approved facility**" means a facility approved under a National Certified Seed Scheme

"**Brushed²**" means soil removed to the point a small transparent film of soil may be present without any visible clumps capable of harbouring cysts. See colour plate below as example.

"**generation zero (G0)**" means mini tubers produced in a soil-less media and from an approved facility

"**infested land**" means any defined paddock or area which has had a positive PCN detection or untested linked land

"**linked land**" means land that –

- has been farmed with equipment used on known PCN infested land; or
- borders PCN infested areas; or
- receives direct drainage from PCN infested areas; or
- is currently or has previously been planted with seed sourced from PCN infested land or land exposed to PCN as a result of a regulatory violation,

- to qualify for ICA44 accreditation and send potatoes to South Australia linked land must be tested and found negative for potato cyst nematode during the current growing season in accordance with the National Potato Cyst Nematode (PCN) Testing Standard.
- To qualify to send nursery stock to South Australia linked land must become accredited and meet the conditions for PS27 with DEPI Victoria.

"**National Certified Seed Scheme**" means

- a scheme which requires an approved method of soil-testing during the current growing season and found free from potato cyst nematode
- seed potatoes certified under this scheme must have approved national certified seed tags attached to the consignment which eliminate the requirement for plant health certification

"**nursery stock**" means all commercially produced plant life excluding potatoes

"**quarantine secure manner**" means sealed inside a strong plastic bag that is then double packed with the words 'quarantine material do not open' and the third layer being a courier satchel or cardboard box

"**root vegetables/bulbs**" means all root vegetables including bulbs and corms

"**tested**" means for one-off seed or potatoes for propagation/planting and linked land the soil has been PCN soil tested in accordance with the requirements of a nationally approved certified seed scheme.

"**tissue culture**" means tissue cultural produced in a soil-less media and from an approved facility

"**un-infested land**" means any clearly defined paddock or area which is not infested or linked land.

[2]Example of Maximum Permissible Soil Adhesion for Brushed Potatoes

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 18A: PSTVD – POTATO SPINDLE TUBER VIROID

PSTVd is a highly contagious disease, transmitted between plants by contact, use of cutting or pruning tools, contaminated machinery or any form of physical contact and can retain its infectious activity in seed for long periods. Detections of Potato Spindle Tuber Viroid (PSTVd) are known to have occurred in Queensland and Western Australia:

1. The entry of potatoes for propagation into South Australia will be prohibited unless (in association with Condition 18) the potatoes also meet the following requirements:

1.1 The potatoes were grown on, or sourced from, a property located in a State or Territory for which an area freedom certificate issued by an officer responsible for agriculture for the State or Territory is currently in force certifying that all or part of the State or Territory or the part the property is located in is known to be free of PSTVd,

Proof: No certification; however documentation that verifies origin may be requested on entry

OR

1.2 Were grown and certified under an approved Certified Seed Potato Scheme that includes mandatory PSTVd testing, or

1.3 Have been treated, tested and certified in accordance with conditions prescribed by the Chief Inspector Plant Health, Biosecurity SA or under an approved accreditation program, administered by the department responsible for agriculture in the affected State or Territory and accompanied by a Plant Health Assurance Certificate,

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate or Approved Certified Seed Tag.

OR

1.4 Have been consigned under other conditions approved by the Chief Inspector and outlined in a Plant Health Import Certificate.

Proof: Accompanied by a Plant Health Import Certificate along with a Plant Health Certificate or Plant Health Assurance Certificate,

2. Agricultural machinery, equipment and packaging that has been used in the production of potatoes must comply with Condition 27 and when used on land infected or associated with PSTVd may only enter provided;

2.1 It is cleaned free of soil and plant material using steam or high-pressure hot water in all accessible areas and decontamination from PSTVd, and

2.2 then all accessible areas disinfested by total saturation with potassium peroxymonosulphate in accordance with the label or a freshly prepared solution of 0.5% sodium hypochlorite and not rinsed for 10 minutes after completion,

OR

2.3 It meets any other treatment approved by the Chief Inspector, Biosecurity SA - Plant Health.

Proof: Accompanied by a Plant Health Certificate a Plant Health Import Certificate or CA12 Laboratory documentation

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 19: VACANT

VACANT

CONDITION 20: SOIL AND SOIL PRODUCTS

Soil and Soil Products include soil, soil samples, turf with adherent soil, plants in soil, media containing soil, rooted plants and root vegetables.

Soil and Soil Products containing soil from high-risk areas may contain pests and diseases of concern and pose a serious biosecurity risk to our horticultural industry.

Rooted plant or root vegetable generally means and includes any bulb, corm, fruit tree, tree, shrub or vine or other plant material capable of transmitting adherent soil.

Soil, and Soil Products are prohibited into South Australia unless they meet the following requirements;

1. Soil, Media Containing Soil, Soil Samples or Turf

1.1 Soil, media containing soil, soil samples not being sent to a CA12 Accredited Laboratory and turf with adherent soil sourced from one of the following **high-risk areas** requires a Plant Health Import Certificate from the Chief Inspector, South Australia that will specify the required treatment and/or additional certification it must be subjected to before it can enter the State.

(1) Vineyards (vineyard soil being soil within 100 metres of an existing live commercial vine or soil where a vine had been previously planted in the past 2 years), Phylloxera Infested Zones (PIZ's), Phylloxera Interim Buffer Zones (PIBZ's) and/or Phylloxera Risk Zones (PRZ's) as described in Condition 7;

(2) The areas described in Condition 2 - Red Imported Fire Ant;

(3) Land infested with or linked to a Potato Cyst Nematode infestation (see Condition 18);

(4) Areas or properties infected with *Fusarium oxysporum* Race 3 of tomato plants (see Condition 21);

(5) Areas or properties infested with Green Snail (see Condition 23);

(6) A PSTVd infested or linked property used for growing potatoes (see Condition 18A);

(7) Any property not covered by a freedom certificate for Tomato Potato Psyllid and CLso (see Condition 17)

Proof: Accompanied by a Plant Health Certificate and Plant Health Import Certificate

1.2 Soil samples or media samples containing soil including those for scientific and commercial purposes can be dispatched to a CA12 Accredited Laboratory using the laboratory documentation and CA12 Declaration.

Proof: Accompanied by CA12 Accredited Laboratory documentation and Declaration.

1.3 Soil, media containing soil, soil samples and turf with adherent soil sourced from outside of the high-risk areas in 1.1 above must have a Biosecurity SA Soil Declaration of Source completed prior to it entering the State, which must accompany the consignment and specify the details of the consignment and origin of the material.

Proof: Accompanied by a Biosecurity SA Soil Declaration of Source (Appendix 10).
The Biosecurity SA Declaration is shown in Appendix 10 or is available at www.pir.sa.gov.au/forms.

2. Rooted Plants[1] in Soil Media or Root Vegetables

2.1 Rooted plants[1] or root vegetables with adherent soil or in a media containing soil, grown in one of the high risk areas listed in 1.1 above must not enter South Australia without meeting the applicable conditions approved by the Chief Inspector in a Plant

Health Import Certificate:

Proof: Accompanied by a Plant Health Certificate and Plant Health Import Certificate

2.2 Root vegetables (other than potatoes) washed free of soil and 'topped and tailed' are exempt from this Condition.

3. Plants in Soil or Potting Mix / Growing Medium containing Soil

3.1 Plants[1] (other than potatoes and grapevines which are restricted elsewhere) in soil or any medium containing soil from one of the high risk areas listed in 1.1 above (which includes grown within 100 metres of a grapevine) may only enter the State provided they meet the following;

(1) Accompanied by a Plant Health Import Certificate from the Chief Inspector, South Australia that will specify the required treatment and/or additional certification it must meet, or

Proof: Accompanied by an Import Certificate from Chief Inspector.

(2) Were grown at least 100 metres from any grapevine on a property with no known history of growing Vitus spp, under an approved Nursery Accreditation Scheme recognised by Biosecurity SA.

Proof: Accompanied by a Plant Health Assurance Certificate or Plant Health Certificate. (PS27)

3.2 Plants[1] grown in soil or any medium containing soil more than 100 metres from any grapevine on a property outside the high risk areas listed in 1.1 above with no known history of growing Vitus spp and not subject to any other condition in this standard may enter under a Biosecurity SA Soil Declaration of Source completed prior to it entering the State, that must accompany the consignment and specify the details and origin of the consignment.

Proof: Accompanied by a Biosecurity SA Soil Declaration of Source (Appendix 10). The Biosecurity SA Declaration is shown in Appendix 10 or is available at www.pir.sa.gov.au/forms.

Seedling plugs/cells complying with the grape phylloxera, tomato-potato psyllid and pyriform scale condition requirements are exempt from the requirements of 3.

4. Plants[1] – Bare Rooted or in Commercial Grade Potting Mix / Growing Medium

4.1 Bare Rooted Plants[1] from a potato cyst nematode infested or linked property must have been grown in an accredited nursery (see Condition 18 - PCN infested or linked properties).

Proof: Accompanied by a Plant Health Assurance Certificate or Plant Health Certificate. (PS27)

4.2 Any household plant[1] or nursery stock[1] (not a grapevine) that is bare-rooted and washed free of soil or in soil-free commercial grade potting medium that it is not restricted by conditions of 1.1 above or any other conditions of this Standard may enter South Australia without certification.

Note: Plants and nursery stock may subject to examination for pests and diseases on arrival in South Australia to determine general hygiene and the presence of a pest or disease may require disinfestation of the plant(s) at the owner's cost or ordered for re-export or destruction.

[1]Fruit fly host plants must be free of fruit unless fruit fly certified.

For Fact Sheets and information on regulated pests go to following web page;
http://www.pir.sa.gov.au/biosecurity/plant_health/exotic_plant_pest_emergency_response

CONDITION 21: TOMATO PLANTS – *FUSARIUM OXYSPORUM* RACE 3

The soil borne fungus *Fusarium oxysporum* Race 3 causes a wilt affecting tomatoes. It is found in the Shire Council of Bowen and the localities Bluewater (Townsville City Council), Brandon (Burdekin Shire Council), Gumlu and Guthalungra (Whitsunday Region) and Farnsfield (Isis Shire Council) in Queensland.

1. Entry into South Australia, of tomato plants grown in the above places is prohibited.

2. Machinery and equipment used in association with the cultivation and harvest of tomato plants grown in the above places must not enter South Australia unless disinfested as follows;

2.1 Soil and plant material must be removed by:

(1) Blowing out debris using a high pressure air hose, and

(2) Thorough power-washing all reachable surfaces, and

(3) Where there are locations within the machinery that soil or debris cannot be removed by the above methods, disassembly is required to remove the debris,

And then,

2.2 Machinery must be sanitised with one of the following:

(1) High-pressure steam to all surfaces (>82ºC),

OR

(2) Hot water power-washing at 30 psi (414 kPa), >82ºC

Tomato plants from other parts of Queensland must bear proof that they originated outside the listed areas.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate or CA12 Laboratory documentation.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 22: DATE PALMS- PARLATORIA DATE SCALE

The pest *Parlatoria blanchardi* (Parlatoria date scale) exists in the Alice Springs area.

Date palm offshoots (propagative material) entering South Australia from the Northern Territory must be certified as either:

1. having originated outside the area of infestation in and near Alice Springs; **or**

2. if from the affected area, inspected and found to be free of the pest, **and** treated with the chemical dimethoate in accordance with the label requirements.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 23: HOSTS OF GREEN SNAIL

Green snail (*Cornu apertus, Cantareus apertus, Helix aperta*) is currently restricted from all of Western Australia and Cobram in Victoria. The concern is for movement of Green snail via its more likely carriers or hosts.

In this context "host produce" includes soil, plants and plant material (excluding defoliated cuttings of all plants and bare rooted plants and bare-rooted trees provided they have no leaves and/or fruit), leafy vegetables, peas, beans, asparagus, strawberries and strawberry plants, cut flowers, turf, hay, straw and other fodder.

"Topped" root vegetables free of soil are exempt from this condition.

Machinery may also be a vector especially within adherent soil or plant material. Machinery must therefore arrive clean and certified free of soil and plant material as meeting Condition 27 and applicable requirements below, either 2.1(1) for Victoria or 5.1 for Western Australia.

1. Restrictions for Western Australia

Host produce from Western Australia may only enter South Australia if it complies with the provisions of the Green Snail Protocol for Plant and Nursery Exports to South Australia (see 3. below).

2. Restrictions for Victoria (Property Management).

Restrictions apply to Victoria following detection of Green snail in the Cobram area. These restrictions detailed below only apply to host product from properties infested with Green snail or properties linked to a property infested with Green snail.

Host product originating from other properties in Victoria can enter South Australia without Green snail certification. The product may still however be required to comply with other unrelated conditions within this standard.

2.1 Host produce is prohibited from entry into South Australia from properties classified as infected with Green snail or linked to a Green snail infected property unless they meet the following requirements;

(1) Used agricultural equipment and packages used in or from risk areas must be cleaned free of organic matter and soil using high pressure water, hot water or steam and visually inspected by a Biosecurity inspector and certified found free of green snail and consigned within 3 days of inspection.

(2) Host produce, hay, pasture, fodder or grain;

a) The consignment must have been baled or containerised and securely transported to an accredited facility for processing; or

b) Within the previous 12 months prior to consignment the property baited annually during the months of April to November inclusive, using a chemical registered for control of green snail in accordance with label specifications, to be laid on the property in 1M wide vegetation free strip around the perimeter of the property and as transects through the property on a grid pattern as indicated below;

i. 50 metres for properties up to 5 hectares,

ii. 100 metres for properties between 5 and 10 hectares,

iii. 200 metres for properties greater than 10 hectares, or

iv. In the case of small properties, at least two transects running through the centre of the property at right angles, or

v. As otherwise approved in writing by the Chief Inspector, and

c) Transects are visually inspected by an authorised inspector within 4 months prior to consignment, along the bait trails 3 to 10 days after baits were laid and found free of green snail; and

d) The consignment has been visually inspected and found free of green snail and consigned within 7 days of inspection.

(3) Nursery stock (potted and bare-rooted nursery stock with leaves and bulbs), cut flowers, all plant cuttings, leafy vegetables and other host produce must be:

a) Within the previous twelve (12) months prior to consignment, the property has been visually inspected during the months of April to November inclusive and found free of green snail and the property has been baited in accordance with an approved accreditation procedure, namely;

i. baited annually during the months of April to November inclusive; and

ii. baited with a registered chemical in accordance with label specifications; and

iii. bait laid on the property in 3m wide vegetation free strip around the perimeter of the property and as transects through the property as per 2.1 2)(c); and

b) the property is inspected by an authorised inspector within 3 months prior to export, along bait trails 3 to 10 days after baits were laid and found free of green snail; and

c) visually inspected and found free of green snail and consigned within 3 days of inspection.

(4) Household plants must be:

a) bare-rooted; and

b) inspected and found free from green snails; and

c) consigned within 7 days of inspection, or

Proof: Accompanied by a Plant Health Certificate, a Plant Health Assurance Certificate (PS27) or CA12 Laboratory documentation.

(5) Consigned under other conditions permitted by the Chief Inspector and specified in Plant Health Import Certificate.

Proof: Accompanied by a Plant Health Import Certificate, Plant Health Certificate or a Plant Health Assurance Certificate.

Definitions for 2. Restriction for Victoria

"**accredited facility**" means a business operating under an approved operation program which processes the chaff by steam-cut treatment or hammer milling.

"**agricultural equipment**" means any machinery and equipment used on infected or linked land.

"**containerised**" means a secure method that avoids spillage.

"**green snail**' means all stages of the species *Helix aperta, Cornu aspertus and Cantareus aspertus*.

"**hammer milling**" means a process which involves a continues mechanism crushing and tumbling material.

"**host material**" means, any leafy vegetables peas, beans, asparagus, all plant cuttings, potted plants, bulbs, turf, bare rooted plants, field grown trees, cut flowers, foliage, hay and straw, diagnostic samples, used agricultural equipment and used packages, but excluded plants in tissue culture and bare-rooted trees without foliage.

"**infested land**" means any defined paddock or area which has had a positive detection or unsurveyed linked land.

"**linked land**" means land that -

i. is all of the allotment that has any part of it located within 200m of green snail infested land boundary; or

ii. receives host material and/or shares agricultural machinery and equipment with green snail infested land.

"**securely transported**" means the vehicle used to transport the host material is covered or secured in a manner to ensure no spillage occurs during transport.

"**steam-cut treatment**" means a method of cutting hay into chaff through pressurised stream.

GREEN SNAIL PROTOCOL FOR PLANT AND NURSERY EXPORTS TO SOUTH AUSTRALIA

3. HOSTS (other than Flowers – see 4.)

3.1 Grown within 2 km of a green snail infestation - will not be permitted to export plants until three months freedom from green snail is verified by monthly bait surveys and three Departmental inspections during the green snail activity period (i.e. April to November inclusive). The property of origin must be accredited by the Department of Agriculture and Food, Western Australia (DAFWA), otherwise referred herein as 'the Department' and certified as follows:

(1) The property on which the host material has been grown and packed has taken the following steps to prevent the entry of green snail:

a) Baited every month between April and November inclusive with chemical registered for control of green snail in accordance with label specifications, to be laid on the property in a continuous unbroken bait trail in the middle of a three (3) metre wide vegetation free strip around the perimeter of the property and on transects through the property on a grid pattern as indicated below:

i. 50 metres for properties up to 5 hectares,

ii. 100 metres for properties between 5 and 10 hectares,

iii. 200 metres for properties greater than 10 hectares, or

iv. In the case of small properties, at least two transects running through the centre of the property at right angles, or

v. As otherwise approved in writing by the Chief Inspector,

AND

b) Has been inspected by an authorised inspector monthly along bait trails 3 to 10 days after baits were laid and found free of green snail.

AND

c) plants and other materials to be purchased from known green snail free areas (accessed as per 3.1(1) of this protocol); and

AND

d) employee/customer/nursery vehicle parking areas or be vegetation free and bait surveyed as per 3.1(1) above.

AND

e) Driveways to be protected by solid trenches (eg. concrete) 100 mm deep and 100 mm across.

AND

(2) The green snail free status of the property to be verified by an ongoing hygiene and bait survey which includes;

a) An additional continuous trench or additional 2m wide vegetation free strip (on the inside edge of the 3 m baited boundary strip and preferably adjacent to the outside perimeter fence or on the outside edge of the physical barrier),

AND

b) an optional continuous unbroken line of bait applied fortnightly between April and November inclusive;

AND

c) Green snail control measures that include;

i. An additional continuous unbroken line of bait (on the inside edge of the 2 metre strip) applied fortnightly between April and November inclusive,

OR

ii. A continuous physical barrier using either

(A) Copper or galvanised sheet bent at a 20° angle, or

(B) An electric fence designed specifically for snails;

AND

d) Has been inspected by an authorised inspector monthly along bait trails 3 to 10 days after baits were laid and found free of green snail.

AND

e) plants and other materials to be purchased from known green snail free areas (accessed as per 3.1(1) of this protocol);

AND

f) Stock for export to be situated more than 30m from the baited trench specified in 3.1(1)(b) above.

AND

g) For plants grown in potting media;

i. All media storage areas are baited and found free of green snail, and

ii. Media has been treated by either;

(A) Fumigation with Methyl Bromide at .6kg/m2 for 72 hours, or

(B) Fumigation with a chemical containing 940g/kg dazomet in accordance with label, or

(C) Heating with a steam/air mix at 60°C for at least 30 mins;

AND

h) Within two days of export, plants must be sprayed with a moluscicide, approved by Biosecurity SA.

(3) Properties where green snails have been detected will not be permitted to export plants until three months freedom from green snail is verified by monthly bait surveys and three Departmental inspections during the green snail activity period (i.e. April to November inclusive).

(4) Highly secured facilities may be granted exemption from clauses 2(h) and (3) above by the Chief Inspector provided all the following criteria can be met:

a) The building(s) housing the plant product has impervious walls and flooring and is highly secured and sealed to a level deemed practically snail-proof by an officer of the Department,

b) In addition to 3.1(2) above a second bait trail shall surround secure building(s)

c) All entrances shall have water traps/baths designed to minimise possible incursion

d) Any Green snail detections shall be reported to the Department for prompt evaluation regarding ongoing exemption

e) The business operating the facility has accreditation with the Department for a monthly surveying and baiting program

f) The facility is assessed by an officer from the Department and a supporting report provided to Biosecurity SA - Plant Health in writing attesting it is a highly secure facility meeting all the criteria of 3.1(4).

3.2 Grown or packed 2km or more from a known green snail infestation: Property of origin must be accredited by the Department and certified as follows:

(1) The property has been bait surveyed within three months (excluding the months December to March which are not suitable for snail activity) prior to export and found free from green snail.

(2) Baited every 3 months between April and November inclusive with a chemical registered for control of green snail in accordance with label specifications, to be laid on the property in a continuous unbroken bait trail in the middle of a three (3) metre wide vegetation free strip around the perimeter of the property and on transects through the property on a grid pattern as indicated below.

a) 100 metres for properties up to 5 hectares,

b) 200 metres for properties between 5 and 10 hectares,

c) 300 metres for properties greater than 10 hectares, or

d) In the case of small properties, at least two transects running through the centre of the property at right angles, or

e) As otherwise approved in writing by the Chief Inspector,

(3) An optional additional continuous unbroken bait trail may be laid a minimum of 1 metre from the inside perimeter bait trail for added protection, and

(4) The Department within 3 months prior to export has inspected the baited trails for green snails 3-10 days after the baits were laid (provided conditions had been suitable for snail activity).

Note: Between December and March, snails are not active and baiting is therefore not effective. Exporters wishing to export for the first time or who have missed their September/October/November baiting cannot export until their property has been bait surveyed and found free from green snail after the following March.

(5) All propagation/potting media with soil component to:

a) originate and be stored on properties which have been baited and found free from green snail (as for 3.2(1) above); or

b) be treated with:

i. methyl bromide fumigation at 0.6kg/m^3 for 72 hours on an impervious floor with the material to be fumigated no more than 660 mm deep; or

ii. a steam/air mix at 60°C core temperature for 30 minutes; or

iii. fumigation with chemical containing 940g/kg dazomet as per label directions.

Note: 3.2 (2) does not apply to bare rooted plants.

3.3 Small lots of household plants from 2km or more of a known infestation: must be certified by the Department as inspected and found free from soil and green snails.

The Chief Inspector may provide a written exemption from the above provision for facilities certified as having been inspected and designated snail-proof by the Department.

Proof: Plant Health Certificate or a Plant Health Assurance Certificate.

4. FLOWERS (includes cut flowers, all plant cuttings and bare rooted stock)

4.1 Grown in Western Australia.

(1) The property of origin must be accredited and certified by the Department as bait surveyed and found free from green snails as for 3.2(1) and 3.2(1) above.

OR

(2) For the period December to March flowers, all plant cuttings and bare rooted stock can be exported without restriction. (Snails are aestivating and do not pose a risk).

OR

(3) The flowers, all plant cuttings and bare rooted stock must be inspected and found free from green snail and certified by the Department.

OR

(4) Certified by an inspector of the Department or by an Accredited Business operating under an Interstate Certification Assurance (ICA) Arrangement as being cover sprayed to the point of run-off with a mixture containing one of the following;

a) 200 mls of a concentrate containing 225 g/Litre Methomyl per 100 litres, or

b) 100 mls of a concentrate containing 375 g/Litre Thiodicarb per 100 litres, or

c) 100 g of a concentrate containing 750 g/kg Methiocarb per 100 litres of water.

4.2 Bush picked flowers and plants must be inspected and found free from green snail by an inspector of the Department.

Proof: Plant Health Certificate or a Plant Health Assurance Certificate.

5. Strawberry fruit

As an alternative to clause 3 above, strawberry fruit may enter South Australia under one of the below conditions:

5.1 Strawberry fruit grown in Western Australia and either:

(1) harvested and packed between the months of **December to March** (inclusive); or

(2) grown in hydroponic production systems.

Proof: Accompanied by a Plant Health Certificate, a Plant Health Assurance Certificate or a General Biosecurity Declaration (Appendix 13).

5.2 Strawberry fruit harvested or packed between **April to November** (inclusive) may be consigned into South Australia under the following:

(1) **Pest Free Place of Production or Pest Free Production Site**

Field grown strawberries harvested or packed between April and November are recognised as a Pest Free Site provided all the conditions listed under 5.2(1)a) below are met:

a) Bait survey and inspection

i. Minimum of three (3) years of data based on a baiting and inspection program equivalent or exceeding condition 5.2(2) below; and

ii. Bait the property in July with a registered chemical in accordance with label or APVMA permit instructions; and

iii. Bait to be laid on the property in a continuous unbroken bait trail in the middle of a two (2) metre wide vegetation free strip located within 5 metres of the perimeter of the property; and

iv. An optional additional 1m wide vegetation free strip within 1m of the outside edge of the perimeter bait trail, laid with an unbroken line of bait on the outside edge of the strip; and

v. Bait to be laid on the property in transects, by a continuous unbroken bait trail in the middle of a two (2) metre wide vegetation free strip, or in a 300mm wide and deep fresh furrow on a grid pattern as indicated below:

(A) 100 metres for properties between 5 and 10 hectares, or

(B) 200 metres for properties greater than 10 hectares, or

(C) In the case of properties less than 5 hectares, at least two transects running through the centre of the property at right angles, or

(D) As otherwise approved in writing by the Chief Inspector; and

vi. The property must be inspected by an authorised inspector along bait trails at between 3 and 10 days after placement of bait and found free of *C. apertus*; and

vii. The consignment must be packed in a secure manner to prevent infestation with *C. apertus*.

Proof: Plant Health Certificate or a Plant Health Assurance Certificate or CA12 Laboratory documentation.

(2) **Bait survey and inspection of property**

Properties unable to meet the requirements of 5.2(1) above may consign strawberry fruit into South Australia under the following conditions:

a) Bait the property in April and July with a registered chemical in accordance with label or APVMA permit instructions; and

b) Bait to be laid on the property in a continuous unbroken bait trail in the middle of a two (2) metre wide vegetation free strip located within 5 metres of the perimeter of the property; and

c) An optional additional 1m wide vegetation free strip within 1m of the outside edge of the perimeter bait trail, laid with an unbroken line of bait on the outside edge of the strip; and

d) Bait to be laid on the property in transects by a continuous unbroken bait trail in the middle of a two (2) metre wide vegetation free strip, or at the base of 300mm wide and deep fresh furrow on a grid pattern as indicated below:

i. 100 metres for properties between 5 and 10 hectares, or

ii. 200 metres for properties greater than 10 hectares, or

iii. In the case of properties less than 5 hectares, at least two transects running through the centre of the property at right angles, or

iv. As otherwise approved in writing by the Chief Inspector; and

e) The property must be inspected by an authorised inspector along mandatory bait trails at between 3 and 10 days after each placement of bait and found free of *C. apertus*; and

f) The consignment must be inspected at 600-unit rate prior to dispatch and found free of *C. apertus*; and

g) The consignment must be packed in a secure manner to prevent infestation with *C. apertus*.

Proof: Plant Health Certificate or a Plant Health Assurance Certificate or CA12 Laboratory documentation.

6. MACHINERY / EQUIPMENT

6.1 Used in Western Australia.

Machinery and equipment that has manipulated topsoil or plant material must be cleaned free of organic matter and soil using high pressure water, hot water or steam and visually inspected by a Biosecurity inspector and certified found free of green snail and consigned within 3 days of inspection.

Proof: Plant Health Import Certificate and Plant Health Certificate or a Plant Health Assurance Certificate (ICA66) or CA12 Laboratory documentation.

7. PROCESSED CHAFF or HAY

7.1 Steam Treatment of Chaff or Hay.

Chaff must be steam treated/steam-cut using steam in excess of 165 degrees for a minimum of 55 seconds then sealed/packaged and stored to prevent infestation by snails.

Proof: Plant Health Import Certificate and Plant Health Certificate or a Plant Health Assurance Certificate.

8. OTHERWISE CONSIGNED

8.1 Product otherwise consigned under conditions permitted by the Chief Inspector as specified in Plant Health Import Certificate.

Proof: Accompanied by a Plant Health Import Certificate and Plant Health Certificate or a Plant Health Assurance Certificate.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 24: VACANT

VACANT

CONDITION 25: PYRIFORM SCALE – (*PROTOPULVINARIA PYRIFORMIS*)

The entry into South Australia of plants and plant material (excluding cut flowers and bare-rooted trees without leaves) that are considered hosts for Pyriform Scale (*Protopulvinaria pyriformis* - see note below) is prohibited unless having met one of the following requirements:

1. Host plants or plant material must not enter South Australia unless they meet the following requirements:

1.1 The Pyriform Scale host material was grown or sourced on a property located in a State or Territory for which an area freedom certificate, issued by an officer responsible for agriculture for the State or Territory where the Pyriform Scale host material was grown or sourced, is currently in force certifying that all of the State or Territory is known to be free from Pyriform Scale, or

Proof: No certification; however documentation that verifies origin may be requested on entry.

1.2 The Pyriform Scale host material was grown or sourced on a property located in a part of a State or Territory, for which an area freedom certificate, issued by an officer responsible for agriculture for the State or Territory where the Pyriform Scale host material was grown or sourced, is currently in force certifying that part of the State or Territory, is known to be free from Pyriform Scale (not the entire State or Territory), or

Proof: Accompanied by a Plant Health Certificate, Plant Health Assurance Certificate or the Biosecurity SA Pyriform Scale Declaration of Source (Appendix 6).
The Biosecurity SA Pyriform Scale Declaration is shown in Appendix 6 or available at www.pirsa.gov.au/forms

1.3 Was grown, sourced, treated, inspected, labelled and certified in accordance with any conditions prescribed by an approved accreditation program, administered by the department responsible for agriculture in the affected State or Territory and accompanied by a Plant Health Assurance Certificate, or

Proof: Accompanied by Plant Health Certificate or Plant Health Assurance Certificate.

1.4 Has been treated in the following manner and accompanied by a Plant Health Certificate detailing the treatment and application:

(1) All plants in the consignment have been treated with an insecticide registered for the control of scale, at rates specified on the label (or used under an approved minor use permit); and

(2) All plants to be inspected at the rate of 600 or 2% of the plants in the consignment (whichever is greater), and no Pyriform Scale detected.

Proof: Accompanied by Plant Health Certificate.

1.5 Has been consigned under other conditions permitted by the Chief Inspector and outlined in a Plant Health Import Certificate.

Proof: Accompanied by a Plant Health Import Certificate and a Plant Health Certificate.

The following plant families are deemed to be hosts of Pyriform Scale:

Acanthaceae	Lythraceae
Agavaceae	Malpighiaceae
Anacardiaceae	Malvaceae
Apocynaceae	Moraceae
Aquifoliaceae	Musaceae
Araceae	Myricaceae
Araliaceae	Myrtaceae
Asclepiadaceae	Oleaceae
Cannaceae	Orchidaceae
Caprifoliaceae	Passifloraceae
Caricaceae	Phyllanthaceae
Convolvulaceae	Pittosporaceae
Ebenaceae	Punicaceae
Elaeocarpaceae	Rubiaceae
Euphorbiaceae	Rutaceae
Fabaceae	Saxifragaceae
Lauraceae	Scrophulariaceae
	Verbenaceae

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 26: MYRTLE RUST (*PUCCINIA PSIDII*, PREVIOUSLY NAMED *UREDO RANGELII*) – ICA42

The entry into South Australia of plants and plant material of the family Myrtaceae including nursery stock, cut flowers, fruit, germplasm, seed, tissue culture, bark-chips/mulch and firewood from any Australian State and Territory that has had a detection of Myrtle Rust (*Puccinia psidii*, previously *Uredo rangelii*) is prohibited unless certified as having met the following requirements:

1. Property Freedom

1.1 The nursery of origin has been inspected by an accredited person within 14 days of dispatch and found free from symptoms of Myrtle Rust; and

1.2 All plants:

(1) in the consignment have been treated with an approved fungicide * within 7 days of despatch; or

(2) in the nursery of the Myrtaceae family have been treated with an approved fungicide* twice within 28 days of despatch at 14 day intervals; and

1.3 The consignment has been inspected at the rate of 600 plants or 2 percent of plants in the consignment and found free from symptoms of Myrtle Rust.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA 42).

2. Fruit and Other Host Products

2.1 For fruit, other host products not covered elsewhere in this condition and non-commercial plants the consignment must be;

(1) treated with an approved fungicide * within 7 days of despatch; and

(2) inspected at the rate of 600 or 2 percent of pieces within the consignment and found free from symptoms of Myrtle Rust.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Import Certificate.

**Approved fungicides are:*

(a) fungicides which contain label instructions relating to treatment of "rust" diseases on ornamentals; and

(b) other chemicals for which the Australian Pesticides and Veterinary Medicines Authority (APVMA) has issues a permit to treat Myrtle rust on plants.

Use of any chemicals must be in accordance with the approved label instructions. Chemicals used under APVMA permit conditions must be used in conjunction with relevant approved permit conditions.

3. Firewood

Firewood may be introduced into the state under this Condition, provided that the following requirements are met:

3.1 if it is seasoned to appropriate dryness for firewood use; and

3.2 if it is free from bark.

4. Diagnostic material

For the conditions of entry into South Australia for plant diagnostic samples of the Family Myrtaceae refer to Condition 6 – Plant Diagnostic Samples.

Proof: Accompanied by a Plant Health Certificate and a Plant Health Import Certificate or CA12 stipulated documentation/Declaration.

5. **Tissue Culture of the Family Myrtaceae** must enter South Australia under the following requirements:

5.1 A person proposing to import Family Myrtaceae tissue cultures into South Australia must give prior notice to the Chief Inspector who may require that person to furnish in writing:

(1) details of the place or places of origin of each culture; and

(2) the species concerned; and

(3) evidence to verify that the tissue cultures has been produced in accordance with Section 8 – Appendix 2.

5.2 On entry to South Australia each consignment must be accompanied by a Plant Health Certificate and is subject to inspection by an approved inspector.

Proof: Accompanied by a Plant Health Certificate and a Plant Health Certificate

6. **Equipment and Machinery**

For the conditions of entry into South Australia for equipment and machinery used in the manipulation and production of host plant material of the Family Myrtaceae must be cleaned free of organic matter and soil using high pressure water, hot water or steam.

Proof: Accompanied by either a Declaration (Statutory or Biosecurity SA – Appendix 9), Plant Health Certificate, Plant Health Assurance Certificate or CA12 Laboratory documentation.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 27: MACHINERY, BINS AND ASSOCIATED FARM / HORTICULTURAL EQUIPMENT

Machinery, empty bins previously used for transportation of fruit fly host produce and any other equipment associated with fruit, vegetable, plant, plant product or soil must not enter South Australia unless it meets the following requirements;

1. All machinery and any other equipment associated with fruit, vegetables, plants, plant products and soil, excluding empty bins previously used for transportation of fruit fly host produce must be clean of fruit, vegetables, plants, plant products and soil and declared or certified as not having been recently used in association with a high-risk pest listed in 3 below.

Proof: Accompanied by either a Declaration (Statutory or Biosecurity SA – Appendix 9), Plant Health Certificate, or Plant Health Assurance Certificate or under CA12 Laboratory documentation.

2. Empty bins that have previously been used for transportation of fruit fly host produce must be thoroughly cleaned to be free of soil and any residual fruit fly host produce, then certified as cleaned.

Proof: Accompanied by either a Plant Health Certificate, a Plant Health Assurance Certificate or CA12 Laboratory documentation.

3. If used in association with any of the following high-risk pests the relevant conditions requirements must be met:

- **3.1** Grape Phylloxera - as required in Conditions 7;
- **3.2** Red Imported Fire Ant - as required in Condition 2;
- **3.3** Potato Cyst Nematode - as required in Condition 18;
- **3.4** Fusarium oxysporum Race 3 - as required in Condition 21;
- **3.5** Green Snail - as required in Condition 23;
- **3.6** PSTVd – as required in Condition 18;
- **3.7** Tomato Potato Psyllid and CLso - as required in Condition 17.
- **3.8** Blueberry Rust – Condition 1
- **3.9** Myrtle Rust – Condition 26

Notes:

Mining equipment that has not manipulated top soil and has not recently been used in one of the high risk areas listed in 3. above will be exempt from this condition.

New unused machinery/and equipment that is clean will be exempt from this condition

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 28: FIRE BLIGHT - FRUITS, PLANTS AND PLANT PARTS

Erwinia amylovora was confirmed in plantings at the Royal Botanic Gardens, Melbourne during 1997, and was subjected to an extensive and apparently successful eradication program. The following restrictions applied to fruits, plants and parts of plants of specified Fire Blight hosts (see listing below) from Victoria during the eradication program.

In the event of another confirmed outbreak of Fire Blight in Australia the following requirements will apply:

1. **Fruits**
   Fruits of the specified Fire Blight hosts are prohibited from within a 5km radius of the outbreak site.

2. **Plants and Parts of Plants** (excluding fruit) Plants and parts of plants (excluding fruit) of the specified Fire Blight hosts are prohibited from within a 20 km radius of the outbreak site unless:

   2.1 They have been grown in a nursery that has been certified by a Departmental inspector:

   (1) Located more than 10kms from the outbreak site; and

   (2) Inspected for visual symptoms of Fire Blight in the previous spring and autumn, and no evidence of *Erwinia amylovora* found; and

   2.2 They are accompanied by a certificate from the exporting nursery stating that the plants were grown on that nursery for the previous 12 months.

Common Name	Genus	Common Name	Genus
Service Berry, June Berry	*Amelanchier spp*	Plum	*Prunus salicina*
Cotoneaster	*Cotoneaster spp*	Fire Thorn	*Pyracantha spp*
Hawthorn	*Crataegus spp*	Pear	*Pyrus spp*
Quince	*Cydonia spp*	Red Raspberry	*Rubus ideus*
Loquat	*Eriobotrya spp*	Thornless Blackberry	*Rubus spp**
Apple	*Malus spp*	Mountain Ash	*Sorbus spp*
Medlar	*Mespilus spp*	-	*Stransvaesia spp*

* Thornless Blackberry is derived from crosses between a range of *Rubus* cultivars.

Note:
Nurseries consigning specified Fire Blight hosts from others parts of the State or Territory where the outbreak has been detected must clearly label the consignments to indicate the origin of the plant material and must comply with Condition 20 of the Standard.
Fruit from outside of the 5 km radius must comply with the other requirements of the Standard.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

CONDITION 29: VACANT

VACANT

CONDITION 30: POLYPHAGOUS SHOT HOLE BORER – (*EUWALLACEA FORNICATUS*)

The polyphagous shot hole borer ("PSHB") is known to exist in the state of Western Australia. Plant material and wood timbers (round or sawn logs with or without bark, including firewood and wood chips) excluding structural timber products are prohibited from entry into South Australia without first meeting the relevant conditions detailed below.

For the purposes of this condition, plant material means all of the plant excluding fruits, leaves, or flowers.

1. Area or Property Freedom

Grown, processed and/or dispatched in an area declared to be free of *Euwallacea fornicatus* in a State or Territory where the pest is known to exist and where a current PIRSA recognised Area Freedom Certificate for *Euwallacea fornicatus* is issued by an officer responsible for agriculture in the State or Territory where the *Euwallacea fornicatus* host material was grown and dispatched.

Proof: Current Area Freedom Certificate available on DCSG SharePoint

2. Treatment of Wood timber and products, and Nursery Stock

Plant material, nursery stock, wood timber and products (round or sawn logs with or without bark, including firewood, wood chips and mulch that includes wood timber and/or bark) excluding structural timber products, must meet one of the following clauses prior to entry into South Australia.

2.1 Consignments of nursery stock containing plants that at the largest part of the plant prior to any processing measure a diameter of less than 20 mm must be inspected at a rate of 2% or 600-unit prior to dispatch and found to be free of any plant material with a diameter of 20 mm or greater.

Proof: Each consignment accompanied with a Declaration (Appendix 16)

2.2 Heat treatment

(1) The temperature of the core of the timber and/or product is measured at a minimum of 56°C for at least 30 minutes; ***and***

(2) The temperature of the core of the timber and/or product is regularly measured at maximum of five (5) minute intervals verifying the temperature has not fallen below 56°C throughout the treatment; ***and***

(3) The treated consignment must permanently bear a treatment symbol approved by the Chief Inspector, or delegate, placed in a visible location and containing the treatment date; ***and***

(4) The treated consignment must be received in South Australia within 21 days of the treatment date.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate.

2.3 Methyl Bromide fumigation

(1) Fumigated for a minimum of 24 hrs at one of the following rates:

a) 10°C – 15.9°C @ 64g/m^3; ***or***

b) 16°C – 20.9°C @ 56g/m^3; ***or***

c) 21°C or above @ 48g/m^3; ***and***

(2) Monitoring at regular intervals throughout the fumigation treatment to ensure minimum concentration is maintained at the following rates:

Starting temperature and dosage		Minimum concentration (g/m^3) at:			
Temperature	Dosage (g/m^3)	2hrs	4hrs	12hrs	24hrs
10°C – 15.9°C	64	48	42	36	32
16°C – 20.9°C	56	42	36	32	28
21°C or above	48	36	31	28	24

And

(3) The treated consignment must permanently bear a treatment symbol approved by the Chief Inspector, or delegate, placed in a visible location and containing the treatment date; ***and***

(4) The treated consignment must be received in South Australia within 21 days of the treatment date.

Proof: Accompanied by a Plant Health Certificate or a Plant Health Assurance Certificate (ICA04).

3. Machinery and Equipment

Used machinery and equipment must meet the requirements of Condition 27 of this Standard.

Proof: Accompanied by the Machinery and Equipment declaration (Appendix 9)

4. Chief Inspector Approval

Consigned in a manner approved by the Chief Inspector.

Proof: Accompanied by a Plant Health Import Certificate ("PHIC") and any other relevant proof specified within the PHIC.

For Fact Sheets and information on regulated pests go to following web page;
https://www.pir.sa.gov.au/biosecurity/plant_health/emergency_and_significant_plant_pests

SECTION 6 - FRUIT AND PLANTS FOR OVERSEAS EXPORT OR IMPORTED FROM OVERSEAS

This section relates to the movement through South Australia of products covered in this Plant Quarantine Standard that have been imported from overseas or grown in other States or Territories and which are intended for export to overseas destinations. The provisions below apply to host fruits and plants, which are not able to satisfy the conditions of entry specified in the Standard prior to arrival in South Australia. It is designed to maintain South Australian plant protection needs during such operations. (See also "Note" below.)

ENTERING FOR OVERSEAS EXPORT

1. Such fruits and plants must be trans-shipped through a premise, which has been declared as a quarantine station pursuant to Section 5 of the Act.
2. Where a Section 5 declaration applies only to a portion of a premise, that part must be separated from the remaining area by barriers of adequate strength and height. Those barriers may be portable in nature or consist of fixed and semi-fixed features of the building proper. A declared area in turn may be formed into compartments by partitions of adequate strength and height.
3. Locks of sturdy design must be fitted to each point of access to the declared area.
4. When host fruits or plants are held in a declared area, Quarantine signs must be displayed at all access points and the area locked.
5. Any host fruits or plants must be accompanied by either:

   5.1 EX 28 (Permit under the Export Control Act 1982), signed by an authorised Biosecurity inspector, **or**

   5.2 EX 186 (Transfer Certificate and Assessment Notice under the Export Control Act 1982), signed by an authorised Department inspector, **or**

   5.3 EX 222 (Notice of Intention to Export Prescribed Goods), issued and signed by an authorised person from a packing shed that operates under a CA arrangement approved by the Department, **or**

   5.4 Interstate Plant Health Certificate (see Section 8 – Appendix 3) detailing

   - the Electronic Clearance Number,
   - Name of Vessel on which goods will be exported or name of Airline and
   - Flight Number on which goods will be exported,
   - Container Number in which the goods are packed, **or**

   5.5 E 16 (Phytosanitary Certificate), signed by an authorised Departmental inspector, **or**

   5.6 Co-Regulation Transfer Certificate (equivalent to EX 186) issued by an accredited packing shed stating that the produce, packing shed and growing area have area freedom for fruit fly. Each packing shed must have its own certificate, **or**

   5.7 Details of Request for Permit (Edisoft) (equivalent to EX 28) issued by an accredited packing shed providing the produce details for export. Each packing shed will have their own certificate. Unless these stipulate area freedom for fruit fly transportation must meet full Security Containerisation requirements (see below).

   All goods must be under quarantine **security containerisation** during transit through the State to the port of export. ***Security containerisation*** *refers to Sealed Shipping Container, Pantechnicon, Tautliner or fully tarped load however in the case of fruit fly host produce travelling through the Riverland without the above fruit fly certification*,* ***security containerisation*** *options will only be Sealed Shipping Container or Pantechnicon.*

6. During transport between the South Australian border and the quarantine station, no person other than an inspector must remove or authorise removal of the fruit or plants from the

transport vehicle.

7. Where any host fruit is rejected for overseas export, it must not be presented for sale, or otherwise released in South Australia unless it is certified and meets the requirements specified in the Conditions under this Standard.

8. The owner or operator of a quarantine station must:

   8.1 observe any directive by an inspector for the sale or disposal of host fruit or plants rejected from overseas export.

   8.2 maintain records of all host fruits or plants giving the nature and volume of these, their dates of entry and exit from quarantine and their source and destination.

ENTERING SA AFTER OVERSEAS IMPORT

9. The products must have met Department requirements for entry to Australia and cleared for release.

10. Host fruits or plants must be accompanied by either:

   10.1 Plant Health Certificate (see Section 8 – Appendix 3) detailing

      (1) The number of the Phytosanitary Certificate if the goods were imported using one, or

      (2) The Electronic Clearance Number, and

      (3) Name of Vessel or name of Airline and Flight Number goods arrived on, and

      (4) Certification that any applicable post-entry treatments or requirements, including those necessary to meet this Standard have been met,

   OR

   10.2

      (1) A copy of the authorised Phytosanitary Certificate, or

      (2) In cases where a Phytosanitary Certificate isn't required for entry to Australia the applicable commercial invoice(s) or Department clearance documentation, and

      (3) Where other post-entry treatments or requirements are necessary to meet this Standard certified proof is required attesting they have been met,

And

11. The packaging shall;

   11.1 Be the original in which goods were imported and shall clearly display the type of goods, country of origin and details of the distributor,

   OR

   11.2 If the goods are to be repacked post-arrival, they must be certified as being packed in a facility and a manner that prevents pest infestation (see 10.1 or 10.2), clearly display the type of goods, country of origin and details of the re-packer or if re-packed under an approved accreditation the details stipulated by the accreditation.

And

12. The products must meet all other entry requirements specified within this Standard

Note*:*

Certification options for fruit fly host produce are either area freedom from fruit flies, treated by an approved disinfestation method or documentation indicated in 5. above.*

Gazettal of the South Australia Riverland area as a quarantine area prohibits the introduction of uncertified fruit fly host material into the Riverland from interstate. As such uncertified fruit fly host material cannot be transhipped through the Riverland area unless in a sealed shipping container or a pantechnicon.

SECTION 7 – GENERAL PROVISIONS

1. Compliance Agreements

1.1 A person may agree in writing to comply with detailed arrangements concerning:

(1) the operation of a quarantine station

(2) any other procedure or requirement under this Standard

Such an agreement may be cancelled if the person who is party thereto fails to comply with its conditions or is considered not a fit and proper person to operate such an arrangement.

2. Control & Eradication of Fruit Flies

When criteria set in Australia's national fruit fly management agreements are met, as gazetted by the Minister under Section 8 of the Act (Annex 1), the following control and eradication procedures shall immediately commence, and corresponding quarantine area(s) shall be imposed. The quarantine area(s) consist of the "fruit fly outbreak area" and the "fruit fly suspension area", both as defined in Section 3 – Interpretations.

The locations of fruit fly outbreaks will be specified on the PIRSA website https://fruitfly.sa.gov.au/

It is an offence to breach these conditions and penalties apply up to $20,000 for an individual and $100,000 for a body corporate.

2.1 Definitions:

"***Authorised Inspector***" means an inspector appointed under Part 5 Division 2 of the Act

"**capable facility**" means a facility capable of processing fruit to the specifications defined in Condition 10, 11, 12, 13 or 14 (Section 5 - Conditions of Entry).

"**Chief Inspectors**" means the Chief Inspector appointed under Part 5 Division 2 of the Act.

"**Chief Inspectors Movement Certificate**" means a certificate issued under the authority of the Chief Inspector that stipulates the movement controls or conditions that must be adhered to in regard to specified host product during an outbreak

"**consumption on the premises**" refers to commercial dining properties where the host fruit is consumed onsite such as cafes, restaurants and other dining facilities within a fruit fly affected area.

"**deep burial**" means the disposal of host fruit by covering all host fruit in one (1) meter or greater of soil or other material approved by the Chief Inspector.

"**Discovery Point**" means the physical location where:

- One or move suspect adult flies have been collected during a single inspection of a trap (regardless of whether or not the detection triggers a fruit fly outbreak); or
- host material containing fruit fly larvae was grown or collected.

"**Fruit Fly Affected Area**" ("FFAA", also known as the *Controlled Movement Zone*) means the entire area within a circle of predetermined radius surrounding a fruit fly *outbreak centre* in which area freedom status is suspended and movement controls are applied.

- The predetermined radius of the Fruit Fly Affected Area is 15 kilometres in the case of an outbreak of Queensland fruit fly.
- The predetermined radius of the Fruit Fly Affected Area is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly.

"**host fruit**" (also known as *host produce*) means any host fruit or fruiting vegetable of fruit flies listed in the Ministerial Notice pursuant to Section 7 of the *Plant Health Act, 2009* (Annex 2), which list is reproduced Table 2 (Section 5) of this Standard;

"**Inspector Direction Certificate**" means a certificate issued by an authorised inspector providing either:

- approval to meet a condition within this section of the Standard; or
- to provide a direction to any person under powers granted under the Act.

"(fruit fly) **outbreak area**" (also known as the *Corrective Action Zone*) means an area within 1.5 kilometres radius of a fruit fly outbreak centre.

"(fruit fly) **outbreak centre**" (also known as the *Epicentre*) means the location related to each single detection or grouping of detections that triggers an outbreak. An outbreak centre may be:

- the Discovery Point where the first larvae or gravid female was detected; or
- a location between a grouping of male flies that precipitated the outbreak.

"(fruit fly) **outbreak trigger**" means the detection of fruit fly larvae in locally grown fruit, the detection of one gravid female fruit fly, or the detection of a pre-determined number of male fruit flies or non-gravid female fruit flies within a 1-kilometre radius within a consecutive fourteen-day period.

- The predetermined number of male fruit flies or non-gravid female fruit flies is five for Queensland fruit fly
- The predetermined number of male fruit flies or non-gravid female fruit flies is three for Mediterranean fruit fly

"(fruit fly) **outbreak zone**" (also known as the *Delimitation Zone*) means all of the land within a 200-metre radius around each Discovery Point once the outbreak trigger has been met.

"**owner**" includes the occupant or manager of land.

"***Quarantine area***" means an area declared under section 8 of the Act as a quarantine area, namely a *fruit fly outbreak zone*, *fruit fly outbreak area* and *fruit fly suspension area*.

"**Sold for the first time**" means the initial sale or exchange of ownership of the host fruit and excludes the resale or reconsignment of the host fruit.

"(fruit fly) **suspension area**" (also known as *Export Assurance Zone*) means the area starting at the outer boundary of the outbreak area to the predetermined radius surrounding a fruit fly outbreak centre in which area freedom status is suspended and movement controls are applied.

- The predetermined radius of the suspension area is 15 kilometres in the case of an outbreak of Queensland fruit fly.

2.2 The predetermined radius of the suspension area is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly. **Management of Host fruit**

a) Host fruit grown within the outbreak zone must be managed in accordance with the requirements of clause 2.2(1) below; and

b) Host fruit grown within or introduced into the outbreak area (excluding the outbreak zone) must be managed in accordance with the requirements of clause 2.2(2) below; and

c) Host fruit grown within or introduced into the suspension area must be managed in accordance with the requirements of clause 2.2(3) below.

(1) **Outbreak zone (Delimitation Zone)**

Movement of host fruit from or within the outbreak zone is prohibited unless managed under the following conditions **and** accompanied with the appropriate

approvals or certificates prior to the host fruit being removed from or moved within the outbreak zone:

a) with regards to host fruit grown within the outbreak zone, the host fruit must not be removed from the property on which the host fruit was grown without approval under a Chief Inspectors Movement Certificate; *or*

b) with regards to host fruit which has been moved into the outbreak zone without prior approval under a Chief Inspectors Movement Certificate, the host fruit must not be moved from any property the host fruit has been stored or handled without approval from the Chief Inspector; *and*

c) approval from the Chief Inspector must not be granted unless host fruit is managed in accordance with one of the sub-clauses *i - iii* below:

i. the host fruit is treated with an approved disinfestation treatment as detailed under 2.3 below and managed under the following conditions:

(A) Treatment initiated and completed within the outbreak zone in which the host fruit was grown; *or*

(B) Consigned under approval from the Chief Inspector, or delegate, under secure conditions as detailed under 2.5 below to a treatment facility located within the surrounding outbreak area for an approved disinfestation treatment; *and*

(C) Prior to treatment, host fruits sourced from the outbreak zone must be segregated and secured from host fruits sourced from the outbreak area; *and*

(D) The approved disinfestation treatment application must be initiated and completed within the outbreak area surrounding the outbreak zone in which the host fruit was grown; *and*

(E) The treatment application, post treatment security and host fruit segregation must be completed and maintained as detailed under **Treatments** 2.3 below; *or*

ii. the host fruit is processed in a manner to remove the quarantine risk as detailed under clause 2.4 Processing below and managed under the following conditions:

(A) the host fruit has been processed to the point the risk of fruit fly has been removed within the outbreak zone in which the host fruit was grown; *or*

(B) the host fruit is consigned under approval from the Chief Inspector, or delegate, under secure conditions as detailed under 2.5 below to a processing facility located within the surrounding outbreak area for processing; *and*

(C) the host fruit must remain under secure conditions at all times while the host fruit is being processed until the point in the process the risk of fruit fly has been removed; *and*

(D) prior to processing, host fruits sourced from the outbreak zone must be segregated and secured from host fruits sourced from the outbreak area; *and*

(E) the host fruit must not be removed from the outbreak area

property until the point in the process at which the risk of fruit fly has been removed is reached; *or*

iii. the host fruit is handled and consigned in a manner as otherwise approved by the Chief Inspector; *and*

d) Green waste containing host fruits, or host fruits consigned for destruction, must be managed and disposed of by one of the following requirements:

i. deep buried within the outbreak zone; or

ii. prior to removing the host fruit from the outbreak zone for deep burial within the fruit fly affected area, the movement of the host fruit is approved under a Chief Inspectors Movement Certificate and the host fruit is disinfested by one of the following methods:

(A) mulched followed by a chemical treatment applied as approved by the Chief Inspector; or

(B) frozen until processed as detailed under clause 2.4 Processing below; or

(C) solarisation by placing all fruit within a completely enclosed plastic covering and leaving in full exposure of the sun until fruit has begun to break down and liquify; *or*

iii. or disposed of as prescribed under a Chief Inspector Movement Certificate; or

iv. with regards to fallen fruit, owners within the Outbreak zone must:

(A) collect such host fruit at least once weekly during the period of the outbreak; and

(B) disposed of host fruit through council managed green waste collection services.

(2) **Outbreak Area (Corrective Action Zone)**

Movement of host fruit from or within the outbreak area is prohibited unless managed under the following conditions **and** accompanied with the appropriate approvals or certificates prior to the host fruit being removed from or moved within the outbreak area:

a) host fruit must be grown outside of the outbreak zone (see clause (1) above); *and*

b) with regards to host fruit grown within the outbreak area, the host fruit must not be removed from the property on which the host fruit was grown without approval under a Chief Inspectors Movement Certificate; *or*

c) with regards to host fruit which has been moved into the outbreak area without prior approval under a Chief Inspectors Movement Certificate, the host fruit must not be moved from any property on which the host fruit has been stored or handled without approval from the Chief Inspector; *and*

d) the sale of host fruit within the outbreak area is prohibited without the approval from the Chief Inspector, or delegate, including host fruit which has been introduced into the outbreak area from the surrounding fruit fly suspension area, outside the fruit fly affected area, or any other area or interstate market; *and*

e) Approval from the Chief Inspector must not be granted unless host fruit is managed in accordance with one of the sub-clauses i - iii below:

i. Treated with an approved disinfestation treatment as detailed under 2.3 below and managed under the following conditions:

(A) treatment of the host fruit must be initiated within the outbreak area; *and*

(I) the treatment is completed within the outbreak area the treatment was initiated in; *or*

(II) the host fruit must remain under secure conditions until the treatment is complete; *and*

(B) if the treatment facility has been provided Chief Inspector approval to treat host fruits sourced from the outbreak zone, host fruits from the outbreak zone and outbreak area must remain segregated until treatments are complete; *and*

(C) the treatment application, post treatment security and host fruit segregation must be completed and maintained as detailed under **Treatments** 2.3 below; *or*

ii. the host fruit is processed in a manner to remove the quarantine risk as detailed under clause 2.4 Processing below and managed under the following conditions:

(A) the host fruit must be processed within the outbreak area the host fruit was grown; *and*

(B) prior to processing, if the processing facility is managing host fruits sourced from both the outbreak zone and outbreak area, host fruits must be segregated at all times; *and*

(C) the host fruit must not be removed from property the processing facility is located until the point in the process where the risk of fruit fly has been removed is reached; *or*

iii. host fruit is handled and consigned in a manner as otherwise approved by the Chief Inspector; *and*

f) Green waste containing host fruits, or host fruits destined for destruction, must be managed and disposed of by one of the following requirements:

i. Deep buried within the outbreak area; *or*

ii. Or disposed of as prescribed under a Chief Inspector Movement Certificate; *or*

iii. With regards to fallen fruit, owners within the outbreak area must:

(A) collect such host fruit at least once weekly during the period of the outbreak; *and*

(B) disposed of host fruit through council managed green waste collection services.

(3) **Suspension Area (Export Assurance Zone)**

Host fruits within the suspension area may move freely **within** the suspension area, however, must be managed under the following conditions **and** be accompanied with the appropriate approvals or certificates:

a) with regards to host fruits grown within the suspension area, unless

otherwise approved by the Chief Inspector under 2.2(3)c)iii below, host fruits must not be removed from the suspension area or sold for the first time within the fruit fly affected area without meeting the requirements of clause 2.2(3)c) below; *or*

b) with regards to host fruit that has been moved into the suspension area from outside of the fruit fly affected area without prior approval under a Chief Inspectors Movement Certificate or Inspectors Direction Certificate, unless otherwise approved by the Chief Inspector under 2.2(3)c)iii below, the host fruit must not be removed from suspension area without meeting the requirements of clause 2.2(3)c) below; *and*

c) Host fruit must meet all the requirements listed in one of clause *i – iii* below:

   i. Treated with an approved disinfestation as detailed 2.3 below; *and*

      (A) treatment of the host fruit must be initiated within the outbreak area; *and*

         (I) the treatment is completed within the fruit fly affected area the treatment was initiated in; *or*

         (II) the host fruit must remain under secure conditions until the treatment is complete; *and*

      (B) the treatment application, post treatment security and host fruit segregation must be completed and maintained as detailed under Approved Disinfestation Treatments 2.3 below; *or*

   ii. the host fruit is processed in a manner to remove the quarantine risk as detailed under clause 2.4 Processing below and managed under the following conditions:

      (A) the host fruit must be processed within the fruit fly affected area the host fruit was grown; *and*

      (B) the host fruit must not be removed from the fruit fly affected area or sold until the point in the process where the risk of fruit fly has been removed is reached; *or*

   iii. host fruit is handled and consigned in a manner as otherwise approved by the Chief Inspector; *and*

d) The management of green waste containing host fruits, or host fruits destined for destruction, must be managed and disposed of by one of the following requirements:

   i. Deep buried within the fruit fly affected area; *or*

   ii. Or disposed of as prescribed under a Chief Inspector Movement Certificate.

2.3 Approved Disinfestation Treatments

Available approved disinfestation treatments include condition 9 – 14 (section 5) of this Standard, however availability of each condition is limited by specified commodities as detailed within section 4 of this standard.

Treated host fruit must be accompanied with plant health certification as evidence an approved disinfestation treatment has been applied.

Businesses and individuals may become accredited to apply an approved disinfestation treatment. Operational Procedures and application forms are available at

www.pir.sa.gov.au/forms.

(1) Approved disinfestation treatments applied during a fruit fly outbreak must:

a) be an accepted treatment for the host fruit as listed within section 4 of this Standard; *or*

b) treated as otherwise prescribed under a Chief Inspectors Movement Certificate; *and*

c) be applied and completed as prescribed within the relevant condition of the Standard, or for accredited businesses as prescribed within the relevant Operational Procedure; *and*

d) be initiated and completed in a facility approved as a capable facility by the Chief Inspector (or delegate) or at a facility accredited to apply such a treatment; *and*

e) be accompanied with the issued treatment certification and approval from the Chief Inspector, or delegate, detailing the owner of the fruit, secure conditions which must be maintained, travel routes (when applicable), and the markets the host fruit may be consigned to; *and*

f) be labelled in accordance with regulation 5 of the *Plant Health Regulations 2009* (SA); *and*

(2) The facility the treatment is initiated and completed within must:

a) be approved by the Chief Inspector, or delegate, as a facility suitable to complete such a treatment by either:

i. An accreditation granted under Part 4 Division 2 of the Act and regulation 7 of the *Plant Health Regulations 2009*; *or*

ii. A Chief Inspector Movement Certificate; *or*

iii. An Inspectors Movement Certificate; *and*

b) establish maintain systems and to segregate treated and untreated host fruit; *and*

c) if, treatment facilities managing host fruit from multiple quarantine areas, establish and maintain systems to segregate and hold securely host fruit from each quarantine area; *and*

d) be capable of securing the treated host fruit detailed under 2.5 below and as soon as practical after the treatment has been complete the host fruit is secure.

2.4 Processing

Host fruit processed and managed as prescribed below does not require additional approvals or secure conditions to be met.

(1) the processing of host fruit must be initiated and completed at a facility approved by the Chief Inspector (or delegate) or at a facility accredited to complete such processing; and

(2) processing facilities managing host fruit from multiple quarantine areas must establish and maintain systems to segregate and hold securely host fruit from each quarantine area; and

(3) Processing means:

a) **freezing** the host fruit until the flesh and pulp of the host fruit is frozen solid and maintained in this frozen state for a period of no less than 24 hours; *or*

b) **dried** to commercial standards; *or*

c) liquidising or crushing host fruit until no lumps of pulp or flesh remain to make either a **juice** or **puree**; *or*

d) **cooking** the host fruit; *or*

e) **preserving** or **canning** the host fruit; *or*

f) Any other method approved by the Chief Inspector in which the final product removes the risk of fruit fly.

2.5 Secure Conditions

Host fruit must be maintained in a state which prevents treated host fruit from becoming infested while in an area where fruit fly is known to exist or preventing untreated fruit fly from becoming exposed in an area where fruit fly is not known to exist.

(1) Secure conditions mean the host fruit in maintained in a completely enclosed in fly proof state to prevent the infestation or spread of fruit flies. This includes:

a) Completely enclosed in an outer covering with no holes or gaps larger than 1.6 mm, measured at the maximum width:

i. Transported in an enclosed vehicle; or

ii. Contained, wrapped or packed in any other manner with no gaps or holes greater than 1.6 mm; or

b) Maintained under low air temperatures:

i. As approved by the Chief Inspector, or delegate, under:

(A) An accreditation granted under Part 4 Division 2 of the Act and regulation 7 of the *Plant Health Regulations 2009*; *or*

(B) A Chief Inspector Movement Certificate; *or*

(C) An Inspectors Movement Certificate; *and*

ii. systems established and maintained to verify that maximum temperature and exposure requirements have been met and records of this; *and*

iii. maintained an environment that ensures the host fruit is not exposed to air temperatures reaching or exceeding:

(A) when securing against or for Mediterranean fruit fly, 13°C for longer than 60 minutes; *or*

(B) when securing against or for Queensland fruit fly, 16°C at all times.

2.6 Eradication and property management requirements

(1) During the course of an eradication program, the owners of lands within the outbreak area (including the outbreak zone) must:

a) Attract fruit flies by the application of a bait mixture made up of one (1) part of a bait containing 0.24 g/L Spinosad as its only active constituent to four (4) parts water; and

b) before commencing bait applications thoroughly rinse the tank and allow a solution of ammonia (1L/100L of hot water) or washing soda (1kg/100L of hot water) to stand in the tank and lines overnight; or apply a proprietary cleaner in accordance with the manufacturer's instructions; and

c) apply the bait by spot spraying the solution into the central foliage of trees or plants at regular intervals so that one (1) litre of concentrate is applied per hectare and repeat this application as below:

i. the owners of lands in an outbreak zone must:

(A) apply the bait as prescribed under clause 2.6(1)a) and 2.6(1)b) above twice weekly commencing within seven (7) days from the date the outbreak is declared and continue this application for six (6) weeks after the last fruit fly or larva(e) is detected; *and*

(B) once the initial period of six (6) week after the last detection has lapsed, repeat application once per week for an addition six (6) weeks; *or*

ii. the owners of lands in an outbreak area must:

(A) apply the bait as prescribed under clause 2.6(1)a) and 2.6(1)b) above once weekly commencing within seven (7) days from the date the outbreak is declared and continue this application for twelve (12) weeks **after** the last fruit fly or larva(e) is detected; *and*

d) maintain an accurate record of each application daily, the quantity of bait received or prepared, the area and number of plants baited and the quantity of bait remaining; *and*

e) discard unused bait after each application day in accordance with label requirements; *and*

f) rinse the equipment thoroughly after every baiting operation; *and*

g) supply and calibrate the equipment to deliver the amount of bait per spot (determined by 2.6(1)c) above) in each application; *or*

(2) apply an alternative bait or spray as approved by the Chief Inspector for the purposes of controlling and eradicating fruit flies.

Note: Biosecurity SA may carry out the above eradication procedures and recover costs from landholders.

SECTION 8 - APPENDICES
APPENDIX 1: PLANT INSPECTION SERVICE OFFICES

PRIMARY INDUSTRIES AND REGIONS (PIRSA)
PLANT INSPECTION SERVICE OFFICES

Adelaide Area

South Australian Produce Market, Pooraka	0417 800 723
Facsimile	(08) 8349 8310
Biosecurity SA - Plant Health, Glenside	(08) 8207 7820
Facsimile	(08) 8207 7844
Email	PIRSA.PlantHealth@sa.gov.au

Loxton

Loxton Research Centre	(08) 8595 9100

Mount Gambier

Mount Gambier District Office	(08) 8735 1300

Nuriootpa

Nuriootpa District Office	(08) 8568 6400

Yamba

Yamba Office	(08) 8586 6761

APPENDIX 2: PLANT TISSUE CULTURES

EXTRACT

Item 4 of "Plant Tissue Culture and Quarantine"
(Australian Quarantine Service 1983)

Growth Conditions for Plant Tissue Cultures

1. Only an agar based medium shall be acceptable. This must have been poured into the container while liquid. The medium should be clear as opaque substances preclude inspection.

2. The plants must have been grown in the vessel in which they are imported.

3. The cultures must be axenic (free from other living organisms) and no prior measures must have been taken to suppress microbial growth.

4. The container must be rigid, clear plastic or glass. Its closure or stopper must prevent the entry of contaminating organisms.

Meristem Culture - Propagation using the smallest part of the meristem tip. As this propagation is a part of the vine that does not have connective tissue, the method is useful for disease elimination.

Fragmented Shoot Apex Culture - Similar to meristem culture but goes one step further by reducing the meristem tip to a number of smaller pieces which increases its usefulness in disease elimination.

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 3: PLANT HEALTH CERTIFICATE

Government of South Australia
Primary Industries and Resources SA

PLANT HEALTH CERTIFICATE

Certificate Number

Name and Physical Address of Exporter:

State: Poste Code:

Declared Name and Physical Address of Consignee:

State: Post Code:

IP No. (if known)	Date Code (as marked on packaging)	Number of Packages	Package Type (e.g. carton, bin, tray)	Item	Name and Physical Address of Grower and / or Packer	Distinguishing Marks	Regulation / Treatment Details	Accreditation Code(s)

This PHC has an Attachment ☐

Additional Declaration:
or
(Re-consignment / Split Consignment Details)

Inspector Declaration: I have read and understood the import conditions of entry of the receiving state for the product(s) listed above

Name of Authorised Officer:

Signature: **Ph**

Place Certified:

Date Certified: D D - M M - Y Y Y Y

Valid for 21 days from date of certification
White Original – Consignment Copy: Yellow – Client Copy: Blue – PHO Copy: Pink – Book Copy
© PIRSA – Plant Health Operations, South Australia

PHO – 110322 V2

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 4: PLANT HEALTH ASSURNACE CERTIFICATE

Government of South Australia
BiosecuritySA

PLANT HEALTH ASSURANCE CERTIFICATE

Original (yellow) – Consignment Copy / Duplicate (white) – Business Copy

Accreditation Details *(all accreditation details must be completed)*

IP Number					Facility No.			Arrangement Code					
S					-								

Certificate Number

Consignment Details (Please print clearly and initial any alterations)

Consignor

Name
Address

Consignee

Name
Address

Reconsigned To
(For reconsigning the produce using ICA-17 or Government Inspector)

Name
Address

Method of Transport
(Provide details where known)

☐ Road	Vehicle Details Reg. No
☐ Rail	Consignment no
☐ Air	Airline/flight no

Certification Details

Accredited Business that Prepared Produce *(as IP# above)*

Name
Address

Grower(s) *(if more than one grower - attach list)*

Name
Address

(for ICA23 each source property must have current Property Approval)

Brand Name or Identifying Marks (as marked on packages)

Date Code(s) (as marked on packages)

No. of Packages	Type of Packages (eg. trays, cartons)	Type of Produce	Authorisation for Re-consignment

Treatment Details

Date	Treatment	Chemical (Act/Ingredient)	Concentration	Duration and Temperature

Additional Certification

Declaration

I, an Authorised Signatory of the accredited business that prepared the plants or plant product described above, hereby declare that the plants or plant produce were prepared in the business's approved facility in accordance with the business's Certification Assurance arrangement and that the details shown above are true and correct in every particular.

Authorised Signatory's Name (Please Print)	Signature	Date

Biosecurity SA - Plant Health **12/12**

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 4A: BIOSECURE HACCP BIOSECURITY CERTIFICATE

BioSecure HACCP Biosecurity Certificate #

BioSecure *HACCP* Biosecurity Certificate

Consignment Details

Consignor (BioSecure *HACCP* Certified business)

Name:
Address:
Telephone:

Consignee

Name:
Address:
Telephone:

Reconsigned To (Splitting consignments or reconsigning whole consignments)

Name:
Address:
Telephone:

Method of Transport (Provide details where known)

☐	Road	Truck / Trailer Registration
☐	Rail	Consignment Number
☐	Air	Airline / Flight Number
☐	Sea	Vessel Name & Voyage Number

Certification Details

Certified Business that Prepared the Product

Name:
Address:
Telephone:

Grower or Packer (if different from Certified business)

Name:
Address:
Telephone:

BH No. of Certifying Business | **Brand Name** or Identifying Marks (as marked on Packages) | **Date Code** (as marked on Packages)

Number & Type of Packages (e.g. Trays, cartons, etc)	Type of Produce (e.g. plants & container size)	Authorisation for Split Consignment	ECCP Code *

* Note: Entry Condition Compliance Procedure (ECCP)

Additional Certification (e.g. Area or property freedom declarations)

Declaration

I, an Authorised Person of the certified business that prepared the plants or plant produce described above, hereby declare that the plants or plant produce have been prepared in the business's approved facilities in accordance with the certification(s) granted to the business under BioSecure HACCP and the details shown above are, to the best of my knowledge true and correct in every particular.

Name of Authorised person _____ Signature of Authorised Person _____ Date _____

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 5: PLANT HEALTH IMPORT CERTIFICATE

Government of South Australia
Department of Primary Industries and Regions

Plant Health Import Certificate

Plant Health Act 2009

Certificate No:	XXX 000000	Valid From:	00.00.0000	Valid To:	00.00.0000

You are authorised to import the following ..... into South Australia under the listed conditions.
This authorisation also registers you as an importer pursuant with section 33 of the Plant Health Act 2009 for the period of the authorisation.

Description	Exporter Details / Comments	Importer Details / Comments

Name of Authorised Officer

Signature

Date

00.00.0000

APPENDIX 6: DECLARATION OF SOURCE PYRIFORM SCALE

Pyriform Scale (Protopulvinaria pyriformis)

Condition 25 – Plant Quarantine Standard South Australia (PQS).

FOR PYRIFORM SCALE HOST PLANT MATERIAL ENTERING SOUTH AUSTRALIA FROM AN AREA OF A STATE COVERED BY AREA FREEDOM CERTIFICATE (i.e State/Territory with only Partial State Freedom).

Important Notes:

- Pyriform Scale plants/plant material hosts have restricted entry into South Australia and are PROHIBITED from an affected State / part of a State unless treated and inspected. Hosts include potted nursery stock (excluding cut flowers and bare-rooted trees without leaves).
- Host material from affected areas not covered by a current Partial State Area Freedom Certificate must be certified as treated in accordance with PQS Condition 25 – do not use this Declaration.
- When completing this declaration you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Plants must be bare-rooted or contained in commercial growing media – no soil.
- Travellers / non commercial loads. Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the plant material does accompanying this declaration was not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the material has been verified with the relevant Department of Primary Industries or equivalent as being a property not located in an area affected by Pyriform Scale; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 7: DECLARATION OF SOURCE CITRUS BLIGHT AND STEM PITTING STRAIN OF TRISTEZA VIRUS

Condition 3 – Plant Quarantine Standard South Australia (PQS).

FOR CITRUS PLANT HOST MATERIAL ENTERING SOUTH AUSTRALIA FROM STATES OTHER THAN QUEENSLAND

Important Notes:

- Due to Citrus Blight and Stem Pitting Strain of Tristeza Virus, citrus plants/plant material hosts are PROHIBITED entry into South Australia from Queensland. Hosts includes cuttings, potted and bare-rooted plants and nursery stock, however fruit and seeds are not hosts.
- Host material from other States must be certified in accordance with Condition 3 as being from a State Free of Citrus Blight and Tristeza Virus or be accompanied by this Declaration.
- When completing this declaration you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Plants must be bare-rooted or contained in commercial growing media – no soil.
- Travellers / non commercial loads - ensure declaration is prepared for presentation prior to arrival into South Australia. Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the citrus plant material accompanying this declaration was not grown or sourced from any other property or location other than the property addresses listed above; the citrus material was not grown or sourced from within Queensland; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 8: DECLARATION OF SOURCE CITRUS RED MITE

Condition 5 – Plant Quarantine Standard South Australia (PQS).

FOR CITRUS PLANT HOST MATERIAL ENTERING SOUTH AUSTRALIA GROWN OUTSIDE NSW COUNTIES of CUMBERLAND and NORTHUMBERLAND or FROM OTHER STATES.

Important Notes:

- Due to Citrus Red Mite citrus plants/plant material hosts are restricted entry into South Australia and PROHIBITED from the NSW Counties of Cumberland and Northumberland unless treated. Hosts include cuttings, potted and bare-rooted plants and nursery stock. Fruit is not a host.
- Host material from outside these counties and other States must be certified from a State Free of Citrus Red Mite, treated or be accompanied by this Declaration.
- When completing this declaration you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Plants must be bare-rooted or contained in commercial growing media – no soil.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the plant material accompanying this declaration was not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the material has grown or sourced from a property in the Counties of Cumberland or Northumberland; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

APPENDIX 9: MACHINERY DECLARATION

Condition 27 – Plant Quarantine Standard South Australia (PQS).

FOR MACHINERY ENTERING SOUTH AUSTRALIA FROM INTERSTATE (OTHER THAN USED IN GRAPE PRODUCTION).

Important Notes:

- Due to various soil and plant borne pests machinery entering into South Australia must meet Condition 27 of the Plant Quarantine Standard South Australia (PQS).
- This declaration can be used to declare cleanliness and that the machinery has not been recently used within a High Risk Area outlined in Condition 27 of the PQS.
- Unless otherwise specified on a PHIC this declaration cannot be used in regard to machinery from a Green Snail risk property/area (see Condition 23) or has been used in the production of grapes (see Condition 7).
- Mining equipment not used in a High Risk Area **and** has not manipulated top soil is exempt from Condition 27 requirements.
- When completing this declaration you must provide all required information to ensure your machinery can be assessed and cleared for entry into South Australia.
- Ensure the declaration is prepared for presentation prior to arrival into South Australia as declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information
  (Sec. 51, Plant Health Act 2009)

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Machine	Registration/Serial Number	District(s) operated within last 12months
……..	……..	…….
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the equipment and machinery listed on this declaration has not been used in a high risk area as described in Condition 27 of the PQS; the equipment and machinery has been thoroughly cleaned free all soil and plant quarantine material (plant debris) by opening and removing all covers or guards designed to open or detach; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 10: DECLARATION OF SOIL SOURCE

Condition 20 – SA Plant Quarantine Standard (PQS).

FOR SITUATIONS WHERE IT IS NECESSARY TO VERIFY SOIL ENTERING SOUTH AUSTRALIA IS NOT SOURCED FROM HIGH RISK AREA.

Important Notes:

- Soil and products containing soil are prohibited entry into South Australia if sourced from the high risk areas indicated in Condition 20 unless;
  - Going to a CA12 Laboratory, or
  - Meet the requirements of PQS conditions that mitigate the associated risks or
  - Sourced from outside the high-risk areas whereby this Declaration can be completed as verification of the source prior to entry into SA.
- When completing this declaration you must provide all required information to ensure your soil material can be assessed and cleared for entry into South Australia. A Direct Inspection is not required for declared products.
- Travelers / noncommercial loads. Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Soil Material (if insufficient space please attach list)

Description of Soil Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the material does not contain soil from any other property or location other than the property addresses listed above; the source addresses of the material has been verified with the relevant Department of Primary Industries or equivalent as being a property not located in a high risk area as detailed within Condition 20 of the Standard; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 11: DECLARATION OF SOURCE TPP AND ZC

Tomato Potato Psyllid and Zebra Chip (*Candidatus Liberibacter solanacearum)*

Condition 17 – Plant Quarantine Standard South Australia (PQS).

FOR TPP and ZC HOST PLANT MATERIAL ENTERING SOUTH AUSTRALIA FROM AN AREA OF A STATE COVERED BY AREA FREEDOM CERTIFICATE (i.e. State/Territory with only Partial State Freedom).

Important Notes:

- Due to TPP/ZC plants/plant material hosts, associated machinery and production equipment have restricted entry into South Australia. Hosts include solanaceous and convolvulaceae plants and plant material, fruit vegetables, nursery stock, as well as machinery, equipment used for production or manipulation of host material.
- Host material and machinery, equipment and tools used for production or manipulation of host material from properties or areas not covered by a current State or Partial Area Freedom Certificate must be certified as treated in accordance with PQS Condition 17 using Plant Health certification – do not use this Declaration.
- When completing this Declaration you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the plant material accompanying this declaration was not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the material has been verified with the relevant Department of Primary Industries or equivalent as being a property not located in an area affected by TPP or ZC; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 12: DECLARATION OF SOURCE BLUEBERRY RUST

Commercial Declaration of Blueberry Rust Property Freedom

Condition 1 – Plant Quarantine Standard South Australia (PQS).

FOR BLUEBERRY RUST HOST FRUIT (**NOT** PLANTS) ENTERING SOUTH AUSTRALIA FROM A PROPERTY INSPECTED BY AUTHORITY AND DECLARED FREE (i.e. State/Territory with only Partial State Freedom).

Important Notes:

- Blueberry Rust (*Thekospora minima*) hosts have restricted entry into South Australia and are PROHIBITED from an affected property unless treated and inspected. Hosts include nursery stock and fruit.
- Host material from an affected property/area or property not declared free must be certified as treated in accordance with PQS Condition 1 – do not use this Declaration.
- This Declaration is for use by commercial growers for fruit only grown on a property inspected by state authority and declared free of Blueberry Rust. NOT for Travellers / non-commercial loads.
- When completing this Declaration, you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the blueberries accompanying this declaration were not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the Blueberry Rust host fruits has been verified with the relevant Department of Primary Industries or equivalent as being a property free of Blueberry Rust; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 13: GENERAL BIOSECURITY DECLARATION

Biosecurity SA – Plant Health

Section 5 – Plant Quarantine Standard South Australia (PQS).

TO ASSIST, CLARIFY OR SUPPORT THAT PRODUCT MEETS REQUIREMENTS FOR ENTRY TO SOUTH AUSTRALIA FROM INTERSTATE

NOT VALID AS SUBSTITUTION FOR REQUIRED PLANT HEALTH CERTIFICATION..

Important Notes:

- Due to various biosecurity pests, products entering into South Australia must meet Conditions of the SA Plant Quarantine Standard (PQS).
- This declaration cannot be used as a substitute for required Plant Health Certification but may sometimes be required to assist, clarify or support that the product does not contravene the PQS.
- This declaration can be used to confirm that the item hasn't been recently used within a High Risk Area defined in the PQS
- This declaration can be used for declaring that grape marc has been sourced from within a PEZ
- This declaration can be used for declaring that grape machinery has been located continuously in a PEZ for the previous 6-months
- When completing this declaration you must provide all required information to ensure your product and claim(s) can be assessed and cleared for entry into South Australia.
- Penalties up to $10,000 apply for providing false or misleading information
  (Sec. 51, Plant Health Act 2009)

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of packages	Address of Production Site
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: ……

……

……

…… and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……..

Address (physical residential address): ……

…… **Contact ph #:** ……..

Signature: …… **Date:** ……..

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 14: DECLARATION OF MELON THRIPS
Melon Thrips (*Thrips Palmi*)

Condition 16 – Plant Quarantine Standard South Australia (PQS).

FOR MELON THRIPS HOST PLANT MATERIAL ENTERING SOUTH AUSTRALIA FROM AREA OF A STATE COVERED BY AREA FREEDOM CERTIFICATE (State/Territory with Partial State Freedom).

Important Notes:

- Due to MT plants/plant material hosts have restricted entry into South Australia and are PROHIBITED from within 100 km of an infected area unless treated. Hosts are indicated in Condition 16 of the PQS.
- Host material from within 100kms of a detection or areas not covered by a current Partial State Area Freedom Certificate must be certified as treated in accordance with PQS Condition 16 using Plant Health certification and this Declaration can't be used.
- When completing this Declaration you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Plants must be bare-rooted or contained in commercial growing media – no soil.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information
  (Sec. 51, Plant Health Act 2009)

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the plant material accompanying this declaration were not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the plant material has been verified with the relevant Department of Primary Industries or equivalent as being greater than 100km from known Melon Thrips as indicated by an Area Freedom Certificate with ongoing specific surveillance; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 15: DECLARATION FOR GRAPE MACHINERY & EQUIPMENT SERVICING ONLY

Condition 7 – Plant Quarantine Standard South Australia (PQS).

FOR USED GRAPE MACHINERY (Including GRAPE HARVESTERS) AND EQUIPMENT FROM SOUTH AUSTRALIA TO INTERSTATE PEZ FOR SERVICING ONLY.

Important Notes:

- Used grape machinery and equipment entering SA must meet Condition 7 of the SA Plant Quarantine Standard (PQS)
- This declaration can be used to declare machinery and equipment for servicing only arrived thoroughly clean from SA and once serviced, the machinery/equipment returned to SA clean as required under Condition 7.2.3 and 7.3.3 of the PQS; namely;
  1. It left SA thoroughly cleaned of soil and plant material, both internally and externally.
  2. It was sent for servicing only to a service centre located within a PEZ.
  3. It did not enter a PIZ, PIBZ or PRZ, operate on grape material or enter any vineyard during the trip.
  4. It was not loaded with any other machinery or equipment during transit outside of SA.
  5. The route must be the most direct and not travel through any PIZ, PIBZ or PRZ areas, excluding small items sent by mail or securely packaged and sent via courier.
  6. The declaration must be completed by the service provider and accompany the machinery to SA
  7. No machinery/equipment from a PIZ, PIBZ or PRZ was present in the service centre at the same time.
- When completing this declaration you must provide all required information to ensure your product and claim(s) can be assessed and cleared for entry into South Australia.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of Service Centre making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Machine	Registration/Serial Number	District(s) operated within last 12months
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the above Service Centre is located within a PEZ; the equipment and machinery listed on this declaration arrived from SA at the above service address for servicing only, arrived thoroughly cleaned of both soil and plant quarantine material (plant debris), wasn't used in production of grapes or in a vineyard whilst outside SA; the equipment and machinery has been thoroughly cleaned free all soil and plant quarantine material (plant debris) by opening and removing all covers or guards designed to open or detach; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Government of South Australia
Department of Primary Industries and Regions

APPENDIX 16: DECLARATION OF SOURCE POLYPHAGOUS SHOT HOLE BORER

Commercial Declaration of Blueberry Rust Property Freedom

Condition 30 – Plant Quarantine Standard South Australia (PQS).

FOR PLANT MATERIAL ENTERING SOUTH AUSTRALIA FROM AN AREA WITHOUT RECOGNISED AREA OR PROPERY FREEDOM (i.e State/Territory with only Partial State Freedom).

Important Notes:

- Polyphagous shot hole borer (*euwallacea fornicatus*) hosts have restricted entry into South Australia and are PROHIBITED from an affected property unless treated and inspected. Hosts include all plant material including nursery stock, excluding leaves, flowers, vegetables, fruits, or plant material which does not measure greater than a diameter of 20 mm at the base of the shoot, stem, or branch prior to any processing.
- When completing this Declaration, you must provide all required information to ensure your host material can be assessed and cleared for entry into South Australia.
- Ensure Declaration is prepared for presentation prior to arrival into South Australia as Declarations cannot be completed post-entry or at a Roadblock.
- Penalties up to $10,000 apply for providing false or misleading information *(Sec. 51, Plant Health Act 2009)*

Section 1: Consignor Details

Name of consignor making declaration (full legal name):

……

Residential Address (physical address – must not be a PO Box)

……

Section 2: Description of Host Material (if insufficient space please attach list)

Description of Host Material	Type of Packaging	Source Location Address and State
……..	……..	……
……..……	……..	……..……

Section 3: Declaration

It is an offence against the *Plant Health Act 2009* to provide false or misleading information, or failing to meet the conditions of the Plant Quarantine Standard South Australia (the Standard) including the incorrect use of this declaration.
False or misleading information, section 51 – maximum penalty $10,000. Failing to meet conditions of the Standard, section 7 – maximum penalty $100,000.

I, the undersigned, hereby make the following declarations: the plant material accompanying this declaration were not grown or sourced from any other property or location other than the property addresses listed above; the source addresses of the plant material has been verified with the relevant Department of Primary Industries or equivalent as being a property free of PSHB **or** the plant material accompanying this declaration does not measure greater than a diameter of 20 mm at the base of the shoot, stem, or branch prior to any processing; and the information provided on this declaration is true and accurate.

Name (Print – full legal name): ……

Address (physical residential address): ……

…… **Contact ph #:** ……

Signature: …… **Date:** ……

Crop Protection 164 (2023) 106121

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Predicting point-source invasion success in the Queensland fruit fly (*Bactrocera tryoni*): An individual-based modelling approach

Bernard C. Dominiak [a,*], Benjamin G. Fanson [b]

[a] New South Wales Department of Primary Industries, Ian Armstrong Building, 105 Prince Street, Orange, NSW, 2800, Australia
[b] School of Life and Environmental Sciences, Deakin University, Geelong, VIC, 3216, Australia

ARTICLE INFO

Keywords:
IBM
Incipient populations
Pest management
Market access
Phytosanitary standards

ABSTRACT

Fruit flies are a major pest worldwide for fruit producing industries. Incursions into fly free areas usually occurs via infested fruit; however, little is reported about the size of a propagule to start a new establishment. Propagule pressure is an important predictor of the probability that an invasive species will establish a breeding population. Recently, individual-based model (IBM) became a valuable modelling tool for exploring invasive species. Here, we developed a spatially-explicit individual-based model (IBM) specifically parameterized for the Queensland fruit fly (Qfly) (*Bactrocera tryoni* Froggatt), a major horticultural pest species in Australia and a major quarantine concern worldwide. Usually, new establishments or incursions originate from the introduction of infested fruit and larvae must progress through several stages to become sexually mature adults. For a Qfly incursion to establish a breeding population, flies must avoid predators and survive long enough to become reproductively mature, find a mate, and find ripening fruit. Additionally, their offspring must survive and successfully reproduce. The IBM model simulated release of a fixed number of flies into a heterogeneous environment of varying suitability. We conducted simulations to delineate the contributions of demographic stochasticity and Allee effects (finding a mate in a spatial environment) on establishment probability. Our model delineated several key influential factors, especially tree density, extrinsic mortality and mating range. We performed sensitivity analyses to identity which biological and ecological mechanisms strongly affect establishment probability. Integrating the model's findings with information on transport of infested fruit helps explain why Qfly incursions are common, but yet most fail to establish. Our model predicted that circa 16 and 50 flies were required for a 50% and 99% chance of establishment respectively. Additionally, our model predicted the mating distance for Qfly was 16.1 m. The mean daily dispersal distance was 30 m. We discuss how this knowledge might be used to better manage Qfly by alterations in surveillance and male annihilation technique.

1. Introduction

The increase in global trade has resulted in many more opportunities for pests to be transported beyond their natural ranges (Bebber et al., 2014). The inadvertent translocation of pest species is a major threat to biological diversity and agricultural industries (Schmitz and Simberloff, 1997). Consequently, the process of biological invasions has become an increasingly studied area, expanding beyond descriptive studies to identifying mechanistic processes underlying invasions (Britton and Gozlan, 2013; Keitt et al., 2001; Kolar and Lodge, 2001; Memmott et al., 2005; Schmitz and Simberloff, 1997: Yonow et al., 2004). It may become possible to better predict invasion success, resulting in better pest management practices by delineating these biological processes (Lockwood et al., 2005).

A significant barrier to a biological invasion is the establishment of a reproducing population in a novel environment. Most species introductions fail to establish (Kolar and Lodge, 2001; Williamson et al., 1986), with many abiotic (e.g. environmental suitability) and biotic factors (e.g. species life history strategies) having been identified for affecting establishment probability for a species (Gozlan et al., 2010; Kolar and Lodge, 2001; Williamson et al., 1986). One of the most consistent predictors of invasion success is propagule pressure, which is a function of the total number of individuals ("propagule size") and the frequency of introductions ("propagule number") (Lockwood et al., 2009). Often, species with higher propagule pressures have increased invasion success (Lockwood et al., 2009).

* Corresponding author.
E-mail address: bernie.dominiak@dpi.nsw.gov.au (B.C. Dominiak).

https://doi.org/10.1016/j.cropro.2022.106121
Received 13 July 2022; Received in revised form 3 October 2022; Accepted 6 October 2022
Available online 22 October 2022
0261-2194/Crown Copyright © 2022 Published by Elsevier Ltd. All rights reserved.

The link between propagule number (frequency of introductions) and population success is intuitively straightforward; the more invasions attempts or larger invasions attempts both result in the higher the probability that at least one will be successful. From a management perspective, the best practice for dealing with propagule number is to decrease the frequency of propagule attempts but it is more difficult to alter the propagule size (larvae per consignment) which is frequently government by climate or host (Follett et al., 2021). However, the efficacy of this practice depends on the success probability for each propagule. The probability of invasion success is dependent on propagule size. Therefore, it is essential to understand the relationship between propagule size and invasion success (Britton and Gozlan, 2013; Gertzen et al., 2011; Leung et al., 2004; Memmott et al., 2005; Yonow et al., 2004).

Small populations are especially susceptible to demographic stochasticity (e.g. uneven sex ratios), environmental stochasticity (e.g. extreme climatic conditions), inbreeding depression, and Allee effects (any process leading to reduction in fitness at low population densities) (Boukal and Berec, 2002; Kolar and Lodge, 2001; Leung et al., 2004; Lux, 2014, 2018; Snyder, 2003; Stephens and Sutherland, 1999) and these factors can lead to population extinction. Consequently, the relationship between propagule size and probability of establishment often follows a dose-response-like curve (Britton and Gozlan, 2013; Gertzen et al., 2011; Memmott et al., 2005; Shea and Possingham, 2000). The identification of the shape of these curves can allow for informed management practices to minimise propagule pressure (Lockwood et al., 2005). However, quantification of dose-response curves is rare, particularly for highly invasive species in which logistical constraints often limit empirical studies (Brodland, 2015; Lewis et al., 2016). Consequently, the use of theoretical models parameterized for specific species can provide initial guidance for management decisions and allow for focused experiments.

Much of the current Australian management approaches are based on practices from the 1990's. Issues such as natural dispersal distances were recently re-examined and results have indicated shorter dispersal distances than previously assumed (Dominiak, 2012; Dominiak and Fanson, 2020). However, shorter quarantine distances have not been widely adopted. The recognition of shorter dispersal distances is becoming increasingly important as Australia moves away from large regional government sponsored fruit fly free areas. Increasingly, the "Systems Approach" for market access is being embraced (Dominiak, 2019; Jang, 2016; van Klinken et al., 2020), however the success of this approach is largely dependent on the recognition of shorter dispersal distances. The Systems Approach places the management of fruit flies clearly back with the producer, allowing them to choose fruit fly control strategies that suit their enterprise. However, surveillance protocols and the use of male annihilation technique (MAT) (as an exclusion technique on property boundaries) remain largely based on the knowledge from the 1990's, despite growing recognition of shorter dispersal distances (Meats et al., 2003; Meats and Leighton, 2004; Dominiak, 2012; Dominiak and Fanson, 2020; Caton et al., 2021).

Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) (Qfly) is the major Tephritid fruit fly pest in Australian horticulture, attacking most fruit and many vegetable crops (e.g., bananas, citrus, coffee, tomato pome fruit, stone fruit) (Clarke et al., 2011; Dominiak and Mapson, 2017; Hancock et al., 2000; Yonow and Sutherst, 1998). Generally, it is understood that Qfly incursions into Pest Free Areas (PFA) in Australia are most often the result of illegal transportation into, and the inappropriate disposal of infested host material within PFAs (Bateman, 1991; Dominiak et al., 2000; Dominiak and Coombes, 2009). Therefore, most new detections of Qfly are principally caused by entries of small parcels of relatively few immature fruit flies, and most fail to establish breeding populations. Previous research has found that 71% (Meats et al., 2003) to 90.1% (Dominiak and Fanson, 2020) of detected incursions self-extinguish without any interventions. However, these estimates represent lower bounds as some incursions likely self-extinguish before any flies are caught in traps and not all detected incursions lead to successfully breeding populations. Here, we utilize a spatially explicit individual-based model (IBM) to simulate incursions of the Qfly in PFAs. Recently, IBM was shown to be very useful to modelling pest dynamics across spatial scales (see Crespo-Perez et al., 2011; Lux, 2014; Lux, 2018).

Little empirical information exists about the initial founding population sizes for most Qfly detections. Similarly, almost nothing is known about which ecological and biological factors for Qfly might affect incursion success. For a Qfly incursion to produce a breeding population, larvae from infested fruit must successfully pupate, find suitable pupal habitat, and successfully eclose. Then the immature adults must disperse into the environment, find food (essential for reproductive maturation in Qfly) (Fanson and Taylor, 2012; Meats and Leighton, 2004; Perez--Staples et al., 2007; Prabhu et al., 2008) and water, avoid predators for about 2 weeks at which point the females become sexually mature (Taylor et al., 2013). Then, male and female flies must be within proximity to successfully mate during a 30min window during dusk (Tychsen, 1978). Because of all these steps, it is thought that the chances of a sexually mature male and female Qfly occurring in the same tree or group of trees is extremely low in pest free areas (Bateman, 1977; Fletcher, 1974; Meats, 1998; Weldon, 2007).

It has been hypothesized that the low establishment probability for Qfly is mainly due to the difficulty of finding a mate (i.e. an Allee effect) in a spatial environment (Bateman, 1977; Dominiak, 2012; Meats, 1998). We develop a spatially explicit IBM that has been parameterized for Qfly to provide a working framework. With this model, we ask the following questions: 1) what is the relationship between establishment probability and propagule size under just demographic stochasticity, under just Allee effects, or both; and 2) which ecological and biological factors most affect the relationship between population size and successful incursion? This knowledge can be used for making more informed management decisions.

2. Methods

2.1. Model description

The model is a spatially-explicit, individual-based model implemented in NetLogo v5.1.0 (Wilensky, 1999; freely downloadable from https://ccl.northwestern.edu/netlogo/). The model's code is available in the electronic supplementary material. Below, we follow the ODD (overview, design concepts and details) protocol for describing agent-based models recommended by Grimm et al. (2020).

Purpose - The purpose of this model is to explore the ecological and biological factors that influence the probability that a point-source invasion results in the establishment of a breeding population of Qfly.

State variables and scales – The principal agents in the model are flies, which are characterized by age (days), sex (male/female), and mating status (unmated/mated). The flies inhabit a 400 × 400 square grid (based on smallest trapping array for surveillance), in which each square ('patch'; 5 m × 5 m) represents either bare ground, non-fruiting tree, or a fruiting tree (Fig. 1). Each patch had a certain probability of being a tree, and if a tree, another probability of being a fruiting tree (Fig. 2). Each fruiting tree had the potential to be repeatedly infested and it could contain larva of different ages, not necessarily in the one piece of fruit. One time step in the model corresponds to one day and there are eight substeps in each day.

Process overview and scheduling – During every time step, a series of actions occur. First, trees with infested fruit are updated in which every larva ages one day. For larva reaching adulthood during the time step, they emerge as adult flies with a certain probability (see Table 1 for parameterization). After updating each patch, the model has each fly conduct a series of behaviours. First, each fly disperses to a new tree or remains in current tree based on a dispersal probability. This dispersal probability can differ between fruiting and non-fruiting trees. If a fly

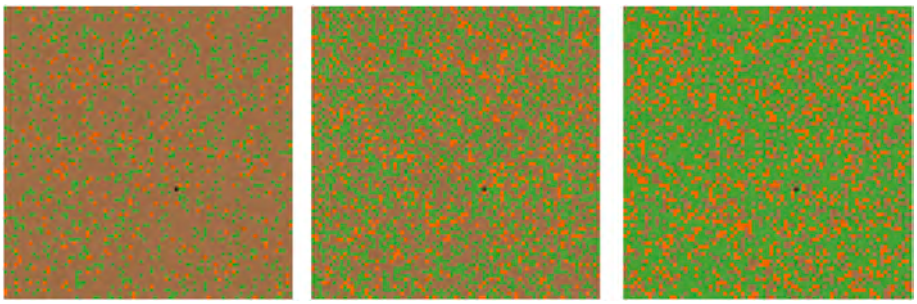


Fig. 1. Schematic of landscapes used in the models. Brown is non-tree patch. Green is a non-fruiting tree and orange is a fruiting tree. Landscapes left to right have increasing probability of trees of 0.1, 0.5, 0.8. Black dot is the origin of a point incursion. All landscapes have 0.2 chance of any given tree fruiting. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

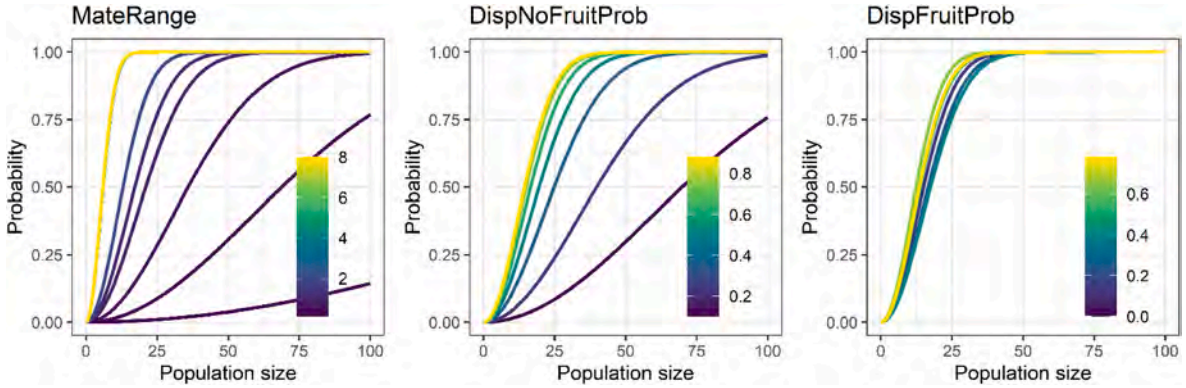


Fig. 2. Effects of mate range, dispersal probability on non-fruit trees and on fruit trees. For each plot, curves represent relationship between initial population size and establishment probability for varying levels of the parameter. Colour bar indicates parameter values. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

disperses, it moves through the landscape with a specified correlated movement (Fig. S1) until it hits another tree (including returning to the original tree), if it survives. Each movement is associated with a mortality risk. Second, if the fly is a mated female and inhabits a fruiting tree, she will lay eggs in a fruit. Then every fly again has a chance to disperse. This dispersal/movement sequence repeats 8 times per day, giving each fly multiple chances to move in a single day. Flight movements appear relatively rare in Qfly, spending ~0.6% of their time flying (Weldon et al., 2010) but multiple movements in a day are likely. At the last time step (the eighth step in any one day), the mating routine occurs (matching dusk mating in Qfly). In this routine, every female that is not mated and is sexually mature (e.g. age >10 days) has the opportunity to mate. If there is a mature male within a specified distance (within same patch), then the female becomes mated and can lay fertilized eggs for remaining lifespan. The model assumes that a male can only mate with one female in a given night given the short 30 min mating period (Tychsen, 1978). Mated females are able to lay eggs the following day. Finally, each surviving fly ages one day and the cycle repeats. The simulation ended if the population went extinct or if the point-source invasion was successful which was defined as a persistent population for 200 days or reaching 1000 individuals (>99.99% of populations of this size persistent for another 200 days).

Design concepts – Successful point-source invasions of Qfly must overcome several obstacles: survival to sexual maturity, finding a sexually mature mate, finding fruit and depositing of eggs in a mature fruit, and the larvae surviving to adulthood. Stochasticity is inserted into the model in regard to landscape structure (e.g. each simulation has unique landscape), sex ratio of initial population and offspring (e.g. binomial distribution), fly movement patterns and survival probabilities (Bernoulli distributions) of both larval flies and adult flies. We explore the parameter space of the model assessing the model's sensitivity to each parameter.

Initialization – Initial founding population of flies were placed in the middle of landscape on a patch with the patch type (soil, fruit tree, non-fruiting tree) randomly. All flies are new adults (age = 0) and the sex is randomly determined (Binomial (0.5,N)). Parameters were initialized as described in Table 1. See 'Parameterization Rationale' in supplemental material.

2.2. Simulations and data analyses

Our main goal was to assess how biological and ecological characteristics affected the relationship between initial population size and probability of establishment. In particular, we were interested in the roles of demographic stochasticity, Allee effects, and the consequence of both processes. Towards this end, we ran three different simulation scenarios. First, we looked at only demographic stochasticity, then only Allee effects, and finally we combined both effects in a single model.

For each simulation scenario, we conducted a sensitivity analysis in which we systematically changed initial population size and one of the other parameters across the possible parameter ranges (Table 1) for 1000 simulations. Sensitivities are ratio of maximum a to minimum a, which were estimated from the dose-response curve fitted to the model results. For Allee and Demographic simulations, not all parameters were relevant to the simulation (see methods). Ranges for each parameter are listed in Table 1. For each simulation, we recorded if the population went extinct. For each parameter, we fitted the following probability of establishment described in (Leung et al., 2004):

$$P = P_{max}(1 - \exp(-a * N^c))$$

where P is the probability a population becomes established. N is the founding population size and a affects how quickly P increases with N.

Table 1
List of parameters used in the model including their initialization value. Initialization values were estimates from the literature, where possible. See 'Parameterization Rationale' in supplemental material. Type is whether the parameter is related to demographics or spatial attributes. Range values were represent extreme values for each parameter.

Category	Parameter	Short Name	Type	Qfly Value	Range	Description
Fly Invasion	Initial Population Size	PopSize			1–100	Number of founding flies.
Fly Mortality	Dispersal Mortality Rates	DisperseMort	Spatial and Demographic	0.009	0–0.032	The probability that a fly dies during a movement from one patch to another
	Non Dispersal Mortality Rates	NoDispMort	Demographic	0.009	0–0.032	The probability that a fly dies just staying in the same tree
	Offspring Mortality	OffspringMort	Demographic	0.4	0.2–0.6	The probability any given larva dies before adulthood.
Fly Dispersal	Probability of Dispersal When No Fruit	DispNoFruitProb	Spatial	0.7	0.1–1.0	The probability of dispersing on tree with no fruit
	Probability of Dispersal When With Fruit	DispFruitProb	Spatial	0.2	0–0.9	The probability of dispersing from a tree with fruit
	Correlatedness Of Movement	DispCorr	Spatial	0.5	0–1	The degree of correlatedness of subsequent movements (only within a dispersal event). 0 is Brownian and 1 is perfectly correlated
Fly Reproduction	Mate Calling Range	MateRange	Spatial	1	0.5–40	Distance (m) in which males can be detected by females during the mating period
	Number of Eggs Laid	EggNumber	Demographic	1	1–7	The number of eggs laid by a mated female during ovipositing event
	Probability Of Laying Eggs	EggProb	Demographic	1.0	0.2–1.0	The probability that a mated female lays eggs if in a fruiting tree
	Length Of Juvenile Period	JuvLength	Demographic	24	14–30	Number of days from egg to adult emergence
	Age Of Sexual Maturity	MateAge	Demographic	9	2–16	Number of days post-enclosion in which a fly sexually matures and will mate
Landscape	Probability of a patch having a tree	TreeProb	Spatial	0.4	0.1–1.0	The probability any given patch has a tree
	Probability that a tree is fruiting	FruitProb	Spatial	0.2	0.1–1.0	Given that a patch has a tree, this is the probability that the tree is fruiting.

P_{max} is the highest establishment probability. Here, we set $P_{max} = 1$. Finally, c affects the effectiveness of N and often represents Allee effects (Leung et al., 2004). We estimated c and a parameters using nonlinear least square means (*nls()* function in R). All curves had a good fit, with $R^2 > 0.96$ for all curves.

2.3. Demographic stochastic simulations

Demographic stochasticity is inherent to all small populations. In our model, this stochasticity is implemented through associating binomial distributions to sex ratio, adult mortality, juvenile mortality, egg laying probability, and offspring sex ratio. To assess the effect of demographic stochasticity without other processes (e.g. Allee effects), we converted the above model into a nonspatial model; in other words, we assume that all flies are in one tree and cannot disperse. Again, a male can only mate with a single female during each night. We ran the sensitivity analysis with only the non-spatial parameters (i.e. we excluded TreeProb, FruitProb, MatingRange, etc.)

2.4. Allee effect simulations

Besides demographic stochasticity, Allee effects can lead to population extinction. Finding mating partners has been one of the most explored mechanisms for Allee effects and has been proposed as a major factor for Qfly invasions (Dominiak, 2012; Meats, 1998). To assess its impact on Qfly invasions, we re-ran the model removing all demographic stochasticity from the model. Thus, we set initial founding population size as even numbers in which sex ratio was 1:1 exactly (Clarke and Dominiak, 2010; Fanson et al., 2014). There was no daily mortality risk as either adult or larva, but adult flies died upon reaching 40 days post eclosion. Females laid eggs in pairs with sex ratio of 1:1. Therefore, the lack of a population establishment is solely due to males and females not finding each other within 40 days. We ran these simulations altering all parameters affecting spatial patterns.

2.5. Full model simulations

The full model included both demographic stochasticity and Allee effects. The sensitivity analysis was run with all parameters.

2.6. Dispersal patterns

Finally, we wanted to know if the dispersal patterns that emerged from the model were similar to empirical finding for released flies. Previous research has shown that trapping patterns for released Qfly can be roughly described by a Cauchy distribution (Meats and Edgerton, 2008). Therefore, we tested whether movement patterns had a similar shape as a Cauchy distribution. We conducted simulations in which flies do not reproduce and recorded the total accumulated number of flies in each patch for 35 days (trapping length in Meats and Edgerton (2008)). Each simulation had 1000 flies and was repeated 100 times. Then, we calculated average number of Qfly visiting each distance after 35 days. Finally, we fitted a Cauchy distribution to these averages by estimating the distribution parameters (location and scale) for the Cauchy using maximum likelihood.

3. Results

3.1. Demographic stochastic simulation

Using a nonspatial model parameterized for Qfly, we estimated the establishment probability in relation to population size for all parameters due solely to demographic stochasticity. For the default Qfly values (Table 1), a population size of 2.0, 3.0, and 5.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). Background mortality rates (NoDispMort) and mating age had the largest effects on

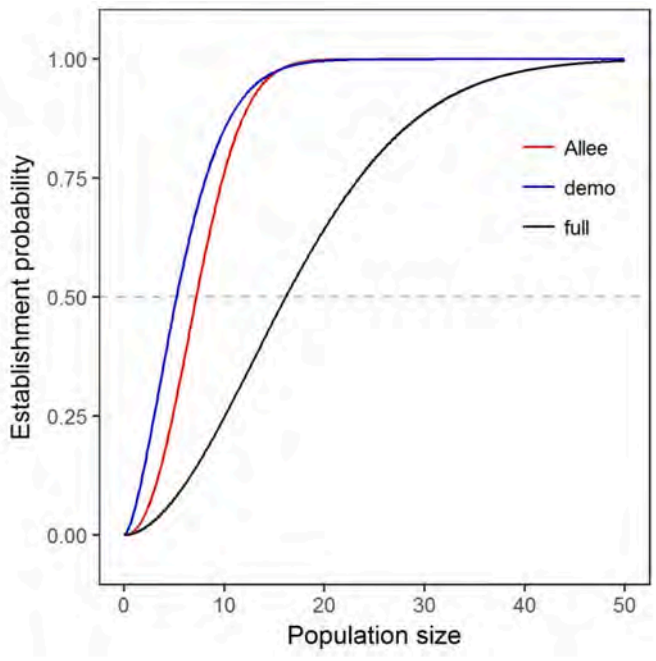


Fig. 3. Plot of the effect of population size on establishment success for each simulation scenario. Plot is the fitted model for the default parameters for Qfly (Table 1). Dashed line is 50% establishment rate.

the relationship between population size and establishment probability (Table 2; Fig. S2).

3.2. Allee effect simulations

Allee effects had slightly smaller effects than demographic stochasticity. For the default Qfly values (Table 1), a population size of 3.0, 4.9, and 7.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). As finding a mate is a key process for establishing a breeding population in this model, mating range had the largest effect (Table 2). Additionally and regarding landscape structure, the density of trees (TreeProb) had a large effect as tree density affects how far flies disperse, with low density of trees leading to further dispersal and hence lower establishment probability.

3.3. Full model simulations

Combining demographic stochasticity and Allee effects resulted in a sharp decrease in establishment probability, and we suggest a very strong interactive effect between the two processes (Fig. 3). For the default Qfly values (Table 1), a population size of 6.0, 10.2, and 16.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). Incursions >50 had greater than a >0.99 probability of becoming established.

The parameters having the greatest effect on establishment probability were non-dispersal mortality risk, mate range, and mate age (Table 2). Mortality reduced the number of flies available for mating and thus made it harder to find mates. Also, increasing the mate range had a large effect on establishment probability, mitigating the Allee effect of mate finding (Table 2). Finally, we found that the time to reproductive maturation (MateAge) strongly affected establishment probability (increasing age decreased establishment probability), as increasing age not only increased number of flies that die before reproduction, but also how far flies disperse into the environment (Table 2).

3.4. Dispersal patterns

Dispersal patterns from the simulations showed that the dispersal pattern in the simulation data were roughly described by a Cauchy distribution (Fig. 4). A main difference between the Cauchy and the simulation data is that the Cauchy distribution has a long tail that reflects long distance dispersal events (e.g. assisted dispersal due to human vehicles, wind storms), which were absent in the simulation. The estimated location factor for the Cauchy distribution was 16.1 m. We estimated the mean daily dispersal was 30 m.

4. Discussion

The main components of biological invasions can be divided into transport/arrival, establishment, and dispersal/range expansion (Kolar and Lodge, 2001). Qfly are one of the better studied Tephritid fruit flies and some information is known about the long distance transport of Qfly (Dominiak and Barchia, 2005; Dominiak et al., 2000; Dominiak and Coombes, 2009) and subsequent dispersal/range expansion of Qfly (Dominiak et al., 2003, 2013; Meats and Edgerton, 2008; Meats et al., 2006; Weldon and Meats, 2010). However, little information is known about what factors affect establishment success. Since Qfly incursions involve small population sizes, there are likely many stochastic events affecting establishment. The model results were well-approximated by dose-response curves and showed that mortality rates, mating range, and landscape structure had the largest effects on the dose-response curve shape.

Table 2
List of ranges in estimated *a* and sensitivities (S) in relation to the probability of obtaining a breeding population for each simulation scenario. Range of *a* is min - max. Sensitivities are ratio of maximum *a* to minimum *a*, which were estimated from the dose-response curve fitted to the model results. For Allee and Demographic simulations, not all parameters were relevant to the simulation (see methods). Ranges for each parameter are listed in Table 1.

Parameter	Allee		Demographic		Full Model	
	a	S	*a*	S	S	S
NoDispMort	–	–	0.0042–5.518	1322	3e-04-5.518	16703
MateRange	0–0.1	295.9	–	–	0–0.02	1293
DispNoFruitProb	0.01–0.03	2.2	–	–	1e-04-0.003	23.5
MateAge	0.01–0.03	3	0.0074–0.089	12.2	7e-04-0.015	19.9
TreeProb	0.01–0.04	3.7	–	–	0.001–0.006	5.6
OffspringMort	–	–	0.0127–0.037	2.9	8e-04-0.004	4.8
EggProb	–	–	0.0152–0.026	1.7	7e-04-0.002	3.2
DispCorr	0.01–0.03	3.9	–	–	0.001–0.003	3.1
DisperseMort	–	–	–	–	0.0017–0.004	2.2
DispFruitProb	0.01–0.05	4.9	–	–	0.0023–0.004	2.0
FruitProb	0.01–0.03	2	–	–	0.0015–0.003	1.8
EggNumber	0.01–0.02	1.3	0.0175–0.032	1.8	0.0022–0.004	1.7
JuvLength	0.01–0.02	1.3	0.0174–0.033	1.9	0.002–0.003	1.6

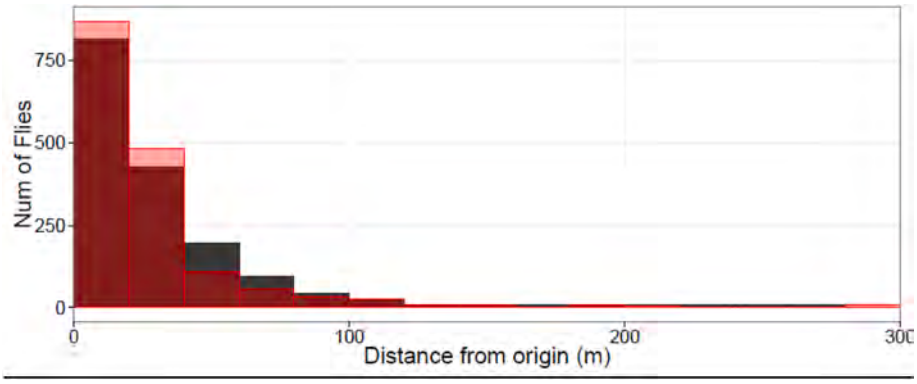


Fig. 4. Histogram of dispersal distances for default scenario. Red bars indicate predicted counts from Cauchy distribution. Black bars are simulation results. Note – The tail of the Cauchy is not shown since some values extend to greater than 100 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.1. Comparison to empirical curves

Our resulting relationship between initial population size and the probability of establishment was consistent with several experimental studies for other species. Our model predicted that ~20 individual Qfly leads to greater than 50% chance that the population will become established. The reverse aspects (of establishment) for eradication of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) were studied by Manoukis and Collier (2021). However, our model predictions are based on our assumptions. For instance, the mortality rate was based on our assumption that adult flies died upon reaching 40 days post eclosion. This assumption may not reflect reality but there is little published on actual field mortality. Also, mating age in the field will driven by several factors such as nutrition and our model may not reflect reality. However, our model is a good starting point to better understand invasion and successful establishment.

Though rare, a few empirical studies have quantified relationship between population size and establishment probability. For psyllids (Memmott et al., 2005), water fleas (Gertzen et al., 2011) and water-striders (Ahlroth et al., 2003), it takes about 20, 10, and 16 individuals, respectively, to obtain a 50% establishment rate. Using fish (topmouth gudgeon) instead of invertebrates, Britton and Gozlan (2013) found that between 10 and 20 individuals is needed for a 50% establishment probability. However, for chrysomelid beetles, between 200 and 500 individuals are needed for ~50% establishment (Grevstad, 1999). Furthermore, several case studies have found that several pest species were founded by small population, such as 5 individuals for muskrat (*Ondatra zibethicus*) introduction in Europe (Long, 2003) and 8 individuals of a parasite wasp (*Anarhopus sydneyensis*) in California (Clausen, 1978).

4.2. Mating range

Not surprisingly, the distance at which a female Qfly can detect a male had one of the largest effects on establishment probability. The default maximum distance was 5 m × 5 m, which equates to a large tree. Such a mating range is very short, compared to other species like moths, fireflies and mosquitoes (Cardé and Baker, 1984), but the empirical support on Qfly mating distance suggests such a short distance (Meats, 1998; Tychsen, 1978). Furthermore, the mating behaviour of Qfly appears to reflect short effective mating distance. Qfly only mate during a short temporal window at dusk, thus allowing little time for females to successfully find a male, assess the mate, and successfully commence copulation (Tychsen, 1978; Tychsen and Fletcher, 1971). Consequently, it is likely that Qfly use other cues to ensure close proximity to other flies at dusk, such as aggregating in fruiting trees (Dalby-Ball and Meats, 2000). In a previous Qfly dispersal model, Meats (1998) assumed uniform spread of Qfly and assumed only a 10% chance of mating if both a female and male were in a 5 m × 5 m patch. Based on our model results, we suggest that Qfly will clump in suitable fruit trees, increasing their overall density and likelihood of being in close proximity of a mate, which increases establishment probability. Previously, aggregation behaviour was identified as an important mechanism to assuage Allee effects, like finding mates in small populations (Stephens et al., 1999).

4.3. Landscape structure

One of the advantages of utilizing a spatially explicit IBM is that we could explore the effect of landscape. For our model, we found that the density of trees strongly affected fly dispersal patterns, with lower density environments leading to flies being more spread out. Since flies were further apart, the population experiences increased Allee effects due to it being more difficult to find a mate. Our model took a very simplistic approach to modelling tree layout in landscape. Much more realistic tree structures can be modelled to determine what attributes of these tree layouts hinder or promote establishment of fruit fly. Furthermore, detailed GIS data could be used to predict location-specific probability.

4.4. Dispersal

How well the model captured dispersal patterns in Qfly affects greatly the applicability of the model's results. The most directly comparable study is Meats and Edgerton (2008) in which immature flies were released in an orchard and a trapping grid spaced at 0.02 km was constructed. Then, Cauchy distributions were fitted to their trapping data, giving median estimates of 0.018 km and 0.028 km, consistent with our model results (Fig. 4). However, such estimates are much smaller than previous studies that estimate much higher mean dispersal distance (0.2–1.0 km; reviewed in (Dominiak, 2012; Dominiak and Fanson, 2020)). Part of the discrepancy is that other studies used mean distance instead of median, which will be higher than the median given the distribution shape of dispersal patterns. However, the mean dispersal in our study was 0.030 km. Despite their reputation as a major pest, Qfly spent 67.5% of their time walking, 18.0% being inactive, grooming 14% and only 0.6% of their time in flight (Weldon et al., 2010). This small investment in dispersal may explain the relatively short dispersal distances reported by recent authors (Dominiak and Fanson, 2020).

4.5. Factors not considered in model

Our model included several processes known to affect establishment probability, e.g. Allee effects, demographic stochasticity, environmental

stochasticity. Also with small populations, inbreeding avoidance and depression can play significant roles, leading to increased population extinction rates (Simberloff, 2009). Additionally, the model did not include environmental stochasticity, especially extreme climatic conditions like heat waves, cold snaps, drought, and floods were not included in this model. Adding these factors would decrease establishment probability, as our model represented environmentally favourable conditions and assumed no inbreeding depression. Thus, our model may be a conservative model from that perspective.

4.6. Qfly management

A better understanding of Qfly establishment is likely to result in two main areas of improved management; the optimising of exclusion techniques and an understanding of fruit fly populations below a breeding population. If the model delineated factors that affect incursion establishment, the appropriate level of exclusion techniques could be deployed in a cost-efficient manner to obtain a balance between costs of deployment and minimisation of the number of Qfly outbreaks and hence interference to domestic and international trade. Many strategies, such as MAT and surveillance, used by producers are based on the perceptions of the 1990's. Traditionally in surveillance, the larger 1 km array was used in orchards. The smaller grid was a 400 m array and this was used in urban areas. We suggest that these distances are inadequate based on our 0.03 km dispersal distance.

One of the techniques used in a Systems Approach is the use of MAT around the property boundary to trap (and effectively exclude) male flies. Based on our results, we recommend a closer distance between MAT devices to maximise this technique, compared with distances based on the 400 m perception or standard. Also, Systems Approaches use surveillance traps within the production area and many producers have transitioned from a 1 km array to a 400 m array to gain higher confidence that there is no breeding population on their property. Based on our results, another change would be to decrease the array distance between traps to improve the chances of detecting a fly. In a draft protocol for citrus, a 250 m array is being proposed (Kingham, pers. comm.). Both these changes come at an increased cost to producers however they increase the likelihood that Qfly will be excluded from the production site and that incursion flies will be detected early before a breeding population can establish. Additionally, this knowledge may revive the concept of "Areas of Low Pest Prevalence" (Dominiak et al., 2015; Jang, 2016; van Klinken et al., 2020) as both these changes increase the confidence that a breeding population is not present, even though some flies are present. This low level of flies is unlikely to breed because of the low probability that a male and female would be within 16 m of each other for the brief mating time at the end of the day.

Any decrease in distances between traps comes at a cost. More traps result in more time required to inspect and potentially more insects to identify and record. These increased costs may be sustainable if there are improved market access outcomes. Certainly, improved confidence is important but there may be other advantages including reduced shipping costs. These changes may result in no end point treatment being required because of the increased confidence that there is no breeding population and hence no immature fruit fly stages in traded fruit. The currently used end point treatments may contribute to global warming and any movement away from these techniques would be beneficial.

At a regional level, Florec et al. (2013) found it was more cost effective to exclude (e.g. use of roadblocks) Qfly than the costs of surveillance once Qfly entered and established in a zone. Random roadblocks in NSW operated on a maximum of 100 days in higher risk periods (Dominiak and Coombes, 2009). The roadblocks at the South Australian border operate every day and for 24 h in high-risk periods. Both program costs are significant. The travelling public obtain fruit from many sources and unregulated backyard or travelling fruit stalls are a source of particular concern. Surveys at roadside vehicle inspection points revealed that up to 18% of travellers carry fruit (Dominiak and Coombes, 2009). A small proportion is infested but this level is poorly understood and appears to vary with the season (Dominiak et al., 2000). While the proportion of travellers with fruit varies considerably, the number of fruit carried by each fruit carrying vehicle remained fairly constant at 6 to 7 items of fruit (Dominiak and Coombes, 2009). Also, it was reported that fines and community awareness programs result in declines in the proportion of vehicles carrying fruit (Dominiak and Barchia, 2005; Dominiak and Coombes, 2009). The travelling public act as the long distance "jump", often resulting in establishment and local dispersal (Sadler et al., 2011). Our model predicted that circa 16 and 50 flies were required for a 50% and 99% chance of establishment respectively. Hence knowledge about the host reproduction number (HRN) (Dominiak, 2022) and host suitability index (HSI) (Follett et al., 2021) becomes increasingly important to understand which carried fruit pose the highest risk to establishing fruit flies in previously uninfested areas. For instance, two kg of capsicum (*Capsicum annum* L.; HRN = 24) would be required to provide a 99% chance of establishment. Alternatively, only one third of kg of peaches (*Prunus persica* L.; HRN = 179) would provide the same chance of establishment (Follett et al., 2021). Produce inspections, feral tree management and community awareness programs would best focus on these higher HRN and HSI hosts as smaller quantities of these are more likely to result in establishment of a Qfly incursion. Roadside signs could be altered to highlight or target specific (high HRN) fruit and this would decrease the probability of infested fruit entering a fruit fly free area and establishing a breeding population.

With the restricted use of dimethoate and fenthion (Dominiak and Ekman, 2013), there will need to be alternative strategies developed to provide confidence that commercial fruit is not infested with Qfly. It seems increasingly likely that the main response will be a Systems Approach (Dominiak, 2019; Jang, 2016; van Klinken et al., 2020) and one option within this approach is the Area of Low Pest Prevalence (Dominiak et al., 2015). Relatively short dispersal distance and shorter mating distance allows growers to minimise incursions into their productions site. Feral trees in the immediate vicinity should be removed because increased distance between trees or possible hosts will lower likelihood of mating near the property boundary. In particular, fruiting trees should be removed; the host ranking for Qfly of fruit trees was provided in Follett et al. (2021). Our prediction of shorter dispersal distances is relatively consistent with Dominiak (2012) and Dominiak and Fanson (2020). These findings reinforce the concept of property isolation is the best defence for growers to produce fruit fly free fruit using a Systems Approach (Dominiak 2019). This concept can be achieved by altering the landscape structure by removing feral trees and tree corridors which support the movement of fly into the production site. Additionally, increased distance between trees does not favour Qfly matings because of their short mating range. Also, Qfly mortality had a large effect on the dose-response curve. Birds and ants are recognised predators. Therefore, strategies to encourage birds and ants could increase predation. Ants are commonly found in many orchards and frequently are controlled with pesticides. Weldon et al. (2020) reported that Qfly spent most of their time walking, grooming or were inactive and these activities make Qfly highly susceptible to ant predation.

Several areas require further research to better understand the establishment potential of Qfly. Some data on the capability of different host fruit to support different numbers of adult flies was only recently published (Follett et al., 2021) but more needs to be done. The knowledge of hosts and their HRN could be used to further fine tune this model to suit individual production systems or crops. For example, guava (*Psidium guajava* (L.) is widely grown as backyard fruit and has a high HRN and HSI for most tephritids (Dominiak, 2021). Our model could be used to investigate both urban and rural invasion potential, depending on the location and hosts.

5. Conclusion

Propagule pressure is one the best predictors of establishment

probability of a successful introduction of a new species (Lockwood et al., 2009). This effect is partly due to the stochastic processes in small populations such as random fluctuations in key factors as sex ratios, death rates, and birth rates that can lead to population extinction. Additionally, other processes, such as Allee effects, may be important processes in small populations. For Qfly invasions, it has been proposed that dispersal after a point source introduction from infested fruit may greatly reduce the probability of breeding as flies are too far apart to find each other at mating time. Our results are consistent with recent papers which indicate that natural dispersal distances are relatively short and not kilometres as reported in the 1980's (Meats and Edgerton 2008; Dominiak 2012; Dominiak et al., 2013; Dominiak and Fanson, 2020; Caton et al., 2021). Our model predicts that this explanation without demographic stochasticity processes only occurs at very low population sizes (<5 individuals). However, the interactive effect of demographic stochasticity and Allee effects does lead to substantial decrease in establishment probability with starting population size. It is possible to understand why most Qfly incursions appear to fail by combining the model results with information on transport of infested fruit.

This understanding will bring new insights into management concerns such as flight distance and hence incursion pressure. Changes in the deployment of MAT and distance between surveillance traps are likely to decrease the chance of a breeding population developing within the production site. Altering the landscape structure and encouragement of predators are two activities that producers can influence to minimise the likelihood of a Qfly establishment on or near their properties. Additionally, there will be a better understanding of the real threat of fruit infestation in areas of low pest prevalence and similar new phytosanitary strategies following the loss of dimethoate and fenthion. Additionally, a broader knowledge of HRN and HSI for Qfly will assist in making this model more useful for the production of Qfly free fruit and the decreased reliance on end point treatments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Jianhua Mo reviewed an early version and improved of this manuscript. New South Wales Department of Primary Industries partially funded this research. We thank the four journal reviewers for their valuable comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2022.106121.

References

Ahlroth, P., Alatalo, R., Holopainen, A., Kumpulainen, T., Suhonen, J., 2003. Founder population size and number of source populations enhance colonization success in waterstriders. Oecologia 137, 617–620. https://doi.org/10.1007/s00442-003-1344-y.

Bateman, M., 1977. Dispersal and species interaction as factors in the establishment and success of tropical fruit flies in new areas. Proc. Ecol. Soc. Aust. 10, 106–112.

Bateman, M.A., 1991. The Impact of Fruit Flies on Australian Horticulture: Horticultural Policy Council Report, vol. 3.

Bebber, D.P., Holmes, T., Smith, D., Gurr, S.J., 2014. Economic and physical determinants of the global distributions of crop pests and pathogens. New Phytol. 202, 901–910.

Boukal, D.S., Berec, L., 2002. Single-species models of the allee effect: extinction boundaries, sex ratios and mate encounters. J. Theor. Biol. 218, 375–394. https://doi.org/10.1006/jtbi.2002.3084.

Britton, J.R., Gozlan, R.E., 2013. How many founders for a biological invasion? Predicting introduction outcomes from propagule pressure. Ecology 94, 2558–2566.

Brodland, G.W., 2015. How computational models can help unlock biological systems. Semin. Cell Dev. Biol. 47, 62–73.

Cardé RT, Baker, T.C., 1984. Sexual communication with pheromones: chemical ecology of insects. In: WJ Bell & RT Cardé). Springer US, Boston, MA, pp. 355–383.

Caton, B.P., Fang, H., Manoukis, N.C., Pallipparambil, G.R., 2021. Quantifying insect dispersal distances from trapping detections data to predict delimiting survey radii. J. Appl. Entomol. 146, 203–216.

Clarke, A.R., Dominiak, B.C., 2010. Positive correlation of male and female *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae) catches in orange-ammonia traps. Gen. Appl. Entomol. 39, 9–13.

Clarke, A.R., Powell, K.S., Weldon, C.W., Taylor, P.W., 2011. The ecology of *Bactrocera tryoni* (Diptera: Tephritidae): what do we know to assist pest management? Ann. Appl. Biol. 158, 26–54. https://doi.org/10.1111/j.1744-7348.2010.00448.x.

Clausen, C.P., 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. In: Agriculture Handbook. United States Department of Agricultre.

Crespo-Perez, V., Rebaudo, F., Silvan, J.F., Dangles, O., 2011. Modeling invasive species spread in complex landscapes: the case of potato moth in Ecuador. Landsc. Ecol. 26, 1447–1461.

Dalby-Ball, G., Meats, A., 2000. Effects of fruit abundance within a tree canopy on the behaviour of wild and cultured Queensland fruit flies, Bactrocera tryoni (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 39, 201–207.

Dominiak, B.C., 2012. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Ann. Entomol. Soc. Am. 105, 434–446.

Dominiak, B.C., 2019. Components of a systems approach for the management of Queensland fruit fly Bactrocera tryoni (Froggatt) in a post dimethoate fenthion era. Crop Protect. 116, 56–67.

Dominiak, B., 2021. Guava Psidium guajava (L.) may have the potential to be a good host for many tephritids. Gen. Appl. Entomol. 49, 31–34.

Dominiak, BC, 2022. The use of Host Reproduction Number and Host Suitability Index to rank hosts of Fruit Flies in Africa. Int. J. Trop. Insect Sci. 42, 2717–2729.

Dominiak, B., Barchia, I., 2005. A survey of travellers carrying host fruit of Queensland fruit fly, Bactrocera tryoni (Froggatt), into a fruit fly free area in 1998/99 following road signposting of penalties for infringements. Plant Protect. Q. 20, 148–154.

Dominiak, B., Coombes, N., 2009. Fruit carrying characteristics of travellers into a quarantine zone in New South Wales in 1999/2000. Plant Protect. Q. 24.

Dominiak, B.C., Ekman, J.H., 2013. The rise and demise of control options for fruit fly in Australia. Crop Protect. 51, 57–67. https://doi.org/10.1016/j.cropro.2013.04.006.

Dominiak, B.C., Fanson, B.G., 2020. Current quarantine and suspension distances are excessive for incipient populations of Queensland fruit fly (Bactrocera tryoni (Froggatt))(Diptera: Tephritidae) in southern New South Wales, Australia. Crop Protect. 138, 105341.

Dominiak, B.C., Mapson, R., 2017. Revised distribution of Bactrocera tryoni in eastern Australia and effect on possible incursions of mediterranean fruit fly: development of Australia's eastern trading block. J. Econ. Entomol. 110, 2459–2465. https://doi.org/10.1093/jee/tox237.

Dominiak, B., Campbell, M., Cameron, G., Nicol, H., 2000. Review of vehicle inspection historical data as a tool to monitor the entry of hosts of Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera :Tephritidae) into a fruit fly free area. Aust. J. Exp. Agric. 40, 763–771.

Dominiak, B.C., Westcott, A., Barchia, I., 2003. Release of sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), at sydney, Australia. Aust. J. Exp. Agric. 43, 519–528.

Dominiak, B.C., Worsley, P.M., Nicol, H., 2013. Release from a point source and dispersal of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt))(Diptera: Tephritidae) at Wagga Wagga. Plant Protect. Q. 28, 120.

Dominiak, B.C., Wiseman, B., Anderson, C., Walsh, B., McMahon, M., Duthie, R., 2015. Definition of and management strategies for areas of low pest prevalence for Queensland fruit fly *Bactrocera tryoni* Froggatt. Crop Protect. 72, 41–46. https://doi.org/10.1016/j.cropro.2015.02.022.

Fanson, B.G., Taylor, P.W., 2012. Protein:carbohydrate ratios explain lifespan patterns found in Queensland fruit fly on diets varying in yeast:sugar ratios. Age 34, 1361–1368. https://doi.org/10.1007/s11357-011-9308-3.

Fanson, B.G., Sundaralingam, S., Jiang, L., Dominiak, B.C., D'Arcy, G., 2014. A review of 16 years of quality control parameters at a mass-rearing facility producing Queensland fruit fly, *Bactrocera tryoni*. Entomol. Exp. Appl. 151, 152–159.

Fletcher, B.S., 1974. The ecology of a natural population of the Queensland fruit fly, *Dacus tryoni* V. The dispersal of adults. Aust. J. Zool. 22, 189–202.

Florec, V., Sadler, R.J., White, B., Dominiak, B.C., 2013. Choosing the battles: the economics of area wide pest management for Queensland fruit fly. Food Pol. 38, 203–213..

Follett, P.A., Haynes, F.E., Dominiak, B.C., 2021. Host suitability index for polyphagous tephritid fruit flies. J. Econ. Entomol. 114, 1021–1034.

Gertzen, E., Leung, B., Yan, N., 2011. Propagule pressure, Allee effects and the probability of establishment of an invasive species (Bythotrephes longimanus). Ecosphere 2 art30.

Gozlan, R.E., Britton, J., Cowx, I., Copp, G., 2010. Current knowledge on non-native freshwater fish introductions. J. Fish. Biol. 76, 751–786.

Grevstad, F., 1999. Experimental invasions using biological control introductions: the influence of release size on the chance of population establishment. Biol. Invasions 1, 313–323. https://doi.org/10.1023/A:1010037912369.

Grimm, V., Railsback, S.F., Vincenot, C.E., Berger, U., Gallagher, C., DeAngelis, D.L., Edmonds, B., et al., 2020. The ODD protocol for describing agent-based and other simulation models: a second update to improve clarity, replication, and structural realism. J. Artif. Soc. Soc. Simulat. 23 (2), 2020.

Hancock, D.L., Hamacek, E.L., Lloyd, A.C., Elson-Harris, M.M., 2000. The Distribution and Host Plants of Fruit Flies (Diptera: Tephritidae) in Australia. DPI Publications, Brisbane, Australia.

Jang, E.B., 2016. Systems approaches for managing the phytosanitary risk of trading in commodities that are hosts of fruit flies. 737-751. In: Ekesi, S., Mohamed, S., de Meyer, M. (Eds.), Fruit Fly Research and Development in Africa - towards a Sustainable Management Strategy to Improve Horticulture. Springer International, Cham.

Keitt, T.H., Lewis, M.A., Holt, R.D., 2001. Allee effects, invasion pinning, and species' borders. Am. Nat. 157, 203–216.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16, 199–204.

Leung, B., Drake, J.M., Lodge, D.M., 2004. Predicting invasions: propagule pressure and the gravity of Allee effects. Ecology 85, 1651–1660.

Lewis, M.A., Petrovskii, S.V., Potts, J.R., 2016. The mathematics behind biological invasions. In: Antman, Greengard & Holmes, vol. 44. Springer International Publishing, Switzerland.

Lockwood, J.L., Cassey, P., Blackburn, T., 2005. The role of propagule pressure in explaining species invasions. Trends Ecol. Evol. 20, 223–228. https://doi.org/10.1016/j.tree.2005.02.004.

Lockwood, J.L., Cassey, P., Blackburn, T.M., 2009. The more you introduce the more you get: the role of colonization pressure and propagule pressure in invasion ecology. Divers. Distrib. 15, 904–910. https://doi.org/10.1111/j.1472-4642.2009.00594.x.

Long, J.L., 2003. Introduced Mammals of the World. Their History, Distribution and Influence. CABI, Wallingford, UK.

Lux, S.A., 2014. PESTonFARM - stochastic model of on-farm insect behaviour and their response to IPM interventions. J. Appl. Entomol. 138, 458–467.

Lux, S.A., 2018. Individual-based modeling approach to assessment of the impacts of landscape complexity and climate on dispersion, detectability and fate of incipient medfly populations. Front. Physiol. 8, 1121.

Manoukis, N.C., Collier, T.C., 2021. Agent-based simulations to determine mediterranean fruit fly declaration of eradication following outbreaks: concepts and practical examples. 869-888. In: Hendrichs, J., Pereira, R., Vreysen, M.J.B. (Eds.), Area-Wide Integrated Pest Management. CRC Press, Boca Raton, FL.

Meats, A., 1998. The power of trapping grids for detecting and estimating the size of invading propagules of the Queensland fruit fly and risks of subsequent infestation. Gen. Appl. Entomol. 28, 47–55.

Meats, A.W., Edgerton, J.E., 2008. Short- and long-distance dispersal of Queensland fruit fly, *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Agric. 48, 1237–1245.

Meats, A., Leighton, S.M., 2004. Protein consumption by mated, unmated, sterile and fertile adults of the Queensland fruit fly, *Bactrocera tryoni* and its relation to egg production. Physiol. Entomol. 29, 176–182.

Meats, A., Clift, A., Robson, M., 2003. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Anim. Prod. Sci. 43, 397–406.

Meats, A.W., Smallridge, C.J., Dominiak, B.C., 2006. Dispersion theory and the sterile insect technique: application to two species of fruit fly. Entomol. Exp. Appl. 119, 247–254.

Memmott, J., Craze, P.G., Harman, H.M., Syrett, P., Fowler, S.V., 2005. The effect of propagule size on the invasion of an alien insect. J. Anim. Ecol. 74, 50–62. https://doi.org/10.1111/j.1365-2656.2004.00896.x.

Perez-Staples, D., Prabhu, V., Taylor, P.W., 2007. Post-teneral protein feeding enhances sexual performance of Queensland fruit flies. Physiol. Entomol. 32, 225–232. https://doi.org/10.1111/j.1365-3032.2007.00568.x.

Prabhu, V., Perez-Staples, D., Taylor, P., 2008. Protein: carbohydrate ratios promoting sexual activity and longevity of male Queensland fruit flies. J. Appl. Entomol. 132, 575–582.

Sadler, R.J., Florec, V., White, B., Dominiak, B.C., et al., 2011. Calibrating a jump-diffusion model of an endemic invasive: metamodels, statistics and Qfly. Sustaining our future: Understanding and Living with Uncertainty, MODSIM 2011International Congress on Modelling and Simulation. Modelling and Simulation society of Australia and New Zealand., Perth, Australia.

Schmitz, D.C., Simberloff, D., 1997. Biological invasions: a growing threat. Issues Sci. Technol. 13, 33–40.

Shea, K., Possingham, H.P., 2000. Optimal release strategies for biological control agents: an application of stochastic dynamic programming to population management. J. Appl. Ecol. 37, 77–86. https://doi.org/10.1046/j.1365-2664.2000.00467.x.

Simberloff, D., 2009. The role of propagule pressure in biological invasions. Annu. Rev. Ecol. Evol. Syst. 40, 81–102.

Snyder, R.E., 2003. How demographic stochasticity can slow biological invasions. Ecology 84, 1333–1339. https://doi.org/10.1890/0012-9658(2003)084 [1333:HDSCSB]2.0.

Stephens, P.A., Sutherland, W.J., 1999. Consequences of the Allee effect for behaviour, ecology and conservation. Trends Ecol. Evol. 14, 401–405.

Stephens, P.A., Sutherland, W.J., Freckleton, R.P., 1999. What is the Allee effect? Oikos 185–190.

Taylor, P.W., Pérez-Staples, D., Weldon, C.W., Collins, S.R., Fanson, B.G., Yap, S., Smallridge, C., 2013. Post-teneral nutrition as an influence on reproductive development, sexual performance and longevity of Queensland fruit flies. J. Appl. Entomol. 137, 113–125. https://doi.org/10.1111/j.1439-0418.2011.01644.x.

Tychsen, P.H., 1978. Mating behaviour of the Queensland fruit fly, Dacus tryoni (Diptera: Tephritidae), in field cages. Aust. J. Entomol. 16, 459–465.

Tychsen, P.H., Fletcher, B.S., 1971. Studies on the rhythm of mating in the Queensland fruit fly, Dacus tryoni. J. Insect Physiol. 17, 2139–2156.

van Klinken, R.D., Fiedler, K., Kingham, L., Collins, K., Barbour, D., 2020. A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. Crop Protect. 129, 104994.

Weldon, C.W., 2007. Influence of male aggregation size on female visitation in *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 46, 29–34. https://doi.org/10.1111/j.1440-6055.2007.00587.x.

Weldon, C., Meats, A., 2010. Dispersal of mass-reared sterile, laboratory-domesticated and wild male Queensland fruit flies. J. Appl. Entomol. 134, 16–25. https://doi.org/10.1111/j.1439-0418.2009.01436.x.

Weldon, C.W., Prenter, J., Taylor, P.W., 2010. Activity patterns of Queensland fruit flies (*Bactrocera tryoni*) are affected by both mass-rearing and sterilization. Physiol. Entomol. 35, 148–153.

Wilensky, U., 1999. NetLogo (and NetLogo User Manual), Center for Connected Learning and Computer-Based Modeling, Northwestern University. http://ccl.northwestern.edu/netlogo/.

Williamson, M.H., Brown, K.C., Holdgate, M., Kornberg, H., Southwood, R., Mollison, D., 1986. The analysis and modelling of British invasions [and discussion]. Phil. Trans. Biol. Sci. 314, 505–522.

Yonow, T., Sutherst, R.W., 1998. The geographical distribution of the Queensland fruit fly, Bactrocera (Dacus) tryoni, in relation to climate. Aust. J. Agric. Res. 49, 935–953.

Yonow, T., Zalucki, M.P., Sutherst, R.W., Dominiak, B.C., Maywald, G.F., Maelzer, D.A., Kriticos, D.J., 2004. Modelling the population dynamics of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*: a cohort-based approach incorporating the effects of weather. Ecol. Model. 173, 9–30. https://doi.org/10.1016/S0304-3800(03)00306-5.

Crop Protection 138 (2020) 105341

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Current quarantine and suspension distances are excessive for incipient populations of Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) (Diptera: Tephritidae) in southern New South Wales, Australia

Bernard C. Dominiak [a,*], Benjamin G. Fanson [b]

[a] New South Wales Department of Primary Industries, 161 Kite Street, Orange, NSW, 2800, Australia
[b] School of Life and Environmental Sciences, Deakin University, Geelong, VIC, 3216, Australia

ARTICLE INFO

Keywords:
Flight distance
Trade
Invasions
Epicentre

ABSTRACT

The Queensland fruit fly (Qfly; *Bactrocera tryoni* Froggatt) is a major horticultural pest species in Australia and considered a serious quarantine concern, both domestically and internationally. When a Qfly outbreak is declared in the main horticultural regions of southeast Australia, a 15 km radius suspension zone is established (area of 707 km^2) around the epicentre of the outbreak. This suspension radius was originally adopted in the early 1990s. Here, we analysed trapping data in New South Wales (Australia) from 2002 to 2010 to evaluate the suitability of the 15 km suspension radius. There were 439 Qfly incursions recorded in Qfly-free zones, but only 9.9% of these incursions resulted in a declared outbreak. For these outbreaks, we conducted two distinct analyses. First, we modelled the distribution of infestation radii from the outbreaks and predicted the suspension distance using multiple levels of risk protection (e.g. probit 8.7, probit 9). Second, we fitted various probability distributions to individual fly trapping data and then estimated upper confidence limits for suspension distances, based on dispersal patterns of Qfly. Overall, the predicted suspension radii were substantially smaller than the current 15 km radius. Our results concur with other studies suggesting that Qfly are relatively poor colonisers. We propose that the current 15 km could be reduced substantially to 3 or 4 km.

1. Introduction

Tephritid fruit flies are significant pests of fruit production in most continents of the world. Different species have evolved in different regions (Krosch et al., 2012) and modern large scale trade has the potential to transport species into fruit fly free areas. For instance, Mediterranean fruit fly (Medfly) (*Ceratitis capitata* Wiedemann) originated in sub-Saharan Africa and has spread to every continent except for Antarctic (Malacrida et al., 2007). Hence, importing countries are understandably sensitive to the possible importation of fruit fly infested produce.

Horticultural products represent a significant contribution to Australia's economy. In Australia, more than $1 billion worth of products are traded domestically and are vulnerable to fruit fly pests. Furthermore, the total average export value for Australia's top 25 commodities that were fruit fly hosts has been estimated at $432 million (Plant Health Australia, 2009). The major threat to this horticultural economy is the native Queensland fruit fly (Qfly) (*Bactrocera tryoni* Froggatt).

Qfly originated in southern Queensland, but has now become distributed along the entire eastern Australian coast (Dominiak and Daniels, 2012). Also, Qfly became distributed inland into the main horticultural production areas along the Murray River. Following the wet seasons in the late 1990s, individual farm control programs were considered unsuccessful to access international trade and a regional management program was developed. The resulting zone became known as the Fruit Fly Exclusion Zone (FFEZ) and managed by a standard set of rules (Sutherst and Yonow, 1998). The initial design of proposed rules for this pest free area was reported by Bateman (1991). The "Code of Practice for the Management of Queensland fruit fly" (the Code) used the findings of Bateman (1991) as a basis. The Code became the universal management rules for all domestic trade and became the basis for international trade with 28 countries (Anonymous, 1997). Some rules such as the threshold for an outbreak have since been reviewed and verified (Dominiak et al., 2011). However other rules such as the reinstatement period and the suspension distance (sometimes called a quarantine distance) have not been reviewed to include research

* Corresponding author.
E-mail addresses: bernie.dominiak@gmail.com, bernie.dominiak@dpi.nsw.gov.au (B.C. Dominiak).

https://doi.org/10.1016/j.cropro.2020.105341
Received 15 May 2020; Received in revised form 27 July 2020; Accepted 30 July 2020
Available online 4 August 2020
0261-2194/© 2020 Elsevier Ltd. All rights reserved.

results since 1991.

In the early 1990s, many countries imposed a suspension distance for Qfly of 80 km, presumably based on one report of long distance flight (Macfarlane et al., 1987). In the review of data for suspension distances for outbreaks, Bateman (1991) reviewed 24 Qfly outbreaks over 11 years. Bateman (1991) found a mean radius of detections from these outbreaks of 0.2 km and a maximum recorded dispersal of 0.73 km. Using the formula for the area of a circle, these distances equate to an infested area of 0.13 and 1.5 sq km respectively. Bateman (1991) claimed "that suspension over a 10–15 km would afford a very generous margin of protection …". Regulators chose the more conservative 15 km; however, the reasons for this choice were not recorded. Simplistically, 15 km is about 20 times longer or about 470 times larger (based on area) than the worst dispersal distance. Perhaps the radius reduction from 80 km (about 20,114 sq km) to 15 km (about 707 sq km) was probably seen as a radical enough reduction but a reduction to 10 km (about 314 sq km) was too radical. The 15 km distance was implemented in 1993 and has been operational since then. The area within the suspension zone is 707 sq km: all produce within this area must be subjected to a disinfestation treatment before export to a fruit fly sensitive market. This was a vast improvement compared to 20,114 sq km associated with an 80 km suspension zone.

However, research since the early 1990s has challenged the validity of the 15 km rule. Several studies using the release of sterile flies have found that flies dispersed only hundreds of metres, not kilometres (e.g. Dominiak and Webster, 1998; Dominiak et al., 2003b; Weldon and Meats, 2007; Meats and Edgerton, 2008). Dominiak (2012) reviewed dispersal distances for Qfly from 21 studies showing that the 15 km suspension distance was very conservative. However, how to calculate a new quarantine distance standard is problematic.

Two distinct methods for estimating quarantine distances for Qfly have been proposed (see Meats et al. (2003), Meats and Edgerton (2008) and Dominiak (2012)). These methods approach suspension distances from very different directions. The first approach (population-level) analyses previous outbreaks, recording the furthest distance a fly is trapped and then fits a statistical model (e.g. linear regression) to predict the probability that a future outbreak has a fly dispersal beyond a specified distance. For instance, using historical data of outbreaks from 1974 to 2000 across Australia, Meats et al. (2003) analysed the relationship between maximal dispersal distances of adult flies and the size of the outbreak, as determined by capture rates in the epicentre during the first two weeks. Then they used regression models to predict the probability a fly disperses more than a specified distance. Meats et al. (2003) suggested that quarantine distances be determined by the probit 9 criteria.

Alternatively, quarantine distances can be estimated by understanding the underlying distribution of dispersal distances (aka individual-level). Much theoretical and empirical work has been conducted on describing patterns in animal movements (e.g.Viswanathan and Afanasyevt, 1996; Kokko and López-Sepulcre, 2006; Benhamou, 2007), including Qfly (Meats et al., 2006; Weldon and Meats, 2007; Meats and Edgerton, 2008; Gilchrist and Meats, 2012). If the underlying distribution is well-described, then distributional theory can be used to estimate the probability that an animal will disperse beyond a specified distance.

The distribution models are part of the suspension zone issue. The second consideration is an appropriate level of protection. Probit offers a range of standards (e.g. 9.0, 8.7, 8.1) however probit is used as a dose response measurement or to assess the percentage of a pest killed by a pesticide. Bliss (1934) proposed transforming the percentage killed into a "probability unit" or probit, and usually the number of treated insects is known or predetermined. Surveillance does not apply a dose to a fruit fly population being surveyed and the number of insects in the field is not known. Therefore, probit analysis is inappropriate for surveillance. However, many regulators are familiar with probit standards. Probit 9 was originally used for disinfestation (Cannon, 1998). Disinfestation often requires the treatment of 30,000 fruit fly. Surveillance of adults for outbreaks often involves less than 10 individuals. Probit 9 is a measure of mortality (RAP Pub, 2004/23). Pest risk pertains to the number of survivors and to an appropriate level of protection (ALOP). This is related to risk of entry, survival rate, reproductive potential and establishment, and not a mortality measure. Probit 9 could be too stringent in cases where the natural rate of pest infestation in the field is low (eg, early stages of incursion) and the chances of survival and reproduction are poor (RAP Pub, 2004/23). Subsequently probit 8.7 was used for disinfestation work in the Pacific area (RAP Pub, 2004/23). Meats and Clift (2005) claimed that 0.001 (probit 8.1) was an appropriate level of confidence for surveillance of domestic fruit flies but that probit 9 might be appropriate for exotic flies.

The goal of this study is to assess proposed suspension formulas for Qfly by reviewing Qfly outbreaks using historical trapping in New South Wales (NSW) from 2002 to 2010. We identified Qfly incursions at inland regions that had no permanent Qfly populations. There was a series of large outbreaks between 1998 and 2001 when many outbreaks merged (flies from adjacent outbreaks overlapped) and the data for each outbreak were too difficult to define into separate outbreaks. Also, the 2010–2011 period was the wettest two year period on record (Imielska, 2011; National Climate Centre, 2012) and again, detections for each individual outbreak overlapped and it became too difficult to maintain our assumptions and hence to analyse the dispersal data. For the 2002–2010 outbreaks, we calculate suspension distances using previously proposed methods and then evaluate the concordance of the predicted suspension distances. A range of confidence levels are examined.

2. Materials and methods

2.1. Surveillance protocol and Code of Practice

As part of the National Fruit Fly Surveillance Program in Australia, trapping grids were established across the export focused area in NSW, Australia. The density of the traps varied from 0.4 km (6.25 traps/km^{-1}) in urban areas to 1 km (1 trap/km^{-1}) in production areas. Traps comprise cuelure that attract male Qfly, and the killing agent maldison (Dominiak et al., 2003c). Traps were cleared fortnightly (June to October), weekly (November to May) or sooner during outbreaks (Anonymous, 1997).

The Code of Practice (CoP) were established in 1993 to provide a consistent approach for the management of Qfly infestations (Anonymous, 1997). This code indicated the triggers/responses required for different levels of fruit fly detection. The response depends on the number and frequency of trapped Qfly. If only 1 male Qfly was trapped within a radius of 1 km in a 2-week period, no action was taken. If 2 male flies were caught within 1 km in a 2-week period, this triggered the deployment of supplementary traps. These supplementary traps were set within 200 m of the primary trap and were checked biweekly. If ≥ 5 male flies were caught within 1 km and within a 2-week span, an outbreak was declared. At this point and not before, two types of localised chemical spraying for 12 weeks commenced, usually entailing protein bait spraying twice weekly within 200 m of the epicentre and weekly between 200 m and 1.5 km. Cover sprays with dimethoate or fenthion were used on infested trees as an immediate response. The soil under infested trees was treated with chlorpyrifos (Anon. 1997). In urban areas, fruit on suspect or infested trees was stripped and destroyed. As part of the clean-up programme, sterile insects may be released for 8–12 weeks after chemical treatment had stopped as these treatments will also kill sterile Qfly.

An outbreak was also declared if a gravid female Qfly was caught in a trap or Qfly larvae are discovered in locally grown fruit. Once an outbreak was declared, a 15-km suspension zone was established and remained in place for a minimum of 12 weeks (the reinstatement date) (see CoP for more information Anonymous (1997)). This reinstatement

period begins after the last fly is trapped. By default, 12 weeks or 84 days is the minimum period for reinstatement.

2.2. Experimental protocol.

We obtained data from the NSW Department of Primary Industries (DPI) by assessing the departmental database "PestMon" (Dominiak et al., 2007). These data sets consisted of trapping data between 2002 and 2010 and restricted to the main horticultural production areas in centre of NSW (Fig. 1). These production areas were considered to have no resident Qfly populations and hence all Qfly caught in these areas most likely represent incursions due to transport of infested fruit (Gilchrist et al., 2004). After 2010, uncharacteristic high levels of rainfall resulted in a rapid increase of Qfly outbreaks, making it impossible to tease apart incursions from newly established breeding populations (see Dominiak and Mapson, 2017).

The trapping data comprised geographical locations of trap (postal address or GPS coordinates), date of trap clearance and number of male and female Qfly caught. From these data, we extracted the following information:

1) Identification of all Qfly detections and determined if that detection was followed by an outbreak based on CoP criteria of larvae in locally grown fruit, one gravid female or 5 males within 1 km over 2 weeks.
2) Determination of the epicentre of the incursion, which was defined as the trap with the highest capture rates when an outbreak is declared (if multiple traps, then the average location).
3) Calculation of reinstatement date based on 12 weeks or 1 generation +28 days since last fly was caught, whichever is longer (Anonymous, 1997).
4) For every trapped fly from start of an outbreak to the reinstatement date, we calculated the shortest distance to the epicentre.
5) Trap location was used to identify if the trap was on a 400 m surveillance grid (urban area) or 1 km grid (orchard).

A complicating issue with this analysis was defining when a trapped fly should be considered from the same incursion. In general, outbreaks were well-defined with occasional exceptions. Therefore, we adopted the approach of Meats et al. (2003) for identifying separate incursions. Briefly, a trapped fly was considered a separate infestation if the fly is trapped more than 2 km from the epicentre and the distance from the epicentre is twice the distance of the next furthest fly detection, which indicates a large spatial gap between catches (Meats et al., 2003).

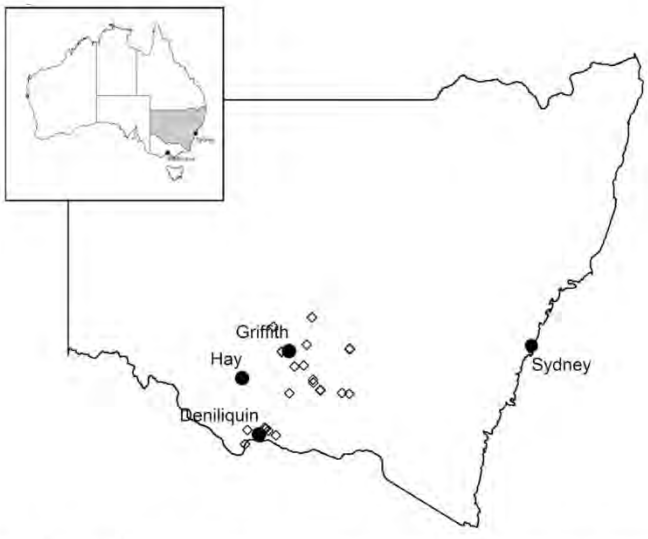


Fig. 1. Map of New South Wales showing locations of the outbreaks between 2002 and 2011.

Another complicating issue is that during an outbreak, supplementary traps (16 wet food lure MacPhail traps and 16 cuelure baited Lynfield traps) were deployed within 200 m of the epicentre. For these supplemental traps, exact geographical locations were not recorded as many traps remained in place for usually only a few weeks. Therefore, we used a conservative approach of adding 200 m to the distance from the primary trap site to the epicentre. Finally, for each outbreak, we assessed the trapping coverage. Only outbreaks that had sufficient trapping coverage were kept for the suspension analyses.

2.3. Data analysis

2.3.1. Unsuccessful Incursions Analysis

For all incursions, we calculated the number of fly detections that did not lead to an outbreak. A fly incursion was considered unsuccessful if < 5 flies were captured and no more flies were caught within 1 km in the next 2 weeks (Anonymous, 1997).

2.3.2. Population-Level Analysis

We adopted the approach from Meats et al. (2003) which used trapping data from 1974 to 2000. For the population-level approach, we recorded the furthest distance a fly is trapped for each outbreak and then fitted a general linear model to predict the probability that a future outbreak will have a single fly disperse beyond a specified distance. We also included capture totals for the first 2 weeks, grid type (0.4 km or 1 km) and production area type as predictor variables in the model. We then calculated the prediction intervals for multiple levels of protection (0.001 (probit 8.1), 0.0001 (probit 8.7), 0.00003 (probit 9)). The upper limit of these prediction intervals indicates the probability that a fly in a future outbreak will disperse further than the suspension distance.

2.3.3. Individual-level analysis

Another approach to estimating suspension distances was to use probability distributions to model the dispersal of flies during outbreaks. We tested six types of probability distributions; Cauchy, power, exponential, inverse square rule, normal, and shifted normal. The Cauchy and power distribution are 'fat' tailed distributions. For the power distribution, the standard approach was that dispersal pattern decay inverse to the square of the distance (Fletcher, 1974). The Cauchy distribution has previously been shown to fit dispersal patterns in sterile flies released from a central location, though its characteristic 'fat' tail at longer distances may be biologically inaccurate (Meats and Edgerton, 2008). Therefore, we compared the Cauchy with two other distributions that have 'skinnier' tails: the exponential and normal distributions. Both distributions have also been used to describe dispersal patterns (Chapman et al., 2007). The normal and the exponential distributions were both similar (depending if the scale factor was large or small, respectively) to the Cauchy near the release sites. However, both the normal and exponential have tails that were much skinnier and may better reflect actual dispersal limitations of flies. Finally, Dominiak (2012) argued for shifting the normal distribution from the epicentre. Thus, we included the shifted normal, which was just the normal distribution shifted by mean dispersal distance.

To fit the distributions, we estimated for each trapping grid type (orchard vs. urban) the characteristic parameters for each distribution using all male trapping results (averaged by trap numbers) within 5 weeks of the outbreak. For both the Cauchy and normal distributions, we assumed the location parameters were zero – in other words, centred on the epicentre. For the Cauchy distribution, the scale parameter can be estimated using the IQR range (Krishnamoorthy, 2010), but since dispersal distances were all positive due to the method of calculation, we estimated the scale parameter using the median of the dispersal distances (location of 50% of the data). The variance estimate for the normal distribution was calculated by obtaining the standard deviation assuming mean was zero. The shifted normal was estimated using mean dispersal data and the standard deviation based on that mean. For the

power distribution (defined by exponent and x_{min} (Clauset et al., 2009),), we used an exponent of 2 following Fletcher's inverse square law and estimated the x_{min} as 0.1 km. Finally, the exponential was calculated using mean dispersal distances.

Next, to assess the fit of the distribution, we estimated the expected number of trapped flies for each distribution at 0.4 km intervals (or 1 km for orchard) and then calculated the goodness-of-fit (χ^2) for each model. Additionally, we used the probability distributions to estimate the suspension distances for multiple levels of protection (probit 8.1, 8.7, and 9). This suspension distance was interpreted as the probability that a single fly will disperse beyond the suspension distance.

Finally, since the individual-level only estimated the probability that a single fly exceeds a certain distance, we estimated the quarantine distance required such that only 1% and 0.1% of outbreaks have one more flies disperse past the quarantine distance. Using the exponential distribution, we calculated these quarantine distances based on the level of protection, outbreak size, and mean dispersal distance for Qfly.

It is known that a mating requires two flies, therefore we repeated this analysis for the case where 2 or more flies (assuming that at least one is a male and one is a female (Clarke and Dominiak, 2010)) exceed the quarantine distances. The range of outbreak sizes were determined from the data and included all flies caught from start of incursion until the reinstatement date.

2.3.4. Practical implications

We examined the practical implications for different suspension distances by estimating the areas associated with each distance. We compared different areas (rather than distances) to demonstrate levels of protection.

3. Results

3.1. Unsuccessful incursions

To calculate the percentage of incursions that failed to cause an outbreak, we used all 439 fly incursions, of which 48 led to an outbreak. Overall, 90.1% of the Qfly incursions died out without any intervention (movement restrictions) or eradication measures (e.g. chemical spraying, SIT). The majority were 1-fly incursions (76.4%), followed by 2-fly (13.5%), 3-fly (7.8%) and 4-fly (2.3%) (Fig. 2).

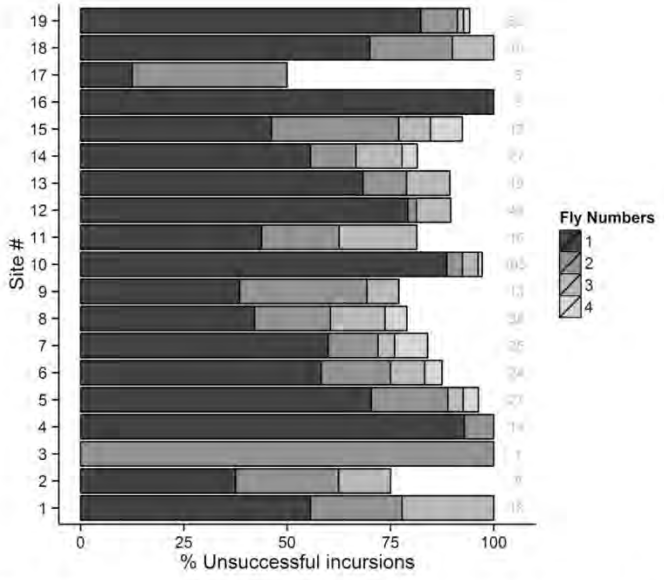


Fig. 2. Percentage of incursions resulting in an outbreak by location. Grey numbers indicate sample sizes (total number of flies caught) for each location. Different colours indicate max biweekly catch rate.

3.2. Population-Level Analysis

The linear model found no significant effect of total flies captured on maximum distance of male flies caught ($F_{1,26} = 2.55$, $p = 0.12$), production zone ($F_{2,26} = 0.13$, $p = 0.88$), or grid type ($F_{1,26} = 0.48$, $p = 0.49$) on maximum dispersal distance (Fig. 3). Since no predictors were significant, we re-ran the linear model with just the intercept and obtained upper prediction intervals of 6.2 km, 7.3 km and 7.8 km for probit 8.1, 8.7, and 9, respectively (Table 1).

3.3. Individual-level analysis

Overall, the exponential distribution fitted the dispersal distances the best, having the lowest goodness-of-fit scores (16.9 and 50.2 for the urban and orchard grids; Table 2). The next best fitting distributions were the normal, Cauchy, shifted normal, and finally power (Table 2). For the urban grid, the largest lack of fit for the exponential distribution was between 400 and 800 m in which the exponential distribution overestimated capture rates (Fig. 4). For the orchard, the main lack of fit was at the 3–4 km distance group, in which the exponential underestimated the capture rate. Using the estimated exponential parameters for the urban results (0.58 km) and the orchard (0.71 km) results, we estimated suspension distances of 4.0/4.8 km (urban/orchard) for probit 8.1, of 5.3/6.5 km for probit 8.7, and 6.0/7.3 km for probit 9 (Table 1).

However, statistical testing of the goodness-of-fit for the exponential results found that the trapping data were significantly different from the exponential distribution (urban, $df = 6, \chi^2 = 16.9$, $p = 0.01$; orchard, $df = 4, \chi^2 = 50.2$, $p < 0.0001$; Table 2), suggesting that dispersal pattern in Qfly do not exactly match the exponential distribution. Therefore, we estimated suspension distances for all distributions to better understand the sensitivity of any suspension estimates based on the exponential distribution (Table 1). The most notable difference among the distributions was the Cauchy distribution which had impracticably long suspension distances (e.g. 4244 km for probit 9), due to the fat tail of the distribution. The other distributions predicted significantly shorter suspension distances (Table 1).

Next, we used the formula recommended in Dominiak (2012) for calculating suspension distances. This formula, $\sqrt{10}$ (mean dispersal + 3 (SD of dispersal), is based on the Shifted Normal. We estimated a

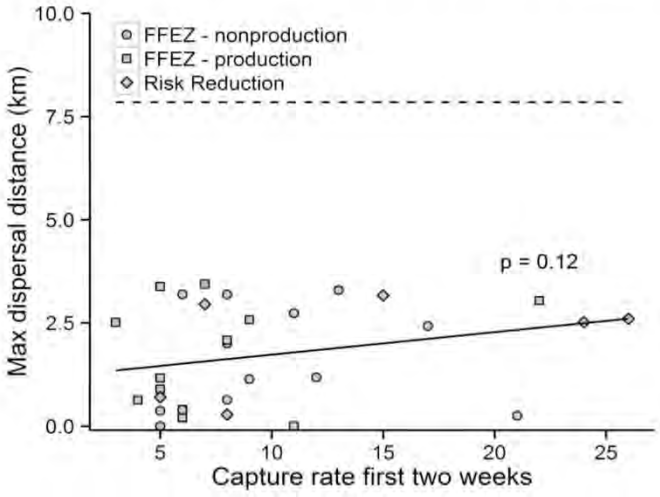


Fig. 3. Relationship between capture rates and maximum dispersal distance. Solid line shows the regression line; no significant effect of capture rates was found ($p = 0.12$). Dotted line is the upper prediction interval for $p = 3/100{,}000$. In the figure, "FFEZ – non production" indicates towns which had no production in their area but were within the FFEZ. "FFEZ – production" indicates towns in close proximity to fruit crops. "Risk Reduction" were towns in the area within 80 km of the FFEZ where Qfly populations were eradicated.

Table 1
Summary of quarantine distances. Mean quarantine distances (km) are listed at three levels of protection.

Method	Grid Type	Levels of Protection (km)		
		99.900% (probit 8.1)	99.990% (probit 8.7)	99.997% (probit 9)
Population level				
Regression	Combined	6.2	7.3	7.8
	Urban	5.7	6.7	7.2
	Orchard	24.7	51.4	75.9
Individual level				
Cauchy	Combined	127.3	1273	4244
Power	Combined	10.1	31.6	57.6
Exponential	Combined	4.3	5.8	6.5
	Urban	4.0	5.3	6.0
	Orchard	4.8	6.5	7.3
Normal	Combined	3.2	3.7	4.0
	Urban	2.7	3.2	3.4
	Orchard	3.8	4.5	4.8
Shifted normal	Combined	2.9	3.3	3.6
	Urban	2.3	2.7	2.9
	Orchard	3.5	4.1	4.4
$\sqrt{10}$* (Mean + 3SD)	Combined			8.9[a]
	Urban	NA	NA	7.2[a]
	Orchard			11.0[a]

[a] Actual level of protection is substantially higher than probit 9.

suspension distance of 7.2 and 11.0 km for 0.0001 and probit 9, respectively (Table 1).

Since we used outbreak data, we calculated quarantine distances based on different outbreak sizes (Table 3). A quarantine distance between 4.7 and 5.9 km (or 6.2–7.3 km) will result in 99% (or 99.9%) of the outbreaks having no flies exceeding the quarantine distance (Table 3). Since mating involves two flies of opposite sex to produce offspring, we also calculated quarantine distances for 2 or more flies, which gave ranges of 3.1–4.2 km (or 3.8–4.9 km) for 99% (or 99.9%).

4. Discussion

4.1. Qfly as poor colonizer

We found that only 9.9% of all Qfly incursions led to an outbreak. Furthermore, it also is likely that we missed other incursions, as Qfly lures are only effective for sexually-mature males 6–10 days post-eclosion (Perez-Staples et al., 2007). Therefore, at least some incursions were very likely to fail before males reached sexual maturity. Therefore, the 9.9% was likely a conservative estimate.

Our results were lower than the 29% outbreak rate by Meats et al. (2003) for trapping records from 1974 to 2000. The difference in incursion rates possibly reflects difference in geographical regions (climatic conditions) and the frequency of transport of infested fruits (Dominiak et al., 1998). Though the estimates differed, both estimates suggested that Qfly were poor colonizers. For instance, the Medfly had an estimate 82% successful outbreak rates (Meats et al., 2003). The lower colonization rates for Qfly were possibly due to the extended sexual maturation period (up to 10 days; Dominiak, 2012) and the shorter dispersal distances of Medfly. Also, other studies suggested that Qfly were poor colonizers (Bateman, 1972; Edge et al., 2001; Weldon, 2007).

4.2. Population-Level Analysis

Meats et al. (2003) conducted a similar analysis with outbreak data from 1974 to 2000 that included 262 incursions (75 outbreaks) in Adelaide region of South Australia (SA). Overall, our mean maximum dispersal was substantially longer than Meats et al. (2003) (1.8 km vs. ~0.5 km). Furthermore, our maximum dispersals were more variable than Meats et al. (2003). Consequently, Meats et al. (2003) found much shorter suspension distances for their regression model, around 2.0 km, in contrast to our analysis that estimated suspension distance of 7.8 km based on probit 9. Finally, our results found a lack of an effect of initial capture rates on maximum dispersal distance in the global model; whereas, Meats et al. (2003) found a significant positive relationship.

These differences may in part reflect the different methods of analysis. Since we were only interested in outbreak cases, we dropped non-outbreak incursions that were included by Meats et al. (2003). Since these small incursions appear to strongly influence the regression line in Meats et al. (2003), excluding these incursions likely explains why we found no significant effect of total capture rates on maximal dispersal distance. Furthermore, including these smaller incursions will also likely dampen the variance estimate.

However, the large differences in the average maximum dispersal distances (and hence suspension estimates) likely reflect actual differences. These differences can not to be explained solely by location effects (i.e. Adelaide vs. inland NSW). However, Reynolds et al. (2012) found differences in SIT results between SA and NSW but could not easily explain why. Meats et al. (2003) conducted a secondary analysis (though not clearly explained in the paper) that included incursion data from SA, Victoria (VIC), and NSW, and showed similar results among the states. Therefore, it appears that temporal differences (e.g. climatic

Table 2
Predicted values for each distribution for urban (0.4 km) and orchard (1.0 km) grids. Each row shows predicted number of flies caught for a given distance interval (km) for each distribution. χ^2 estimates are shown in parentheses. Bold shows best fitting distribution.

Distance group	Observed	Predicted Number (Deviance)				
		Cauchy	Power	Exponential	Normal	Shifted Normal
Urban Grid (0.4 km)						
[0.0,0.4)	174	221.3 (10.1)	251.2 (23.7)	157.2 (1.8)	118.7 (25.8)	105.3 (44.8)
[0.4,0.8)	54	43.7 (2.4)	27.9 (24.4)	78.5 (7.6)	93.5 (16.7)	97.1 (19.2)
[0.8,1.2)	44	16.0 (49.3)	10.7 (103.1)	39.2 (0.6)	58.1 (3.4)	68.2 (8.6)
[1.2,1.6)	24	8.2 (30.8)	5.7 (59.0)	19.6 (1.0)	28.4 (0.7)	31.9 (2.0)
[1.6,2.0)	10	4.9 (5.2)	3.5 (11.9)	9.8 (0.0)	11.0 (0.1)	9.5 (0.0)
[2.0,2.4)	3	3.3 (0.0)	2.4 (0.2)	4.9 (0.7)	3.3 (0.0)	1.8 (0.9)
[2.4,2.8]	5	2.4 (2.9)	1.7 (6.2)	2.4 (2.7)	0.8 (22.1)	0.2 (112.5)
[2.8,Inf)	0	7.1 (7.1)	11.2 (11.2)	2.4 (2.4)	0.2 (0.2)	0.0 (0.0)
Cumulative χ^2		(107.9)	(239.7)	(16.9)	(69.0)	(187.9)
Orchard Grid (1.0 km)						
[0,1)	144	175.7 (5.7)	182.7 (8.2)	152.8 (0.5)	123.2 (3.5)	119.7 (4.9)
[1,2)	32	12.5 (30.4)	8.7 (62.4)	36.7 (0.6)	61.0 (13.8)	65.1 (16.9)
[2,3)	13	4.2 (18.1)	3.1 (31.8)	8.8 (2.0)	14.9 (0.2)	14.9 (0.2)
[3,4]	12	2.1 (45.9)	1.6 (68.6)	2.1 (46.4)	1.8 (58.1)	1.2 (96.4)
[4,Inf)	0	3.2 (3.2)	5.0 (5.0)	0.7 (0.7)	0.1 (0.1)	0.0 (0.0)
Cumulativeχ^2		(103.3)	(176.1)	(50.2)	(75.7)	(118.4)

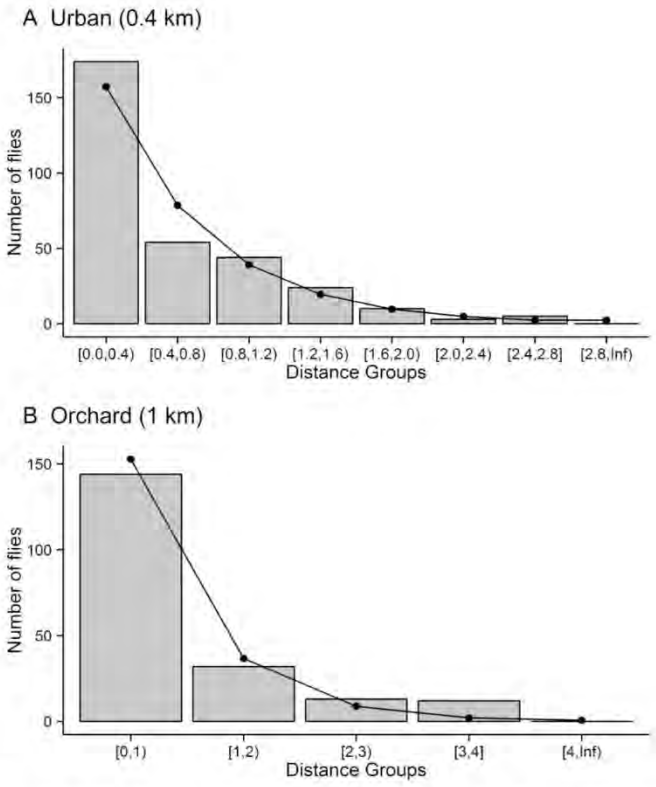


Fig. 4. Observed trapping rates compared to the predicted rates from the exponential distribution. Top plot shows urban trapping grid and the bottom plot is the orchard trapping grid. Bars show the actual trapping data and black line indicates predicted rate from the exponential distribution.

Table 3
Estimated quarantine distances based on outbreaks of different sizes. For varying outbreak sizes, we estimated the quarantine distance required such that only 1% and 0.1% of the outbreaks have one or more flies (and two or more flies) disperse past the quarantine distance.

Outbreak Size	Levels of Protection (km)			
	0.01 (1%)		0.001 (0.1%)	
	≥1 flies	≥2 flies	≥1 flies	≥2 flies
20	4.7	3.1	6.2	3.8
40	5.2	3.5	6.6	4.2
60	5.4	3.7	6.9	4.5
80	5.6	3.9	7.1	4.7
100	5.8	4.1	7.2	4.8
120	5.9	4.2	7.3	4.9

conditions, spraying methods for managing Qfly outbreaks, habitat structure) may be responsible for these differences.

4.3. Individual-level analysis

Exponential and normal distributions have been commonly used to describe animal movement in ecology, although some studies found that animal movements may be better described using distribution with 'fatter' tails (Viswanathan and Afanasyevt, 1996; Chapman et al., 2007; Meats and Edgerton, 2008). We found that the exponential distribution fitted the data better than other distributions for both grid types.

In a comparable analysis, Meats and Edgerton (2008) fitted a Cauchy distribution to short range dispersal of both sexually immature and mature flies (laboratory reared), and long range dispersal across multiple research studies. The Cauchy distribution fitted their trapping data well, though no comparison to the exponential was performed. The main difference between the Cauchy and the exponential is the fatness of the tail, and this is seen by the extreme large suspension estimate for the Cauchy (4244 km for probit 9). The Cauchy distribution arises when an animal moves with a mix of short and long trajectories.

Little is known about how individual flies move through their environment, though most flights are assumed to be short (reviewed in Dominiak, 2012). However, it would not be surprising due to environmental (e.g. wind storm) and/or human factors (e.g. vehicular transport), occasionally Qfly is transported a long distance in infested fruit. Some of these aspects are known. Regarding wind, Dominiak et al. (2003a), Dominiak et al. (2013), and Worsley et al. (2008) could not demonstrate any influence of wind on fruit fly distribution; however, additional research is needed to be more confident in this aspect. Regarding human transport, Dominiak et al. (1998) demonstrated that 18% of unregulated vehicle movements carried fruit. Community awareness and spot fines reduced fruit carriage to 5.4% (Dominiak and Coombes, 2009). However, there have been no studies on the accidental transport of wild flies. We cannot include or exclude any of these factors. If so, then it may be that fly movements actually follow more of a normal or exponential distribution (skinnier tail distribution), but these accidental transport modes result in a Cauchy-like distribution.

4.4. Quality of estimates

There are several caveats in using natural Qfly outbreaks. First, it is possible to misdiagnose a trapped fly as belonging to an outbreak when it was actually a separate incursion. The majority of Qfly outbreaks in the inland NSW towns were assumed to be caused by the introduction of infested fruit consignments. It is very possible that these infested fruit consignments may be divided, resulting in multiple infestations. Analysis of fruit carriage by the travelling public has demonstrated that families (the second highest carriage group) travel more frequently during school holidays and these periods are more likely to result in multiple incursions (Dominiak and Coombes, 2009).

Another important caveat was the sparseness of the trapping grids at further distances. Around epicentres, trapping locations were usually well populated. However, after a few kilometres, trapping locations often become sparse, occurring in distinct clumps. Therefore, we could be missing the majority of long-distance dispersers, although these may self-extinguish for lack of hosts, shelter and nutrition. The sparseness of the trapping grid would lead to underestimation of suspension distances. On the other hand, the opposite result could also be true. Trapping grids were mostly placed in town locations. If long distance Qfly movements were mainly due to human transport, we may be actually transporting Qfly directly from one trapping grid to another. Therefore, the surrounding environment may actually be at a much lower risk than the trapping evidence suggests. There are more humans per square kilometre in urban areas compared to horticultural production areas. Therefore, it is more likely that incursions will occur where more humans live, i.e. in urban areas.

Based on Table 3, there is little support for the 15 km rule, and there was even less support for the 30 km rule for large outbreaks. There appears to be no reasoning for the 30 km rule other than it was twice 15 km. In Table 3 for different outbreak size, an increase from 20 flies to 100 flies does not result in a five times increase in the dispersal distance. So how should a larger outbreak be handled? Whatever way is decided, doubling the suspension zone has no scientific support. Also, Table 3 highlights another aspect. If we examine the 20 fly outbreak at 0.001 level of protection, the data indicate that one fly might reach the 6.2 km distance. However, two flies (male and female) are needed for a mating, and we see that two flies might reach 3.8 km. However, if events were completely random, then these two flies would be distributed in the circumstance of a 3.8 km radius circle. This circumference was estimated to be nearly 24 km. If everything was random, then these two flies would be about 12 km apart (on opposite sides on the circumference) at mating time. Not surprisingly, flies near the epicentre would be closer.

Therefore, while we put forward the one and two fly calculation in Table 3, we ponder if this has any merit based on the mean and maximum dispersal distance, other than to demonstrate the lack of support for doubling the suspension distance.

4.5. The elephant in the room – levels of protection and surveillance efficiency

The major issue in our paper is the appropriate level of protection. There is an apparent absence of scientific peer reviewed papers of surveillance and levels of protection. We have been obligated to provide a range of protection levels at every step. One pressing need for the future is a consensus of surveillance and appropriate risk levels. Preferably, we need to establish the standard method to calculate the risk based on factors such as pest biology (dispersal) and efficiency of surveillance traps.

One approach for this is the statistical calculations (probit 9, etc), assuming the probit method is deemed appropriate. Another method is the more practical approach in Table 4. If countries (such as Australia) can demonstrate the dispersal distances of particular species (such as Qfly), and it is accepted that dispersal is based on area (not radius), then a simple level of protection could be applied based on area. Given that the calculation of mean dispersal is probably more reliable than the maximum dispersal distance, then a level of protection could be applied to mean dispersal distance such that it encompasses the maximum dispersal distance. This recognises that while a small number may disperse longer distances, these are invariable over dispersed, as demonstrated in the circumference example. Alternatively, the suspension zone could be based on a smaller multiplier of the area subjected to bait spray, knowing that the over-dispersed flies are further punished by the spray program. From Table 4, four times the baited area (7.1 sq km) would result in a suspension zone of 28.4 sq km, or a suspension distance of about 3 km.

The rationale for the current 15 km suspension distance is not explicitly clear nor statistically-based. Though our study has limitations, we provided a formal analysis that allows for a systematic evaluation of the suspension distance.

4.6. Practical implications

The practical implications of the choice of suspension distance is provided in Table 4. The mean and maximum dispersal are calculated from the data as described above. A breeding population must lie somewhere in between these two distances. There are no clear data to estimate the area occupied by a breeding population, so for simplicity to get one sq km, we estimate that the breeding population exists at 0.57 km from the epicentre. We actually think it is closer to the mean than the maximum however for the current paper, we postulate that the breeding population covers an area of one sq km. If this is so, the area requiring bait spray in seven times larger than the breeding population and the current suspension zone is 707 times larger than the proposed breeding area.

4.7. Recommendations

There are few definitive conclusions in our study. Accidental long distance transport of Qfly results in a Cauchy-like distribution. However, all other analyses indicate that the current 15 km suspension distance is excessive for natural dispersal. Additionally, there are no data to support a 10 km suspension distance. While there is support that suspension zones should be shorter than 10 or 15 km, the recommended suspension zone varied depending on the ALOP. Also, we recommend that the exponential distribution is used, however other countries or jurisdictions may choose a different distribution.

Many surveillance experts claim that probit 9 is inappropriate because it is a response dose statistic that is not readily adaptable to surveillance approaches. However, if the probit 9 standard or its equivalent is adopted using exponential distribution, then the rural/urban combined data result in a suspension distance of 6.5 km. Another option is to claim a different suspension distances for orchard (7.3 km) and urban (6.0 km) areas. These are likely to be the worst case scenario.

If probit 8.7 is chosen, then we predict that 5.8 km for the combined data or 6.5 km or 5.3 km for orchard and urban areas respectively. If the Meats et al. (2003) standard of probit 8.1 is used, then the distances become 4.3, 4.8 and 4.0 for each of these areas.

However, these suspension distances predict an ALOP for a single fly. Is this appropriate? Single flies are not reproductive - it takes a male and a female to become reproductive. Mated females stay near fruiting trees and therefore mated females are unlikely to travel these distances. However, even the two fly calculation is questionable as we demonstrated by the circumference example.

Table 4
The estimated areas requiring disinfestation for fruit fly sensitive markets based on different suspension distances.

Suspension radius (km)	Suspension area (sq km)	Characteristics
0.2	0.13	Mean dispersal
0.57	1.0	Possible breeding area
0.73	1.5	Maximum dispersal
1.5	7.1	Bait spraying in Anon. (1997)
3.0	28	
4.0	50.3	Proposed new suspension
5.0	78.6	
7.2	162.9	USA standard
7.5	176.8	Half the current Australian standard (Anon. 1997)
15	707	Current Australian standard (Anon. 1997)
30	2828	Current Australian standard for large outbreaks (Anon. 1997)
80	20,114	Quarantine distance before 1996

Author contribution

Both authors were involved in the original idea and manuscript construction. Bernie Dominiak accessed the data and Ben Fanson conducted the analysis. Fine tuning of final theories and presentation was conducted by both authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Inspectors who cleared the traps using the bar code readers to record information and sent samples for identification are gratefully acknowledged. The identification staff at Orange Agricultural Institute who identified wild and sterile flies greatly contributed to the program. Staff who maintained the NSW DPI PestMon database and the ICT links are gratefully acknowledged. Dr Pat Barkley made useful comments on an early version of this paper. This research was funded by the NSW Department of Primary Industries.

References

Anonymous, 1997. Code of Practice for the Management of Queensland Fruit Fly. In: Standing Committee on Agriculture and Resource Management. Canberra, Australia.
Bateman, M.A., 1972. The ecology of fruit flies. Annu. Rev. Entomol. 17, 493–518.
Bateman, M.A., 1991. The Impact of Fruit Flies on Australian Horticulture, vol. 3. Horticultural Policy Council Report, Canberra, (. Australia).

Benhamou, S., 2007. How many animals really do the Levy walk? Ecology 88, 1962–1969.
Bliss, C.I., 1934. The method of probits. Science 79, 38–39.
Cannon, R., 1998. Sampling to comply with a maximum pest limit. Biometrics 847–858.
Chapman, D.S., Dytham, C., Oxford, G.S., 2007. Modelling population redistribution in a leaf beetle: an evaluation of alternative dispersal functions. J. Anim. Ecol. 76, 36–44.
Clarke, A.R., Dominiak, B.C., 2010. Positive correlation of male and female *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae) catches in orange-ammonia traps. Gen. Appl. Entomol. 39, 9–13.
Clauset, A., Shalizi, C.R., Newman, M.E., 2009. Power-law distributions in empirical data. SIAM Rev. 51, 661–703.
Dominiak, B., Coombes, N., 2009. Fruit carrying characteristics of travellers into a quarantine zone in New South Wales in 1999/2000. Plant Protect. Q. 24.
Dominiak, B., Rafferty, T., Barchia, I., 1998. An analysis of travellers carrying fruit near Griffith, NSW, during Easter 1996 to assess the risk of Queensland fruit fly (Bactrocera tryoni Froggatt). Gen. Appl. Entomol. 28, 13–19.
Dominiak, B., Gillespie, P., Tom, G., 2007. Changes in data management and the impediments to change-a case study for fruit fly surveillance. Plant Protect. Q. 22, 95.
Dominiak, B.C., 2012. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Ann. Entomol. Soc. Am. 105, 434–446.
Dominiak, B.C., Webster, A., 1998. Sand bed release of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) at Young, NSW. Gen. Appl. Entomol. 28, 9–11.
Dominiak, B.C., Daniels, D., 2012. Review of the past and present distribution of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) and Queensland fruit fly (*Bactrocera tryoni* Froggatt) in Australia. Aust. J. Entomol. 51, 104–115.
Dominiak, B.C., Mapson, R., 2017. Revised distribution of Bactrocera tryoni in eastern Australia and effect on possible incursions of mediterranean fruit fly: development of Australia's eastern trading block. J. Econ. Entomol. 110, 2459–2465.
Dominiak, B.C., Westcott, A., Barchia, I., 2003a. Release of sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), at Sydney, Australia. Aust. J. Exp. Agric. 43, 519–528.
Dominiak, B.C., McLeod, L., Landon, R., 2003b. Further development of a low-cost release method for sterile Queensland fruit fly *Bactrocera tryoni* (Froggatt) in rural New South Wales. Aust. J. Exp. Agric. 43, 407–417.
Dominiak, B.C., Daniels, D., Mapson, R., 2011. Review of the outbreak threshold for Queensland fruit fly ('Bactrocera tryoni'Froggatt). Plant Protect. Q. 26, 141.
Dominiak, B.C., Worsley, P.M., Nicol, H., 2013. Release from a point source and dispersal of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt))(Diptera: Tephritidae) at Wagga Wagga. Plant Protect. Q. 28, 120.
Dominiak, B.C., Gilmour, A., Kerruish, B., Whitehead, D., 2003c. Detecting low populations of Queensland fruit fly, *Bactrocera tryoni* (Froggatt) with McPhail and Lynfield traps. Gen. Appl. Entomol. 32, 49–53.
Edge, V., Gardner, R., Green, A., Cook, K., Cornish, J., 2001. In: Technical Review of the Tri-state Strategy for Queensland Fruit Fly, p. 62. R. t. S. C. o. A. a. R. Management.
Fletcher, B.S., 1974. The ecology of a natural population of the Queensland fruit fly, *Dacus tryoni* V. The dispersal of adults. Aust. J. Zool. 22, 189–202.
Gilchrist, A.S., Meats, A.W., 2012. Factors affecting the dispersal of large-scale releases of the Queensland fruit fly, Bactrocera tryoni. J. Appl. Entomol. 136, 252–262.
Gilchrist, A.S., Sved, J.A., Meats, A., 2004. Genetic relations between outbreaks of the Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), in Adelaide in 2000 and 2002. Aust. J. Entomol. 43, 157–163.
Imielska, A., 2011. Seasonal climate summary southern hemisphere (summer 2010-2011): second-wettest Australian summer on record and one of the strongest La Niña events on record. Australian Meteorological and Oceanographic Journal 61, 241.
Kokko, H., López-Sepulcre, A., 2006. From individual dispersal to species ranges: perspectives for a changing world. Science 313, 789–791.
Krishnamoorthy, K., 2010. Handbook of Statistical Distributions with Applications. Taylor & Francis.
Krosch, M.N., Schutze, M.K., Armstrong, K.F., Graham, G.C., Yeates, D.K., Clarke, A.R., 2012. A molecular phylogeny for the Tribe Dacini (Diptera: Tephritidae): systematic and biogeographic implications. Mol. Phylogenet. Evol. 64, 513–523.
Macfarlane, J., East, R., Drew, R., Betlinski, G., 1987. Dispersal of irradiated Queensland fruit-flies, dacus-tryoni (Froggatt) (Diptera, Tephritidae), in southeastern Australia. Aust. J. Zool. 35, 275–281.
Malacrida, A., Gomulski, L., Bonizzoni, M., Bertin, S., Gasperi, G., Guglielmino, C., 2007. Globalization and fruitfly invasion and expansion: the medfly paradigm. Genetica 131, 1–9.
Meats, A., Clift, A., 2005. Zero catch criteria for declaring eradication of tephritid fruit flies: the probabilities. Anim. Prod. Sci. 45, 1335–1340.
Meats, A., Clift, A., Robson, M., 2003. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Anim. Prod. Sci. 43, 397–406.
Meats, A.W., Edgerton, J.E., 2008. Short- and long-distance dispersal of Queensland fruit fly, *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Agric. 48, 1237–1245.
Meats, A.W., Smallridge, C.J., Dominiak, B.C., 2006. Dispersion theory and the sterile insect technique: application to two species of fruit fly. Entomol. Exp. Appl. 119, 247–254.
National Climate Centre, 2012. Special Climate Statement 38: Australia's Wettest Two-Year Period on Record; 2010–2011. Australia's National Meteorological Service. Bureau of Meteorology.
Perez-Staples, D., Prabhu, V., Taylor, P.W., 2007. Post-teneral protein feeding enhances sexual performance of Queensland fruit flies. Physiol. Entomol. 32, 225–232.
Plant Health Australia, 2009. The National Plant Health Status Report 08/09. Plant Health Australia, Canberra (ACT, Australia).
RAP Pub, 2004/23. Rregional Standards for Phytosanitary Measures. RAP publication.
Reynolds, O.L., Smallridge, C.J., Cockington, V.G., Penrose, L.D., 2012. The effect of release method and trial site on recapture rates of adult sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. vol. 51, 116–126.
Sutherst, R.W., Yonow, T., 1998. The geographical distribution of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*, in relation to climate. Aust. J. Agric. Res. 49, 935–954.
Viswanathan, G., Afanasyevt, V., 1996. Lévy flight search patterns of wandering albatrosses. Nature 381, 30.
Weldon, C.W., 2007. Influence of male aggregation size on female visitation in *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 46, 29–34.
Weldon, C.W., Meats, A., 2007. Short-range dispersal of recently emerged males and females of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) monitored by sticky sphere traps baited with protein and Lynfield traps baited with cue-lure. Aust. J. Entomol. 46, 160–166.
Worsley, P.M., Dominiak, B.C., Gilmour, A.R., James, D.G., 2008. Pilot study at Cowra of intra-town dynamics of Queensland Fruit Fly (*Bactrocera tryoni* (Froggatt)) populations based on trap catch data. Plant Protect. Q. 23, 86–89.

Doc 9

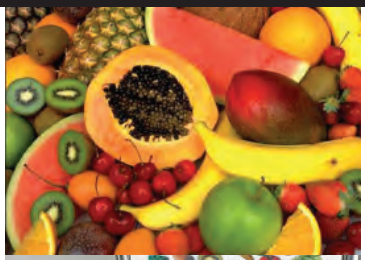
AUSTRALIAN INTERSTATE QUARANTINE

A TRAVELLER'S GUIDE

Quarantine Domestic

CHECK WHAT YOU'RE CARRYING. PENALTIES APPLY.

ENJOY YOUR TRIP AND LOOK AFTER AUSTRALIA



September 2021
ISBN: 978-0-9944022-1-9

PLEASE NOTE:

This document is a guide only for private interstate travellers.

Commercial importers and exporters must follow information for producers on the Interstate Quarantine website.

Help us protect our agricultural industries and environment from pests and diseases.

Use this simple guide before you travel and keep it with you. It will help you check what you can and can't take across state and quarantine borders and avoid on-the-spot fines.

CONTENTS

State and quarantine borders 3
Key 3
NSW (including ACT) 4
Northern Territory 6
Queensland 8
South Australia 10
Tasmania 12
Victoria 14
Western Australia 16
Some of the major threats 18
Further information 19

STAY UP TO DATE:

Quarantine requirements may change as new pests, diseases and weeds are detected.

For the most up to date information, visit the Interstate Quarantine website **interstatequarantine.org.au** or telephone 1800 084 881 during business hours Mon-Fri.

AUSTRALIA'S INTERSTATE QUARANTINE AND BIOSECURITY RULES

Pests, diseases and weeds can travel with you as you visit different areas of Australia. There are restrictions on what you can take as you cross state and quarantine borders within Australia. Travellers face on-the-spot fines for taking prohibited items across borders.

Check before you travel

It's always good to check any restrictions that might apply to your trip. You can also check restrictions online at **interstatequarantine.org.au** or by ringing Freecall 1800 084 881 (business hours Mon-Fri)

Eat it or bin it

If you reach a border with produce that can't be taken across, eat it or bin it. There are interstate quarantine bins at some domestic airports, ferry terminals and state and quarantine zone borders. You must dispose of any restricted products at that point. That way you can be sure you're not giving a pest or disease a free ride into new areas.

The risks

Pests, diseases and weeds can be spread from one part of Australia to another through the movement of many items including:

- plant or plant products
- fruit and vegetables
- animals or animal products
- soil
- agricultural machinery and other equipment.

Following the rules about moving these items will help to minimise the risk to Australia's unique environment and valuable agricultural markets.

AUSTRALIAN STATE BORDERS

Please see **interstatequarantine.org.au** for a detailed map of Australian quarantine borders.

KEY TO THE TABLES

NO ✗
You **cannot** carry this item with you when travelling to this state or territory.

ASK ⚠
You **need** to obtain an appropriate permit or certificate or provide more information to carry this item with you when travelling to this state or territory. Please contact the relevant authority indicated for the destination state or territory.

YES ✓
You **can** carry this item with you without restriction when travelling to this state or territory.

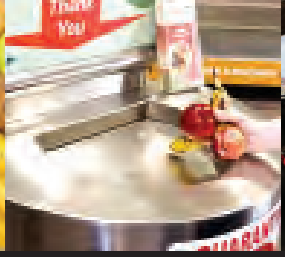
DESTINATION:

NEW SOUTH WALES/AUSTRALIAN CAPITAL TERRITORY

TRAVELLING TO NSW & ACT

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NT	QLD	SA	TAS	VIC	WA
Fruit and vegetables (fresh)	⚠	⚠	⚠	✓	⚠	⚠
Fruit and vegetables (cooked, canned, freeze-dried, dehydrated)	✓	✓	✓	✓	✓	✓
Fruit salad (sliced fresh)	✓	✓	✓	✓	✓	✓
Herbs (fresh)	✓	✓	✓	✓	✓	⚠
Herbs & spices (dried)	✓	✓	✓	✓	✓	✓
Nuts (dried)	✓	✓	✓	✓	✓	✓
Ware potatoes and sweet potatoes	✓	✓	✓	✓	⚠	✓
Vegetable salad	✓	✓	✓	✓	✓	✓
Food items from:	**NT**	**QLD**	**SA**	**TAS**	**VIC**	**WA**
Dairy products including milk, cheese & yoghurt (fresh & powdered)	✓	✓	✓	✓	✓	✓
Eggs	✓	✓	✓	✓	✓	✓
Fish (canned, smoked/cured)	✓	✓	✓	✓	✓	✓
Honey	⚠	⚠	⚠	⚠	⚠	⚠
Processed foods (noodles, bread, baby food, cereals, sauces, biscuits, fruit cake)	✓	✓	✓	✓	✓	✓
Meats (sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Rice	⚠	⚠	⚠	⚠	⚠	⚠
Tea & coffee	✓	✓	✓	✓	✓	✓
Other from:	**NT**	**QLD**	**SA**	**TAS**	**VIC**	**WA**
Agricultural and recreational equipment (contaminated with soil)	⚠	⚠	⚠	⚠	⚠	⚠
Dogs, cats	✓	✓	✓	✓	✓	✓
Livestock (cattle, pigs, sheep, horses)	⚠	⚠	⚠	⚠	⚠	⚠
Native birds & mammals	⚠	⚠	⚠	⚠	⚠	⚠
Reptiles	⚠	⚠	⚠	⚠	⚠	⚠
Animal skins & hides	✓	✓	✓	✓	✓	✓
Boots (free of soil)	✓	✓	✓	✓	✓	✓
Fish (live)	⚠	⚠	⚠	⚠	⚠	⚠
Garden tools (free of soil)	✓	✓	✓	✓	✓	✓
Honeycomb, bees & used beekeeping equipment	⚠	⚠	⚠	⚠	⚠	⚠
Soil	✗	✗	✗	✗	✗	✗
Plant items from:	**NT**	**QLD**	**SA**	**TAS**	**VIC**	**WA**
Banana planting material	✗	✗	✗	✗	✗	✗
Bulbs, corms (dormant)	✓	✓	✓	✓	✗	✗
Citrus plants, cuttings or budwood	⚠	✗	✓	✓	✓	⚠
Cut flowers & foliage	✓	✓	✓	✓	✓	✗
Fruit and vegetables (plants, seedlings & seeds)	⚠	⚠	⚠	✓	⚠	⚠
Grapevines, cuttings or budwood	✗	✗	✗	✗	✗	✗
Lupin plant material	✓	✓	⚠	✓	✓	⚠
Potato planting material	✗	✗	✗	✗	✗	✗
Pot plants & nursery stock	⚠	⚠	⚠	✓	⚠	⚠
Timber (raw or treated)	✓	✓	✓	✓	✓	⚠



For more information on carrying the following items into New South Wales and Australian Capital Territory, please contact:

- **Plants or plant products** – 1800 084 881 or quarantine@dpi.nsw.gov.au
- **Animals or animal products** – 1800 084 881 or quarantine@dpi.nsw.gov.au
- **Bees or bee products** – 1800 084 881 or quarantine@dpi.nsw.gov.au
- **Noxious weeds reporting** – 1800 680 244 or weeds@dpi.nsw.gov.au
- **Native birds and wildlife** – 1300 361 967 or wildlife.licensing@environment.nsw.gov.au
- **Fish or fish products** – 1300 550 474 or information-advisory@dpi.nsw.gov.au
- **Aquatic pests or exotic fish** – 1800 675 888 or aquatic.biosecurity@dpi.nsw.gov.au

TRAVELLING WITHIN NEW SOUTH WALES/AUSTRALIAN CAPITAL TERRITORY

Greater Sunraysia Pest Free Area (PFA)

Part of the far west and Murray regions. Do not take fruit (including capsicum, chilli, tomato and eggplant) into the PFA.

Phylloxera Exclusion Zone

All of NSW except for Albury/Corowa and the Sydney Basin. Do not take grapevines, cuttings or budwood into this zone. Soil that has been in contact with any grapevine material cannot be brought into this zone.

Rice Biosecurity Zone

Most of the Murrumbidgee and Murray regions. Do not bring rice plants or grain such as paddy rice or brown rice into the zone. Some other rice products are also not allowed into the zone.

Seed Potato Protected Area

Parts of the south-eastern, central west and northern regions. Do not bring potato planting material or soil that has been in contact with potato planting material into these areas.

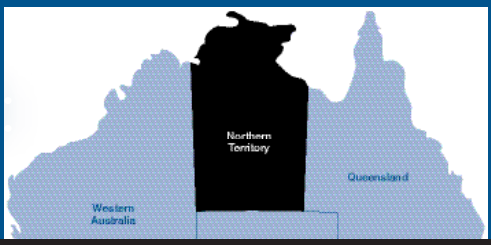
Citrus Red Mite Biosecurity Zone

Established across the Central Coast region of New South Wales, including near Gosford, the County of Northumberland and Sydney metropolitan homes in the County of Cumberland. Do not move citrus plants out of this area.

For more information, visit the website interstatequarantine.org.au or telephone FREECALL 1800 084 881

See maps at **interstatequarantine.org.au/zones.** For more information on legislation go to **dpi.nsw.gov.au/biosecurity/managing-biosecurity/legislation**

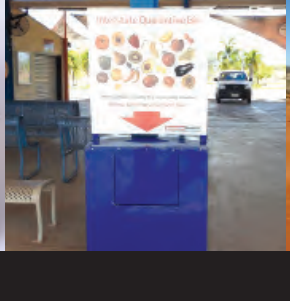
DESTINATION
NORTHERN TERRITORY



TRAVELLING TO NT

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	QLD	SA	TAS	VIC	WA
Banana	⚠	⚠	⚠	⚠	⚠	⚠
Citrus	⚠	⚠	⚠	⚠	⚠	⚠
Fruit (commercially-grown)	✓	✓	✓	✓	✓	⚠
Fruit and vegetables (cooked, canned, freeze-dried, dehydrated)	✓	✓	✓	✓	✓	✓
Fruit and vegetables (cucumber fly hosts eg zucchini, cucumber, melons, pumpkin, tomato, passionfruit)	⚠	⚠	⚠	⚠	⚠	⚠
Fruit and vegetables (home-grown)	⚠	⚠	⚠	⚠	⚠	⚠
Fruit salad (fresh)	✓	✓	✓	✓	✓	✓
Herbs (fresh)	⚠	⚠	⚠	⚠	⚠	⚠
Herbs & spices (dried)	✓	✓	✓	✓	✓	✓
Nuts (dried)	✓	✓	✓	✓	✓	✓
Pawpaw (papaya)	⚠	⚠	⚠	⚠	⚠	⚠
Potato (ware and seed)	⚠	⚠	⚠	⚠	⚠	⚠
Vegetable salad	✓	✓	✓	✓	✓	✓
Vegetables (non-leafy, commercial)	⚠	⚠	⚠	⚠	⚠	⚠
Vegetables (leafy eg lettuce)	⚠	⚠	⚠	⚠	⚠	⚠
Food items from:	**NSW**	**QLD**	**SA**	**TAS**	**VIC**	**WA**
Dairy products including milk, cheese & yoghurt (fresh & powdered)	✓	✓	✓	✓	✓	✓
Eggs (chicken & duck)	✓	✓	✓	✓	✓	✓
Fish (fresh, canned, smoked, cured)	✓	✓	✓	✓	✓	✓
Honey	⚠	⚠	⚠	⚠	⚠	⚠
Processed foods (noodles, bread, rice, baby food, cereals, sauces)	✓	✓	✓	✓	✓	✓
Meats (sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Tea, coffee & biscuits	✓	✓	✓	✓	✓	✓
Other from:	**NSW**	**QLD**	**SA**	**TAS**	**VIC**	**WA**
Dogs & cats	✓	✓	✓	✓	✓	✓
Feral animals (fox, cane toad, dingo, European carp etc)	✗	✗	✗	✗	✗	✗
Fish (domestic or aquarium)	⚠	⚠	⚠	⚠	⚠	⚠
Horses	⚠	⚠	⚠	⚠	⚠	⚠
Livestock (cattle, pigs, sheep)	⚠	⚠	⚠	⚠	⚠	⚠
Native wildlife & caged birds	⚠	⚠	⚠	⚠	⚠	⚠
Yabbies	✗	✗	✗	✗	✗	✗
Animal skins & hides	✓	✓	✓	✓	✓	✓
Fishing bait (snails, worms etc)	✗	✗	✗	✗	✗	✗
Boots (free of soil)	✓	✓	✓	✓	✓	✓
Garden tools (free of soil)	✓	✓	✓	✓	✓	✓
Soil	✗	✗	✗	✗	✗	✗
Potting mix and compost	⚠	⚠	⚠	⚠	⚠	⚠
Machinery and equipment (agricultural, earthmoving)	⚠	⚠	⚠	⚠	⚠	⚠



Plant items	from: NSW	QLD	SA	TAS	VIC	WA
Bulbs, corms (dormant)	✓	✓	✓	✓	✓	✓
Cut flowers & foliage	⚠	⚠	⚠	⚠	⚠	⚠
Fruit and vegetables (plants & seedlings)	⚠	⚠	⚠	⚠	⚠	⚠
Grapevines, cuttings or budwood	⚠	⚠	⚠	⚠	⚠	⚠
Maize (seed)	⚠	⚠	✓	✓	✓	✓
Pot plants & nursery stock	⚠	⚠	⚠	⚠	⚠	⚠
Pinewood & pinewood products	✓	✓	✓	✓	✓	⚠
Seeds	⚠	⚠	⚠	⚠	⚠	⚠
Weeds & weed seeds	✗	✗	✗	✗	✗	✗

For more information on carrying the following items into Northern Territory, please contact:

- **Plants or plant products** – 08 8999 2118 or email plantbiosecurity@nt.gov.au
- **Livestock** – 08 8999 2030
- **Live fish** – 08 8999 2144
- **Native birds and other wildlife** – email pwpermits@nt.gov.au
- **Aquatic pests** – 08 8999 2126 or 0413 381 094
- **Fisheries** – 08 8999 2144

Note: No plant or plant product, whether listed or not, is permitted entry if found to be affected by a pest or disease.

TRAVELLING WITHIN NORTHERN TERRITORY

Movement of plant products into and/or out of the following zones is regulated

Ti Tree Fruit Fly Exclusion Zone (FFEZ)

The Ti Tree FFEZ extends from Tennant Creek to Alice Springs. Do not take fruit (including capsicum, chilli, tomato, eggplant, cucumber, zucchini and squash) into the FFEZ.

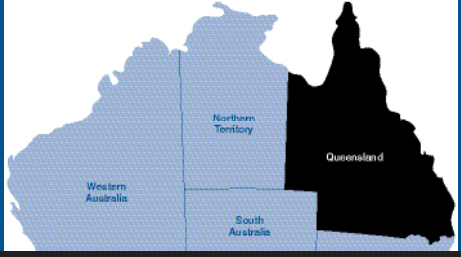
Adelaide River

Restrictions apply to fruit and vegetables when travelling south from Darwin to prevent the spread of the pest melon thrips.

The following produce must not be carried south along the Stuart Highway beyond the Adelaide River township:

- beans
- capsicum
- chilli
- cucumber
- eggplant
- melons
- mango fruit and mango plants (unless treated against leaf hopper)
- okra
- pumpkin
- silverbeet
- squash
- tomato
- zucchini.

DESTINATION: QUEENSLAND



TRAVELLING TO QLD

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	NT	SA	TAS	VIC	WA
Citrus fruit	✓	✓	✓	✓	✓	✗
Fruit (fresh, except banana and mango)	✓	✓	✓	✓	✓	✗
• banana fruit (must be removed from bunch stalk)	✓	✗	✓	✓	✓	✗
• mango fruit (stalks must be removed)	✓	✓	✓	✓	✓	✗
Fruit salad (fresh)	✓	✓	✓	✓	✓	✓
Fruit and vegetables (dried, cooked, frozen, canned)	✓	✓	✓	✓	✓	✓
Herbs (fresh)	✓	✓	✓	✓	✓	✓
Herbs & spices (dried)	✓	✓	✓	✓	✓	✓
Mushrooms	✓	✓	✓	✓	✓	✓
Nuts (dried)	✓	✓	✓	✓	✓	✓
Potatoes washed or brushed (soil free, for consumption, not for planting)	✓	✓	✓	✓	✓	✓
Vegetables						
• Cucurbits (eg cucumber, pumpkin, squash, zucchini)	✓	✓	✓	✓	✓	⚠
• Fruiting (eg capsicum, chilli, eggplant, tomato, tamarillo)	✓	✓	✓	✓	✓	⚠
• Leafy (eg lettuce, cabbage, cauliflower, broccoli, kale)	✓	✓	✓	✓	✓	⚠
• Root (soil free with tops removed)	✓	✓	✓	✓	✓	⚠
Food items **from:**	**NSW**	**NT**	**SA**	**TAS**	**VIC**	**WA**
Camping foods (freeze-dried/dehydrated)	✓	✓	✓	✓	✓	✓
Dairy products including milk, cheese & yoghurt (fresh & powdered)	✓	✓	✓	✓	✓	✓
Eggs	✓	✓	✓	✓	✓	✓
Fish (fresh, canned, smoked, cured)	✓	✓	✓	✓	✓	✓
Honey	✓	✓	✓	⚠	✓	✓
Meats (sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Processed foods (eg noodles, bread, rice, cereals, baby food, fruit cake, tea)	✓	✓	✓	✓	✓	✓
Other **from:**	**NSW**	**NT**	**SA**	**TAS**	**VIC**	**WA**
Animals (dogs, cats, guinea pigs, rats, mice, exotic birds)	✓	✓	✓	✓	✓	✓
Animals (fish and axolotl – aquarium not noxious)	✓	✓	✓	✓	✓	✓
Animals (fish – declared noxious)	✗	✗	✗	✗	✗	✗
Animals (pet rabbits, pet ferrets, exotic reptiles, exotic amphibians other than axolotl, exotic mammals)	✗	✗	✗	✗	✗	✗
Animals (livestock – cattle, pigs, sheep, horses)	⚠	⚠	⚠	⚠	⚠	⚠
Animals (native birds & wildlife)	⚠	⚠	⚠	⚠	⚠	⚠
Animal skins & hides	✗	✗	✓	✓	✓	⚠
Boots (free of soil and organic matter **and** not associated with bananas, cucurbit plants (eg cucumbers, melons), sugarcane, mangoes or grape vines)	✓	✓	✓	✓	✓	✓
Garden tools (washed and totally free of soil)	✓	⚠	✓	✓	⚠	✓
Honeycomb, bees & used beekeeping equipment, including used hives	✓	✓	✓	⚠	✓	✓
Soil or anything containing soil	✗	✗	✗	✗	✗	✗

Plant items from:	NSW	NT	SA	TAS	VIC	WA
Banana plants and seeds of Musaceae (*Musa*, *Musella* and *Ensete*)	✗	✗	✗	✗	✗	✗
Bare rooted plants	✓	✓	✓	✓	⚠	✓
Bulbs, corms etc (dormant and free of soil)	✓	✓	✓	✓	⚠	✓
Cut flowers & foliage	✓	✓	✓	✓	✓	⚠
Flower seedlings	✓	✓	✓	✓	⚠	✓
Fruit and vegetables (plants & seedlings)	⚠	⚠	⚠	⚠	⚠	⚠
Grapes, grapevines, cuttings or budwood	✗	✗	✗	✗	✗	✗
House/pot plants	⚠	⚠	⚠	⚠	⚠	⚠
Native plants	⚠	⚠	⚠	⚠	⚠	⚠
Pine family plants (*Pinus, Picea,* Christmas trees)	✓	✓	⚠	✓	⚠	⚠
Pine timber (dried)	✓	✓	✓	✓	✓	⚠
Plants of the *Saccharum* genus (sugarcane, pit-pit)	✗	✗	✗	✗	✗	✗
Potato planting material	✗	✗	✗	✗	✗	✗
Stock feed (hay, grains, bird food)	✓	✓	⚠	✓	✓	✓
Strawberry plants	✓	✓	✓	✓	✓	✓
Weeds & weed seeds	✗	✗	✗	✗	✗	✗

For more information on carrying the following items into Queensland, please contact:

- **Plants or plant products**, **skins and hides**, **movement of livestock**, **pets (except declared noxious fish), declared noxious fish** – Department of Agriculture and Fisheries customer service centre on 07 3404 6999 or callweb@daf.qld.gov.au
- www.daf.qld.gov.au/biosecurity
- **Native plants, birds and wildlife** – Environment and Heritage Protection 1300 130 372

TRAVELLING WITHIN QUEENSLAND

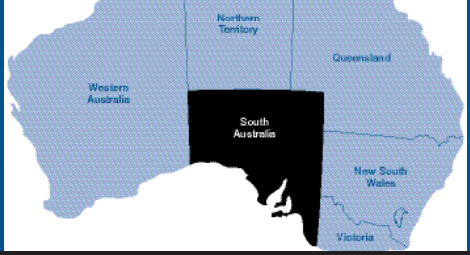
Movement of plant products into and/or out of areas within Queensland is regulated.

The whole of the state is a biosecurity zone for bananas, grape plants, mangoes and sugarcane. Do not take any plants, soil or items that have been in contact with these plants into Queensland.

For more information about the following biosecurity zones please contact the DAF customer service centre on 07 3404 6999.

- Banana pest biosecurity zone
- Far northern pest biosecurity zone 1 and 2
- Electric ant biosecurity zone
- Fire ant pest biosecurity zone
- Papaya ring spot biosecurity zone
- Grape Phylloxera exclusion zone – do not take grapes, grape vines, cuttings, budwood or soil from within 100m of a living grape vine into this zone.
- Sugarcane pests biosecurity zone.

DESTINATION:
SOUTH AUSTRALIA



TRAVELLING TO SA

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	NT	QLD	TAS	VIC	WA
Asparagus	✓	✓	✓	✓	✓	⚠
Fruit (fresh)	✗	✗	✗	✓	✗	✗
Fruit and vegetables - processed (dried, preserved, cooked, frozen, canned)	✓	✓	✓	✓	✓	✓
Herbs (fresh cut)	✓	✓	✓	✓	✓	⚠
Herbs and spices (dried)	✓	✓	✓	✓	✓	✓
Melons (watermelon, rockmelon, honeydew)	⚠	⚠	⚠	✓	✓	⚠
Mushrooms	✓	✓	✓	✓	✓	✓
Nuts (dried)	✓	✓	✓	✓	✓	✓
Onions, garlic cured, topped and tailed	✓	✓	✓	✓	✓	✓
Onions, garlic, leeks, spring onions, chives (fresh)	✓	✓	✓	✓	✓	⚠
Pineapple	✓	✓	✓	✓	✓	✓
Potatoes washed or brushed (soil free – ware, not for planting)	✓	✓	✓	✓	✓	⚠
Spinach, silver beet	⚠	⚠	⚠	✓	✓	⚠
Vegetables - cucurbits (cucumber, pumpkin, squash, zucchini)	⚠	⚠	⚠	✓	✓	⚠
Vegetables - fruiting (capsicum, chilli, eggplant, tomato, tamarillo)	✗	✗	✗	✓	✗	✗
Vegetables - leafy (lettuce, cabbage, cauliflower, broccoli, kale)	✓	✓	✓	✓	✓	⚠
Vegetables - root, soil-free with tops removed (carrot, turnip, parsnip, beetroot, sweet potato)	✓	✓	✓	✓	✓	✓

Food items from:	NSW	NT	QLD	TAS	VIC	WA
Camping food (freeze-dried, dehydrated), eggs	✓	✓	✓	✓	✓	✓
Dairy products (eg milk, cheese and yoghurt)	✓	✓	✓	✓	✓	✓
Fish (fresh, canned)	✓	✓	✓	✓	✓	✓
Fruit salad (fresh)	✗	✗	✗	✓	✗	✗
Honey, honeycomb, beeswax, pollen, bees, hives, used equipment	⚠	⚠	⚠	⚠	⚠	⚠
Meats (poultry, sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Processed foods (eg noodles, bread, rice, cereals, baby food, biscuits, cakes)	✓	✓	✓	✓	✓	✓

For more information on carrying the following items into South Australia, please contact:

- **Fruit, vegetables, plant material, bee products and bee equipment** – 08 8207 7820
- **Aquarium/exotic fish and plants** – 1800 065 522
- **Livestock and animal health enquiries** – 08 8207 7900
- **Native animals:** Fauna Permits 08 8124 4972
- **Exotic pets/animals** – Invasive Species Unit 08 8429 0823

Note: Produce status can be affected by transiting through other states. In addition to the origin of any produce, you must also take into account the advice for the state in which you last travelled before entering South Australia.

Other	from: NSW	NT	QLD	TAS	VIC	WA
Animals (dogs, cats) domestic	✓	✓	✓	✓	✓	✓
Cartons (fruit and vegetable, used for packaging containers)	✓	✓	✓	✓	✓	✓
Eggs (poultry hatching)	✓	✓	✓	✓	✓	✓
Live Pacific oysters	✓	✓	✓	✗	✓	✓
Soil (dirt)	✗	✗	✗	✗	✗	✗
Stock feed (hay, fodder)	✓	✓	⚠	✓	⚠	⚠
Plant items	**from: NSW**	**NT**	**QLD**	**TAS**	**VIC**	**WA**
Bulbs, corms (dormant)	✓	✓	✓	✓	✓	⚠
Citrus plants (no fruit or soil, commercial potting mix only)	⚠	⚠	✗	⚠	✓	⚠
Cut flowers (excluding Myrtaceae)	⚠	⚠	⚠	⚠	⚠	⚠
Date palms	✓	⚠	⚠	✓	⚠	⚠
Fruit and vegetable plants including seedlings	⚠	⚠	⚠	⚠	⚠	⚠
Grapevines, cuttings, budwood	✗	✗	✗	✗	✗	✗
House/pot plants and cuttings/nursery stock/potted herbs	⚠	⚠	⚠	⚠	⚠	⚠
Pine timber (dried)	⚠	⚠	⚠	⚠	⚠	⚠
Wood (firewood and ornamental, dried & bark-free)	✓	✓	✓	✓	✓	✓
Seeds (edible or sprouting) not maize for planting	✓	✓	✓	✓	✓	✓

TRAVELLING WITHIN SOUTH AUSTRALIA

Kangaroo Island

Do not take rabbits, bees or bee products onto the island. Potatoes are also prohibited unless they have been washed or brushed free of soil and are in new packaging.

Riverland of South Australia

Do not take fresh, unprocessed fruit and fruiting vegetables (including capsicum, chilli, tomato and eggplant) into the Riverland of South Australia

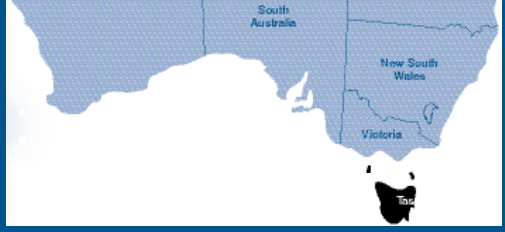
South Australian Quarantine Checkpoints

Quarantine stations and fruit disposal bins are strategically placed throughout South Australia. Mobile quarantine stations can operate anywhere and at anytime within South Australia.

South Australia's Riverland region is a recognised Pest Free Area and zero tolerance measures are in place at the Yamba Quarantine Station and at random roadblocks.

If caught with uncertified fruit or fruiting vegetables, travellers can face significant fines and penalties. Eat or dispose of produce in roadside disposal bins before approaching the Yamba Quarantine Station.

DESTINATION
TASMANIA



TRAVELLING TO TASMANIA

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	NT	QLD	SA	VIC	WA
Fruit and vegetables (fresh)	⚠	⚠	⚠	⚠	⚠	⚠
Fruit and vegetables (cooked, hard frozen, canned, preserved, dried commercially)	✓	✓	✓	✓	✓	✓
Fruit salad (fresh)	✗	✗	✗	✗	✗	✗
Herbs (fresh)	⚠	⚠	⚠	⚠	⚠	⚠
Herbs & spices (dried & non-viable)	✓	✓	✓	✓	✓	✓
Nuts (dried only)	✓	✓	✓	✓	✓	✓
Onions, shallots, chives, garlic	⚠	⚠	⚠	⚠	⚠	⚠
Potatoes (fresh or seed)	✗	✗	✗	✗	✗	✗
Seeds (all) (peas, lupin, chickpeas & canola have specific import requirements)	⚠	⚠	⚠	⚠	⚠	⚠
Food items **from:**	**NSW**	**NT**	**QLD**	**SA**	**VIC**	**WA**
Camping foods (freeze-dried, dehydrated)	✓	✓	✓	✓	✓	✓
Dairy products including milk, cheese & yoghurt (fresh & powdered)	✓	✓	✓	✓	✓	✓
Eggs	✓	✓	✓	✓	✓	✓
Fish (canned)	✓	✓	✓	✓	✓	✓
Fish (flake, snapper, coral trout, barramundi, tuna, whiting, trevally, ling, squid, prawns, crab meat, crayfish) (fresh/frozen, whole/fillets)*	✓	✓	✓	✓	✓	✓
Fish (salmon, trout, eel, hake, cod, perch, mullet, flounder, bream, flathead, sardine); shellfish (oysters, clams, mussels, abalone (dead or alive)	✗	✗	✗	✗	✗	✗
Honey** (must be declared to Biosecurity Officers)	✓	✓	✓	✓	✓	✓
Meats (poultry, sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Meats (pork, lamb, beef - for personal consumption)	✓	✓	✓	✓	✓	✓
Processed foods (noodles, bread, rice, cereals, baby food, biscuits, fruit cake, pastries, jams, sauces)	✓	✓	✓	✓	✓	✓
Tea & coffee	✓	✓	✓	✓	✓	✓
Other foods: sandwiches, pizza, fish& chips, souvlakis, hamburgers, pasta, sweet/savoury rolls, pies, sushi	✓	✓	✓	✓	✓	✓
Other **from:**	**NSW**	**NT**	**QLD**	**SA**	**VIC**	**WA**
Agricultural equipment contaminated with plant material or soil	✗	✗	✗	✗	✗	✗
Animals (cats, horses, guinea pigs, zebra finch, budgerigars, cockatiels, canaries and domestic fowls)	✓	✓	✓	✓	✓	✓
Animals (dogs - treated for hydatid tapeworm prior to arrival, inspected & found free of ticks within 24 hours of arrival)	⚠	⚠	⚠	⚠	⚠	⚠
Animals (feral - eg fox, cane toad, European carp, Indian myna etc)	✗	✗	✗	✗	✗	✗
Animals (fish - freshwater or marine)						
• Private or commercial imports	⚠	⚠	⚠	⚠	⚠	⚠
• Fishing bait (snails, worms etc)	✗	✗	✗	✗	✗	✗
• Fish products	⚠	⚠	⚠	⚠	⚠	⚠
• Goldfish	✗	✗	✗	✗	✗	✗

* Seafood must be labelled with scientific and common names
** Honey must be free of wax and bee debris

Other *continued*	from: NSW	NT	QLD	SA	VIC	WA
Animals (livestock - cattle, pigs, sheep)	⚠	⚠	⚠	⚠	⚠	⚠
Animals (native wildlife, aviary birds)	⚠	⚠	⚠	⚠	⚠	⚠
Animals (pigeons, poultry & hatching eggs)	✓	✓	✓	✓	✓	✓
Animals (reptiles, amphibians, ferrets)	✗	✗	✗	✗	✗	✗
Animals (yabbies/freshwater crayfish)	✗	✗	✗	✗	✗	✗
Animal skins & hides (untanned)	⚠	⚠	⚠	⚠	⚠	⚠
Boots (free of soil)	✓	✓	✓	✓	✓	✓
Fishing & diving equipment inc. boats & waders (marine or freshwater), clean & dry	⚠	⚠	⚠	⚠	⚠	⚠
Garden tools (free of soil)	✓	✓	✓	✓	✓	✓
Honeycomb, bees & used beekeeping equipment	✗	✗	✗	✗	✗	✗
Soil or anything containing soil	✗	✗	✗	✗	✗	✗
Plant items	**from: NSW**	**NT**	**QLD**	**SA**	**VIC**	**WA**
Bulbs, corms	⚠	⚠	⚠	⚠	⚠	⚠
Cut flowers & foliage	⚠	⚠	⚠	⚠	⚠	⚠
Fruit and vegetables (plants, seedlings & seeds)	⚠	⚠	⚠	⚠	⚠	⚠
Grapevines, cuttings or budwood	⚠	⚠	⚠	⚠	⚠	⚠
House/pot plants & nursery stock	⚠	⚠	⚠	⚠	⚠	⚠
Stock feed (hay, grain, birdseed/sticks, pelletised feed)	⚠	⚠	⚠	⚠	⚠	⚠
Timber & timber products (untreated, including firewood) not inc. furniture	⚠	⚠	⚠	⚠	⚠	⚠
Weeds & weed seeds	✗	✗	✗	✗	✗	✗

For more information on carrying the following items into Tasmania, please contact 03 6165 3777 or email biosecurity.tasmania@dpipwe.tas.gov.au

- **Plants or plant products and seafood**
- **Fish, fish products and fishing/diving equipment (marine and freshwater)**
- **Livestock/pets/domestic animals (including livestock restrictions applying to Bass Strait Islands** – Biosecurity Vet
- **Dogs (treatment for hydatid tapeworm prior to arrival)** – 1800 684 215
- **Native wildlife (reptiles, birds, mammals, insects) and aviary birds** – 03 6165 4305 or email Wildlife Permits Officer wildlife.reception@dpipwe.tas.gov.au

Please note: Taking rabbits to King, Flinders and other Bass Strait Islands is prohibited.

Tasmanian biosecurity checkpoints

Plant and animal biosecurity examinations are conducted at all points of entry into Tasmania. On-the-spot fines apply for both commercial and non-commercial imports.

Cat restrictions

If you own, acquire, breed or sell a cat in Tasmania provisions under the Cat Management Act 2009 apply. Microchipping and desexing now required.

DESTINATION: VICTORIA

TRAVELLING TO VICTORIA

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	NT	QLD	SA	TAS	WA
Asparagus	✓	✓	⚠	⚠	⚠	⚠
Fruit (fresh)	⚠	⚠	⚠	⚠	⚠	⚠
Fruit salad (fresh)	✓	✓	✓	✓	✓	✓
Fruit and vegetables (dried, dehydrated, freeze-dried, cooked, frozen, canned)	✓	✓	✓	✓	✓	✓
Grapes (table)	⚠	⚠	⚠	⚠	⚠	⚠
Herbs (fresh)	✓	✓	✓	✓	✓	⚠
Herbs & spices (dried)	✓	✓	✓	✓	✓	✓
Nuts (dried)	✓	✓	✓	✓	✓	✓
Vegetables (leafy eg lettuce, cabbage)	✓	✓	⚠	✓	✓	⚠
Vegetables (root eg carrot, parsnip)	✓	✓	✓	✓	✓	⚠
Vegetable salad	✓	✓	✓	✓	✓	✓
Food items from:	**NSW**	**NT**	**QLD**	**SA**	**TAS**	**WA**
Dairy products including milk, cheese & yoghurt (fresh & powdered)	✓	✓	✓	✓	✓	✓
Eggs	✓	✓	✓	✓	✓	✓
Fish (fresh, canned, smoked, cured)	✓	✓	✓	✓	✓	✓
Honey	⚠	⚠	⚠	⚠	⚠	⚠
Meats (sausage, salami, sliced meats)	✓	✓	✓	✓	✓	✓
Processed foods (noodles, bread, rice, cereals, baby food, biscuits, fruit cake)	✓	✓	✓	✓	✓	✓
Other from:	**NSW**	**NT**	**QLD**	**SA**	**TAS**	**WA**
Animals (dogs & cats)	✓	✓	✓	✓	✓	✓
Boots (free of soil)	✓	✓	✓	✓	✓	✓
Garden tools (free of soil)	✓	✓	✓	✓	✓	✓
Honeycomb, bees & used beekeeping equipment	⚠	⚠	⚠	⚠	⚠	⚠
Soil	⚠	⚠	⚠	⚠	⚠	⚠
Used agricultural equipment	⚠	⚠	⚠	⚠	⚠	⚠
Plant items from:	**NSW**	**NT**	**QLD**	**SA**	**TAS**	**WA**
Bulbs, corms	✓	✓	✓	✓	✓	⚠
Cut flowers & foliage	⚠	⚠	⚠	⚠	✓	⚠
Fruit & vegetables (plants, seedlings & seeds)	⚠	⚠	⚠	⚠	⚠	⚠
Grapevines, cuttings or budwood	⚠	✓	⚠	✓	✓	⚠
House/pot plants & nursery stock	⚠	⚠	⚠	⚠	⚠	⚠
Stock feed (hay, grains, bird food)	⚠	✓	⚠	⚠	✓	⚠
Timber (raw or treated)	✓	✓	✓	✓	✓	⚠
Weeds & weed seeds	⚠	⚠	⚠	⚠	⚠	⚠

For more information on items you wish to carry into Victoria, please contact:
Agriculture Victoria – 136 186 or visit www.agriculture.vic.gov.au/psb

TRAVELLING WITHIN VICTORIA

Movement of plant products in and out of the following zones is regulated

Greater Sunraysia Pest Free Area

The Greater Sunraysia Pest Free Area (PFA) was established to protect fruit production areas along the Murray River from Queensland fruit fly.

Do not take fruit or fruiting vegetables (including capsicum, chilli, tomato and eggplant) into the PFA. Fruit disposal bins are in place and quarantine roadblocks may operate in this zone. Signs on major roads indicate when you are entering the PFA.

Phylloxera Control Areas

Control areas have been established in Victoria to prevent the spread of the grapevine pest phylloxera. Signs on major roads indicate when you are entering a Phylloxera Exclusion Zone or leaving a Phylloxera Infested Zone, and that restrictions on the movement of grapevines exist for each zone.

Potato Plant Protection Districts

Potato Plant Protection Districts (PPDs) are established around some Victorian seed potato production regions in order to reduce biosecurity threats. Signs on major roads indicate when you are entering a PPD and what restrictions on potato movement apply.

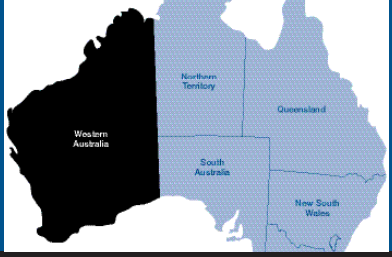
Toolangi Plant Protection District

The Toolangi Plant Protection District is a protected area in which plant breeding programs are conducted. The entry of plants for propagation into this area is restricted.

For more information about these zones, please contact Agriculture Victoria on 136 186 or visit www.agriculture.vic.gov.au/psb

FREECALL 1800 084 881

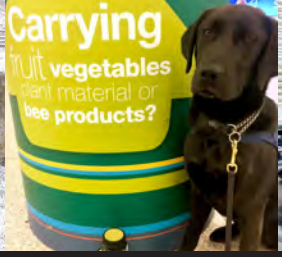
DESTINATION:
WESTERN AUSTRALIA



TRAVELLING TO WA

Please examine the listed products carefully. Although broad terms such as 'fruits and vegetables' are used, exceptions may apply.

Fruits, vegetables & nuts (products) from:	NSW	NT	QLD	SA	TAS	VIC
Fruit and vegetables (fresh) • exceptions (providing they are free of soil, pests, disease and any sprouting green growth or material): beetroot, carrot, coconut, corn on the cob, ginger, mushrooms (commercially packaged), parsnip, pineapple, swede, galangal, sweet potato, taro, turnip	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓
Fruit and vegetables (frozen or commercially dried or packed) • excluding muntries, riberries, grapes, guava, mango (with seed), uncooked banana leaves and unpeeled onions, garlic and potatoes	✓ ✗	✓ ✗	✓ ✗	✓ ✗	✓ ✗	✓ ✗
Fruit and vegetables (cooked)	✓	✓	✓	✓	✓	✓
Nuts (raw walnuts in shell)	✗	✗	✗	✗	✗	✗
Nuts (other)	✓	✓	✓	✓	✓	✓
Food items **from:**	**NSW**	**NT**	**QLD**	**SA**	**TAS**	**VIC**
Dairy products	✓	✓	✓	✓	✓	✓
Eggs	✓	✓	✓	✓	✓	✓
Herbs (fresh cut, free of soil, pests & diseases)	✗	✗	✗	✗	✗	✗
Herbs & spices (commercially dried, except cloves)	✓	✓	✓	✓	✓	✓
Honey & other hive products (unless certified as heat-treated)	✗	✗	✗	✗	✗	✗
Lentils, split peas, beans (split or processed)	✓	✓	✓	✓	✓	✓
Meat products (fresh, frozen, dried or processed)	✓	✓	✓	✓	✓	✓
Seafood (fish for consumption)	✓	✓	✓	✓	✓	✓
Seafood (other)	⚠	⚠	⚠	⚠	⚠	⚠
Processed foods (biscuits, fruit cake, fruit juice, cordial, polished rice, cereals, bread, chips, baby food, jams, pickles, soups)	✓	✓	✓	✓	✓	✓
Processed items (flour, sugar, tinned F&V, rice milled)	✓	✓	✓	✓	✓	✓
Rice (unmilled)	✗	✗	✗	✗	✗	✗
Seeds (edible – commercially packaged up to 5 kg) • exceptions: pumpkin, sun flower, pepita, chia seed	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓	⚠ ✓
Tea & coffee (commercially packaged, beans)	✓	✓	✓	✓	✓	✓
Truffles (for consumption – free of soil, pests, disease)	⚠	⚠	⚠	⚠	⚠	⚠
Other **from:**	**NSW**	**NT**	**QLD**	**SA**	**TAS**	**VIC**
Animals (birds/fish/aquariums/wildlife): pets or other	⚠	⚠	⚠	⚠	⚠	⚠
Animals (domestic: cats & dogs)	✓	✓	✓	✓	✓	✓
Animals skins & hides (free of plant material, seeds, soil & pests)	✓	✓	✓	✓	✓	✓
Animals (livestock eg cattle, pigs, sheep, horses)	⚠	⚠	⚠	⚠	⚠	⚠
Birdseed	✗	✗	✗	✗	✗	✗
Bees & apiary equipment	✗	✗	✗	✗	✗	✗
Containers (agricultural/horticultural; used, including bags, cartons, fruit boxes and potato sacks)	✗	✗	✗	✗	✗	✗
Crustaceans (including bait crustaceans eg bait prawns)	✗	✗	✗	✗	✗	✗
Soil (including in plant pots)	✗	✗	✗	✗	✗	✗



Plant items	from: NSW	NT	QLD	SA	TAS	VIC
Bulbs	⚠	⚠	⚠	⚠	⚠	⚠
Cut flowers & foliage	⚠	⚠	⚠	⚠	⚠	⚠
Garden/house/pot plant	⚠	⚠	⚠	⚠	⚠	⚠
Seeds	⚠	⚠	⚠	⚠	⚠	⚠
Stock feed (hay/fodder)	✗	✗	✗	✗	✗	✗
Timber (dressed/without bark)	✓	✓	✓	✓	✓	✓
Wood (firewood: dried & bark-free)	✓	✓	✓	✓	✓	✓
Wood (ornamental: dried & bark-free)	✓	✓	✓	✓	✓	✓

For more information on carrying items into Western Australia, please contact:

Quarantine WA – Department of Primary Industries and Regional Development – 08 9334 1800 or qwa.import@dpird.wa.gov.au

Department of Biodiversity, Conservation and Attractions (DBCA) – 08 9219 9831 or wildlifelicensing@dbca.wa.gov.au

- **Aviary birds**
- **Native animals (reptiles, birds, mammals, insects).**

TRAVELLING WITHIN WESTERN AUSTRALIA

Broome area

Movement of palm plants and palm foliage from the Broome area is restricted.

Kununurra and Carnarvon areas

Movement of banana plants (except fruit), leaves, and soil from the Carnarvon and Kununurra areas is restricted.

Banana containers from areas infested with Panama disease (tropical race 4) are not allowed into the Carnarvon and Kununurra areas.

Ord River Irrigation Area (ORIA – near Kununurra)

There are restrictions on the movement of cut flowers and foliage, fruit, plants and vegetables from the ORIA.

From 1 April to 30 November each year, there are restrictions on the movement of citrus and stone fruit into the Ord River Irrigation Area.

Kimberley division

There are restrictions on the entry of nursery stock, cut flowers and foliage, and leafy vegetables into the Kimberley division.

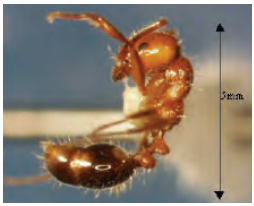
Potato growing areas (Gingin and South West)

Potatoes imported into WA from another State/Territory have restrictions on entry into WA potato growing areas.

For more information go to **agric.wa.gov.au/quarantine**

SOME MAJOR THREATS

Red imported fire ant (*Solenopsis invicta*)

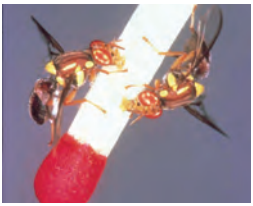


Red imported fire ant. DAFF Qld (Peter Green)

Threat: Red imported fire ants inflict a fiery sting, which may cause an allergic reaction. Invasions can make recreational areas unusable and damage native flora and fauna and pets.

Spread: By the movement of infested materials such as pot plants, soil, mulch and timber.

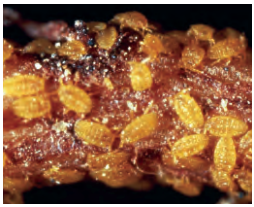
Queensland fruit fly (*Bactrocera tryoni*)


Queensland fruit flies. DEPI Vic

Threat: The feeding of Queensland fruit fly larvae (maggots) makes fruit inedible, lowering production and severely affecting trade to sensitive markets.

Spread: By the movement of uncertified host fruit out of infested areas. Most fresh fruits, including capsicum, chillies and tomatoes, are fruit fly hosts.

Grape phylloxera (*Daktulosphaira vitifoliae*)


Phylloxera aphids. DEPI Vic

Threat: The feeding of the phylloxera aphid on grapevine roots causes vines to decline and possibly die. It can also affect market access for the viticulture industry.

Spread: By the movement of grapevine rootlings, equipment and soil from infested areas.

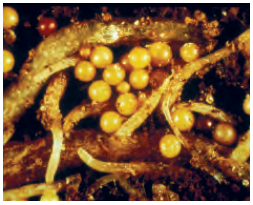
Green snail (*Cantareus apertus*)

Green snail. DAF WA

Threat: Green snail can significantly damage a wide range of plants, including most leafy vegetables, cereal crops, lupins, pasture grasses and native plants.

Spread: By the movement of host plant material.

Potato cyst nematode (*Globodera rostochiensis*)


PCN-infested potato roots. DEPI Vic.

Threat: Potato cyst nematode (PCN) feeds on the roots of potatoes, tomatoes and related crops, reducing crop yields and resulting in trade restrictions.

Spread: By the movement of host plants or of soil attached to plants, bulbs, advanced trees or agricultural equipment.

European house borer (*Hylotrupes bajulus*)

(L-R) EHB larva, male adult and female adult. DAF WA

Threat: European house borer (EHB) larvae chew through the wood of seasoned coniferous timber and can cause major structural damage to buildings and furniture.

Spread: By the movement of infested host timber, including building materials, wooden pallets and pine furniture.

Further information on pests and diseases of quarantine importance is available at **interstatequarantine.org.au**

FURTHER INFORMATION

New South Wales and Australian Capital Territory

NSW Department of Primary Industries
105 Prince St, Orange NSW 2800
Ph: 1800 680 244
Email: quarantine@dpi.nsw.gov.au
Website: www.dpi.nsw.gov.au

Northern Territory

Department of Primary Industry and Resources
Biosecurity & Product Integrity Division
NT Quarantine
GPO Box 3000, Darwin NT 0801
Ph: 08 8999 2118 **Fax:** 08 8999 2010
Email: quarantine@nt.gov.au
Website: www.nt.gov.au

Queensland

Department of Agriculture and Fisheries
Biosecurity Queensland
GPO Box 46, Brisbane QLD 4001
Ph: 13 25 23
Email: info@daf.qld.gov.au
Website: www.biosecurity.qld.gov.au

South Australia

Primary Industries and Regions
Biosecurity SA – Plant Health
33 Flemington St, Glenside SA 5065
Ph: 08 8207 7820 **Fax:** 08 8207 7844
Email: pirsa.planthealth@sa.gov.au
Website: www.pir.sa.gov.au

Tasmania

Department of Primary Industries, Parks, Water and Environment
13 St. Johns Ave, New Town TAS 7008
Ph: 03 6165 3777 **Fax:** 03 6173 0225
Email: biosecurity.tasmania@dpipwe.tas.gov.au
Website: www.dpipwe.tas.gov.au/biosecurity/quarantine-tasmania

Victoria

Agriculture Victoria
Box 4, Melbourne Markets Admin Building
55 Produce Rd, Epping VIC 3076
Ph: 136 186
Email: plant.standards@ecodev.vic.gov.au
Website: www.agriculture.vic.gov.au/psb

Western Australia

Department of Primary Industries and Regional Development
Quarantine WA
Locked Bag 69 Welshpool DC, WA 6986
Level 1, 24 Fricker Rd, Perth Airport WA 6105
Ph: 08 9334 1800 **Fax:** 08 9334 1888
Email: followup@dpird.wa.gov.au
Website: www.agric.wa.gov.au/quarantine

Do not take fruit, vegetables, plants or flowers across State and quarantine borders. **PENALTIES APPLY.**

Jangan membawa buah-buahan, sayur-sayuran, tanaman atau bunga melewati batas-batas negara bagian dan karantina. **DENDA DIBERLAKUKAN**

Está prohibido pasar frutas, verduras, plantas y flores al otro lado de los límites estatales y los de cuarentena. **SE IMPONDRÁN MULTAS.**

لا تنقل الفواكه، الخضروات، النباتات أو الزهور عبر حدود الولايات أو حدود الحجر الصحي. **تُفرض الغرامات.**

不要把水果、蔬菜、植物或鮮花帶過州和檢疫邊境。**違者受罰。**

州境界及び検疫線を越えて果物、野菜、植物または花を持ち込まないでください。**違反者には罰則が適用されます。**

IF IN DOUBT, THROW IT OUT

For more information, visit the website
interstatequarantine.org.au
or telephone Freecall **1800 084 881**

Quarantine Domestic

FOR MORE INFORMATION CALL
1800 084 881

Journal of Economic Entomology, 110(6), 2017, 2459–2465
doi: 10.1093/jee/tox237
Advance Access Publication Date: 11 October 2017
Research Article

OXFORD

Revised Distribution of *Bactrocera tryoni* in Eastern Australia and Effect on Possible Incursions of Mediterranean Fruit Fly: Development of Australia's Eastern Trading Block

Bernard C. Dominiak[1,3] and Richard Mapson[2]

[1]Biosecurity and Food Safety, NSW Department of Primary Industries, Locked Bag 21, Orange, NSW 2800, Australia, [2]Department of Economic Development, Jobs, Transport and Resources, 2 Codrington Street, Cranbourne, VIC 3977, Australia, and [3]Corresponding author, e-mail: bernie.dominiak@dpi.nsw.gov.au

Subject Editor: Lisa Neven

Received 23 March 2017; Editorial decision 4 August 2017

Abstract

Bactrocera tryoni (Froggatt) (Diptera: Tephritidae), commonly called 'Queensland fruit fly' in Australia, and Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) (Diptera:Tephritidae) are the two most economically important fruit fly in Australia with *B. tryoni* in the east and Mediterranean fruit fly in the west. The two species coexisted for several decades, but it is believed that *B. tryoni* displaced Mediterranean fruit fly. In southeastern Australia, this was deemed inadequate for export market access, and a large fruit fly free zone (fruit fly exclusion zone) was developed in 1996 where *B. tryoni* was eradicated by each state department in their portion of the zone. This zone caused an artificial restricted distribution of *B. tryoni*. When the fruit fly exclusion zone was withdrawn in Victoria and New South Wales in 2013, *B. tryoni* became endemic once again in this area and the national distribution of *B. tryoni* changed. For export markets, *B. tryoni* is now deemed endemic to all eastern Australian states, except for the Greater Sunraysia Pest-Free Area. All regulatory controls have been removed between eastern states, except for some small zones, subject to domestic market access requirements. The eastern Australian states now form a *B. tryoni* endemic trading group or block. All Australian states and territories maintain legislation to regulate the movement of potentially infested host fruit into their states. In particular, eastern states remain active and regulate the entry of commodities possibly infested with Mediterranean fruit fly. The combination of regulatory controls limits the chances of Mediterranean fruit fly entering eastern states, and if it did, Mediterranean fruit fly is unlikely to establish in the opposition to a well-established *B. tryoni* population.

Key words: competition, trade, dispersal

Australia has 80 native fruit fly species (Drew 1989) with the most economically important species being the Queensland fruit fly (*Bactrocera tryoni* Froggatt) (Diptera: Tephritidae). The pre-European settlement endemic range of *B. tryoni* is considered to be Queensland and possibly northern parts of coastal New South Wales (NSW), where it bred in the fruits of coastal and rainforest plants (Gurney 1910, Froggatt 1910). As the European population of the young Australian colonies increased, so did plantings of imported fruit and fruiting vegetables, providing additional hosts for fruit flies to complete their life cycle. In the eastern states during 1920s, *B. tryoni* moved from native hosts into the imported orchard fruits (Gurney 1925).

Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) (Diptera: Tephritidae) is an introduced pest in Australia. Of Afrotropical origin, Mediterranean fruit fly spread to the Mediterranean region and from there was introduced into Western Australia between 1895 and 1897 (May 1963, Sproul et al. 2001). The pest was initially detected in NSW, Victoria, and South Australia (White and Elson-Harris 1992, Bonizzoni et al. 2004) but has not been detected in eastern Australia in 60 years (Dominiak and Daniels 2012). Both *B. tryoni* and Mediterranean fruit fly co-existed in areas of NSW and Victoria for several years before Mediterranean fruit fly disappeared. In Western Australia, Mediterranean fruit fly established rapidly where no *B. tryoni* were resident. Tasmania has remained free from both fruit fly species largely due to inclement climate and rigorous biosecurity activities (Dominiak and Daniels 2012).

For reasons not entirely understood, *B. tryoni* had displaced Mediterranean fruit fly throughout the eastern states by the mid-1950s (Anon. 1947, O'Loughlin 1964). The distribution and early history of both flies were reviewed by Dominiak and Daniels

© The Author(s) 2017. Published by Oxford University Press on behalf of Entomological Society of America.
All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

(2012). Regional fruit fly management in the early 1990s temporarily changed the *B. tryoni* distribution in southeastern Australia (Dominiak and Daniels 2012) when the fruit fly exclusion zone (FFEZ) resulted in local populations of *B. tryoni* being eradicated. The Victorian and NSW components of the FFEZ were disbanded in July 2013, and it is appropriate to redraw the current fruit fly distribution. Zalucki (2016) claimed that the mapping of fruit fly distributions in past reports should 'be expunged from the thinking. . . '; however, Australia's trade partners require that the distribution of fruit fly species are clearly articulated and mapped. This review redefines the *B. tryoni* distribution after July 2013 in southeastern Australia for export and domestic trade. This review also examines the implications on the likelihood that Mediterranean fruit fly could be transported into eastern states and if an introduction did occur, the chances of Mediterranean fruit fly establishment in a *B. tryoni* established population are highly unlikely.

Australian Fruit Fly Monitoring and Surveillance

The distribution of Australia's endemic and introduced fruit fly species has been recorded using internationally accepted trapping and monitoring systems (Smith 2000). Additional data have also been collected through official surveys, extension activities, identifications at quarantine roadblocks and voluntary reporting by growers, trained entomologists and the general public.

Beyond the general surveillance networks, specific trapping networks were in place to demonstrate that major horticultural production regions in all states and territories were free of certain economically significant fruit flies (Drew 1989). These regions included the FFEZ covering parts of South Australia, Victoria, and NSW. This pest-free area was on the ecological edge of the range of *B. tryoni* and covered approximately 135,000 km^2 based on local government boundaries (Dominiak et al. 2000). Pest-free status enabled horticultural commodities produced in these regions to enter domestic and some export markets without additional phytosanitary requirements. The FFEZ was maintained with a highly regulated quarantine system (Anon. 1996, Dominiak and Daniels 2012).

Review of Fruit Flies in Eastern States

Queensland is recognized as the 'home' of *B. tryoni*, and *B. tryoni* is native in that state. The Mediterranean fruit fly position is less clear. Early identification records between *B. tryoni* and Mediterranean fruit fly became confused (May 1963). Although French (1907) reported that Mediterranean fruit fly had been bred from bananas and oranges imported from Queensland in 1906, Tryon (1926) claimed that Mediterranean fruit fly was never clearly identified from fruit grown in Queensland. Veitch (1934), Caldwell and May (1943), and May (1944) only mention the presence of *B. tryoni* in orchards.

To date, there have been no confirmed detections of Mediterranean fruit fly in traps or attacking fruit grown in Queensland (Tryon 1926, May 1962, Bateman 1991, Dominiak and Daniels 2012). Permkan and Hancock (1994) note the last Mediterranean fruit fly report from Queensland was in 1931. A search of the Australian Plant Pest Database (2012) reveals 11 records of Mediterranean fruit fly in Queensland. Only two records have hosts and both were citrus. Seven records identify Toowoomba, two records identify Stanthorpe, and two samples only list 'Queensland' as location records. The first nine list 'Jarvis, H' as the identifier. The earliest samples were dated in 1928, and seven samples list 1931 as the year of detection. The samples in the collection were examined, and four samples had the letters 'IMP' on the voucher label (Desley Tree, personal communication). In the New Collins Concise English Dictionary, 'IMP' is listed as an abbreviation for seven words, one of which is 'imported' (Collins 1982). It is likely that that these Mediterranean fruit fly samples were detected in fruit 'imported' into Queensland. If this theory is correct, then there are no data to indicate that Mediterranean fruit fly ever established a breeding population in Queensland.

The distribution of *B. tryoni* in NSW and Victoria, apart from the FFEZ and the Greater Sunraysia Pest-Free Area (GSPFA), has not changed since described by Dominiak and Daniels (2012). *B. tryoni* is endemic in these states. However, there are some regulated areas for domestic market access such as the Yarra Valley pest-free place of production and the Guyra pest-free place of production. Mediterranean fruit fly has not been detected in NSW since 1941 (Anon. 1947) and Victoria since 1953 (O'Loughlin 1964, 1983).

Fruit Fly Exclusion Zone

The Murrumbidgee Irrigation Area (MIA) is the main regional horticultural production region in NSW. The MIA became a quarantine area in 1912 and fruit was only allowed to be transported into the area after application of an effective phytosanitary treatment (Sproule 1975). Despite these measures, Mediterranean fruit fly was recorded in the MIA in 1923 (O'Loughlin 1964, Sproule 1975). By 1936, Mediterranean fruit fly had been eliminated and had not been found since in the MIA as shown by continual surveillance trapping (Sproule 1975; Gillespie 2003). The first known incursion of *B. tryoni* into the MIA was in 1934, 2 yr before the last detection of Mediterranean fruit fly. *B. tryoni* outbreaks within the MIA were immediately eradicated, and the area eventually became part of the NSW portion of the FFEZ that was officially recognized as being free from all fruit flies of economic significance.

Following the wet season in 1989, it was decided that *B. tryoni* would be better managed by a regional program with a perimeter of exclusion measures around the MIA and other production areas. The FFEZ was established in 1996 and covered major horticultural growing areas of South Australia, Victoria, and NSW (Fig. 1). While the latter two states were nominally in *B. tryoni* endemic areas, resident *B. tryoni* populations were eradicated from within the FFEZ. Eradication was possible because of cold winters, hot dry summers, and the lack of fruit fly hosts outside commercial orchards and home gardens. The FFEZ was surrounded by semi-desert where *B. tryoni* were highly unlikely to establish. If establishment occurred, *B. tryoni* would be highly unlikely to disperse naturally through semi-desert into production areas within the FFEZ (Dominiak 2012).

Clarke et al. (2011) reviewed the literature on *B. tryoni* dispersal and concluded that the natural flight distance of *B. tryoni* could be as high as several kilometers but maximum flight distances were more frequently measured in a few hundred meters (Dominiak 2012). Therefore, incursions were highly unlikely to be the result of natural flight. Transport of infested produce, usually in tourist traffic, has been considered to be the main source of *B. tryoni* outbreaks (Bateman 1977, Yonow and Sutherst 1998; Meats et al. 2008, Dominiak and Coombes 2009). However, any incursions of *B. tryoni* into the FFEZ were immediately eradicated (Anon. 1996, Campbell et al. 2009) with more frequent incursions detected in the NSW portion of the FFEZ than the other states. For export and domestic trade purposes, the FFEZ was considered to be free of both *B. tryoni* and Mediterranean fruit fly, excepting occasional *B. tryoni* incursions in discrete areas. Many incursions are lower than international

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

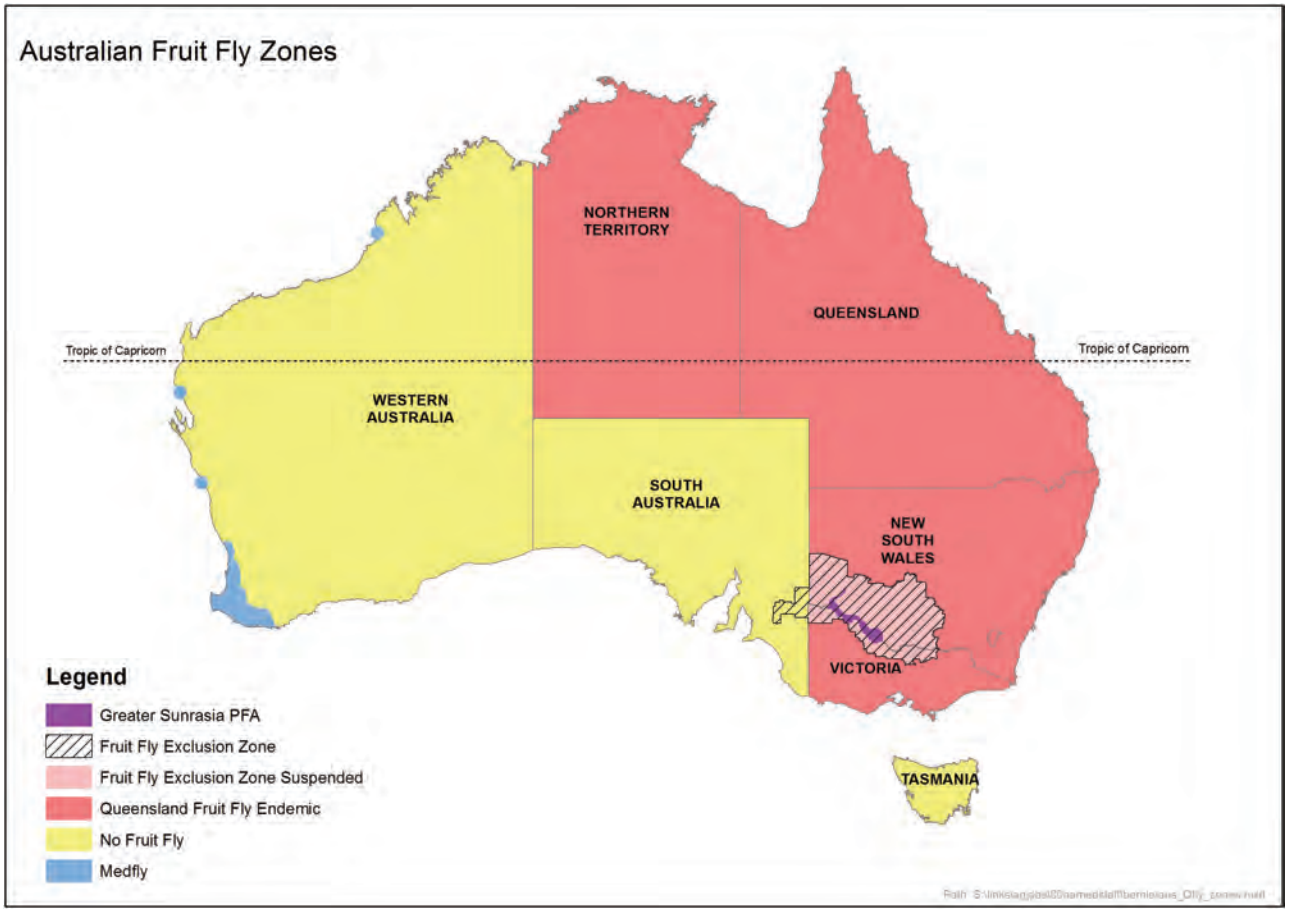


Fig. 1. Revised distribution of *Bactrocera tryoni* and Mediterranean fruit fly in Australia.

standards for an established population and are regarded as transient populations (Anon. 1996; Dominiak et al. 2011, 2015)

Climate and the Fruit Fly Exclusion Zone

Temperature and rainfall are the two main key drivers for *B. tryoni* establishment and population development (Yonow and Sutherst 1998). It may be instructive to demonstrate the changing climate over the last 15 years in the NSW portion of the FFEZ and recognize that similar climatic patterns and fruit fly outbreaks occurred in Victoria. An extensive community and traveler awareness campaign were conducted to inform travelers of the obligations not to carry fruit. This awareness program was designed to gain public support and understanding for the regional fruit fly eradication program (Dominiak and Coombes 2010). A vehicle inspection program was conducted on the eastern entry highway to increase public awareness of the traveling public and increase compliance to legislation governing restricted fruit movements (Dominiak and Coombes 2009). Within the NSW portion of the FFEZ, there were approximately 450 cuelure (International Pheromone Systems, United Kingdom) Lynfield traps (manufactured by NSW Department of Primary Industries) in towns and orchards inspected 41 times per year (the number changed periodically as urban, and orchard areas changed). This equated to over 18,000 trap inspection events each year. In most years (July to June), these approximately 18,000 trap inspection events resulted in less than 200 *B. tryoni* being detected in the entire NSW FFEZ. Previous research has found that 71% of single fly detections do not progress further and are indicative of a transient population (Meats et al. 2003) and the number of outbreaks was low. The NSW FFEZ was traditionally dry, and *B. tryoni* outbreaks are easily eradicated because *B. tryoni* is dependent on higher moisture to sustain high populations (Dominiak et al. 2006). Warmer temperatures also result in more generations per year (Yonow and Sutherst 1998).

Wet years in 1999 and 2001 resulted in approximately 1,500 detections in the NSW FFEZ but numbers declined to nearly 500 detections in 2002 and 2003. Another wet year in 2003 and 2004 resulted in over 7,000 detections, and many outbreaks took longer than normal to eradicate due to the wet conditions. However, these climatic events were usually single wet years, and the following dry cycle allowed eradication to be successful. The dry years returned, and detections fell to less than 140 detections per year from 2006 to early 2010.

The 2010 and 2011 years were wet (Webb 2012). The 2-yr pattern started in autumn 2010 and was wetter than the average in eastern Australia (Campbell 2011). The summer of 2010 and 2011 was the second wettest Australian summer in Australia on record (Imielska 2011). With the favorable wet weather, over 27,700 flies were detected in the FFEZ and many fruit fly outbreaks occurred. The winter of 2011 provided some respite. The spring of 2011 was the ninth wettest on record. NSW was wetter than usual, but cooler than average, in the summer of 2011 and 2012 (Webb 2012). The continuing wet conditions exacerbated an already difficult fruit fly season. There were over 23,100 *B. tryoni* detections in the 2011–2012 season. The individual years 2010 and 2011 were the third and second wettest on record for Australia, respectively. This combination gave Australia its wettest two calendar years on record.

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

This was followed by the summer of 2012–2013 which was the hottest Australian summer on record accompanied by extreme rainfall on the east coast (White and Fox-Hughes 2013). For NSW, this was ranked the seventh warmest summer on record. Winter 2013 was Australia's third warmest winter on record (Martin 2014). By this time, there were over 100 outbreaks of *B. tryoni* in NSW FFEZ and eradication attempts had failed. It was decided that eradication was technically unfeasible and economically unsustainable.

In July 2013, legislation underpinning movement controls in NSW FFEZ was withdrawn. In Victoria, FFEZ legislation was allowed to lapse in July 2013. A sentinel network of traps remains in place as an early warning for possible exotic fruit fly incursions and to demonstrate the continued absence of Mediterranean fruit fly. In the South Australian FFEZ, outbreaks did not occur, and this part of the FFEZ remains *B. tryoni* and Mediterranean fruit fly free. The legislation to support regulatory actions remains in place in South Australia for the entire state, including their portion of the FFEZ.

Greater Sunraysia Pest-Free Area

As an added level of security to improve export market access, the GSPFA was developed in 2007 and supported by legislation in Victoria and NSW (Fig. 1). This zone is 10,416 km^2 and was developed to assist local fruit industries, primarily citrus, stone fruit, and table grapes, to access key export markets under area freedom certification. In comparison to the rest of FFEZ, this area was relatively free from *B. tryoni* outbreaks. The GSPFA conducted roadside vehicle inspection and conducted awareness programs for road travelers. The wet years of 2010 and 2011 resulted in 88 outbreaks and pest-free status was eventually suspended by the state governments in Victoria and NSW in 2013. In late 2014, the management of the GSPFA transitioned to a grower-based committee. Joint legislation in Victoria and NSW provided for a levy of $3 per tonne to be raised to fund fruit fly management programs. Strategic plans are currently being developed to either reinstate pest freedom conditions for some or all parts of this zone or to transition to other market access options such as areas of low pest prevalence (Dominiak et al. 2015). The GSPFA has been free from Mediterranean fruit fly for over 50 years but continues to maintain a monitoring network to detect any incursions.

Revised Distribution and Management of *B. tryoni*

Queensland has managed *B. tryoni* since trading began in colonial times and continues to the present (Lloyd et al. 2010). *B. tryoni* is endemic in NSW; however, the FFEZ caused a temporary and artificial alteration in *B. tryoni* distribution by preventing establishment in this area. Following the closure of the FFEZ in NSW and Victoria (Fig. 1), regulatory controls associated with some parts of this region are maintained for domestic market access in these states. *B. tryoni* is deemed endemic to all of NSW and Victoria although not to GSPFA for export markets.

B. tryoni is endemic in Northern Territory and Queensland for export markets. There are no movement restrictions for domestic trade between these four states on account of *B. tryoni*. These four *B. tryoni*-affected states now form a common domestic trading block dealing with endemic *B. tryoni* populations using interstate certification agreements (Jessup et al. 2007).

Western Australia remains *B. tryoni* free other than occasional incursions (Hardie D., personal communication). *B. tryoni* was detected in 1989, 1995, and 2011. In 2015, six flies were detected, which exceeded the outbreak threshold (Dominiak et al. 2011) and triggered an immediate eradication response. South Australia also remains *B. tryoni* and Mediterranean fruit fly free for export and domestic markets other than occasional incursions. Tasmania remains free of *B. tryoni* and Mediterranean fruit fly for export and domestic markets due to inclement climate and strict import restrictions (Anon. 2011).

Interspecies Competition Between *Bactrocera* and *Ceratitis*

The interspecies competition was reviewed by Dominiak and Daniels (2012). There are many factors including differences in oviposition requirements (Anon. 1939, Allman 1939a, Stange 1999) with Australian conditions possibly favoring *B. tryoni*. Queensland fruit fly will deposit eggs into Mediterranean fruit fly sting holes, but Mediterranean fruit fly does not lay eggs into fruit with fruit fly larvae already present. Where a fruit contains larvae of both species, *B. tryoni* larvae develop almost to the exclusion of Mediterranean fruit fly larvae. When Mediterranean fruit fly emerge, adults tend to be abnormally small (Allman 1939a). Small fruit flies have fewer reserves of carbohydrate and protein for adult eclosion and spent a higher proportion of time looking for food instead of reproducing (Fitt 1984, Blay and Yuval 1999, Kaspi et al. 2000, Dominiak et al. 2008).

B. tryoni reportedly has better mobility, greater reproductive capacity, longer lifespans, more aggressive than Mediterranean fruit fly. *B. tryoni* infests a wider range of target host species, particularly native rainforest fruits, compared to Mediterranean fruit fly (Anon. 1989, Fisher 1996, Waterhouse and Sands 2001, Bonizzoni et al. 2004, Dominiak 2012). Another factor contributing to the decline of Mediterranean fruit fly was the enforcement of regulations requiring the collection and destruction of infested fruit (Allman 1939b). *B. tryoni* can complete its life cycle in both native and introduced hosts. In contrast, Mediterranean fruit fly is restricted to commercial fruit crops and some ornamentals (Gurney 1925, Edwards 1961). As a result, cover sprays of insecticides probably affected Mediterranean fruit fly more than *B. tryoni* (Edwards 1961, Fletcher and Bateman 1983).

Regarding the failure of Mediterranean fruit fly to establish in Queensland, the climate was considered a less important factor than competition from *B. tryoni*. Vera et al. (2002) reported that modeling Mediterranean fruit fly climatic requirements indicated that an ideal location was in Queensland but Mediterranean fruit fly was never reported infesting fruit in Queensland. The climate in coastal Queensland is very similar to areas of Brazil. The failure of Mediterranean fruit fly to establish in Queensland was claimed by Vera et al. (2002) to support the hypothesis that Mediterranean fruit fly was excluded by biotic factors such as competition, rather than climate. Many other parts of Australia are subject to dry stress that would normally adversely influence Mediterranean fruit fly populations. Vera et al. (2002) indicated that the CLIMEX model showed good agreement with the distribution of Mediterranean fruit fly in Western Australia, but not in eastern Australia.

If *B. tryoni* has displaced Mediterranean fruit fly through competition in Australia, it would follow similar international examples where *Bactrocera* species has displaced *Ceratitis* (Christensen and Foote 1960, Debach 1966, Duyck and Quilici 2002, Ekesi et al. 2009, Mziray et al. 2010). For instance, in China, Liu et al. (2017) found that *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) and *Bactrocera correcta* Bezzi (Diptera: Tephritidae) laid more eggs and had shorter larval development time than *C. capitata*. The

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

competitive advantage was primarily based on the larval stage: adult aggressive behavior and recognition of preinfested hosts did not play a role. What does this mean for the Australian eastern trading block of states? The endemic nature of *B. tryoni* in these eastern states means that Mediterranean fruit fly is extremely unlikely to establish. However, these states maintain a network of Mediterranean fruit fly traps to enable the early detection in the likely event of a Mediterranean fruit fly incursion and establishment.

Legislative Controls in Australian States

Australia has two main fruit fly pests, Mediterranean fruit fly in Western Australia and *B. tryoni* in eastern states. Each state aims to prevent the transport of fruit infested with fruit fly species currently not endemic in their state. Australia is a federation of states, and each state has its own legislation (Table 1). Each state and territory regulations cover a range of activities involving the movement of any at risk produce including fruit fly host produce. Transport of fruit fly host produce is facilitated by small parcels via road vehicles and by large-scale commercial produce. Road travelers have been subjected to a variety of road-side vehicle inspections and awareness programs (Dominiak and Coombes 2009, 2010).

Commercial consignments are much larger and significantly increase the risk of transporting potentially infested fruit across state borders. This risk is recognized and regulated by the Interstate Certificate Assurance scheme that is supported by legislation in each state (Jessup et al. 2007). Since the loss of the FFEZ, almost all *B. tryoni* regulations along the eastern states of Australia have been removed. For export markets, *B. tryoni* is deemed endemic in all eastern states (except GSPFA) and effectively form an eastern trading block in Australia. These states maintain legislation to exclude Mediterranean fruit fly even in the unlikely event that Mediterranean fruit fly might be introduced but face the challenge of establishing a Mediterranean fruit fly population in the opposition of an entrenched *B. tryoni* population.

The Australian Government has primary responsibility for preborder and border biosecurity activities, export certification, trade negotiations, and quarantine. The states and territories are responsible for biosecurity matters affecting their rural industries, environment, and community, including surveillance (Plant Health Australia 2014).

Conclusion

Mediterranean fruit fly remains confined to Western Australia, confined by geography, and host movement controls. The states of Queensland, NSW, Victoria, Tasmania, Northern Territory, and South Australia are Mediterranean fruit fly pest-free areas (FAO 2015). South Australia has occasionally isolated detections of Mediterranean fruit fly, but all incursions are rapidly eradicated. *B. tryoni* is resident in parts of Queensland, the Northern Territory, NSW, and Victoria. Occasional *B. tryoni* detections occur in South Australia. The states of Tasmania, Western Australia, and South Australia are *B. tryoni*-free areas for export and domestic trade (FAO 2015). The GSPFA is now the only regulated region for domestic and export markets other than an Australian state. The *B. tryoni* endemic nature of eastern Australia means that it is highly unlikely that Mediterranean fruit fly will establish in eastern Australia if host movement controls fail. Despite this, all eastern states and South Australia maintain regulatory legislation and controls on host produce coming from Western Australia. There is an opportunity to review the current Mediterranean fruit fly monitoring network given the very low chance that Mediterranean fruit fly might establish in the *B. tryoni* endemic regions in eastern Australia.

Apart from the FFEZ, these fruit fly distributions have remained largely unchanged for half a century. Major geographical barriers prevent the movement of these species. The spread of either pest is only likely through human-assisted transport of host materials. The east–west divide is maintained by strict enforcement of domestic quarantine restrictions by state and territory regulators. Status is verified through extensive surveillance and monitoring networks and due to the long distance of desert between eastern states and western states.

Table 1. States of Australia and the legislation to regulate the entry of fruit fly

Australian state	State legislation to regulate the entry of susceptible host produce	Fruit fly regulated to prevent entry
Queensland	Plant Protection Act 1989	Mediterranean fruit fly
New South Wales	Biosecurity Act 2015	Mediterranean fruit fly
Victoria	Plant Biosecurity Act 2010	Mediterranean fruit fly
Northern Territory	Plant Health Act 2008	Mediterranean fruit fly
Western Australia	Plant Diseases Act 1914	*Bactrocera tryoni*
South Australia	Plant Health Act 2009	Mediterranean fruit fly, *B. tryoni*
Tasmania	Plant Quarantine Act 1997	Mediterranean fruit fly, *B. tryoni*

Acknowledgments

Earlier versions of the manuscript were improved by comments from Lloyd Stringer, Alison Seyb, Fay Haynes, Gary D'Arcy, Geoff Raven, and Craig Hull. The map was created by Peter Worsley.

References Cited

Allman, S. L. 1939a. The Queensland fruit fly. Observations on breeding and development. Agric. Gaz. N. S. W. 50: 499–501.

Allman, S. L. 1939b. The Queensland fruit fly. Observations on breeding and development. Agric. Gaz. N. S. W. 50: 547–549.

Anon. 1939. Insect pests and their control. Agric. Gaz. N. S. W. 50: 152–153.

Anon. 1947. Fruit flies (Strumeta tryoni). Agric. Gaz. N. S. W. 58: 532–534.

Anon. 1989. Queensland fruit fly eradication programme proposed by the WA Department of Agriculture. Environmental Protection Authority, Perth, Western Australia. Bulletin 400. August 1989. p. 9.www.epa.wa.gov.au/proposals/queensland-fruit-fly-eradication-program.

Anon. 1996. Code of practice for the management of Queensland fruit fly. Standing Committee on Agriculture and Resource Management, Department of Primary Industries, Canberra.

Anon. 2011. Review of import requirements for fruit fly host produce from mainland Australia, p. 117. Department of Primary Industries, Parks, Water and Environment, Tasmania.

Australian Plant Pest Database. 2012. www.planthealthaustralia.com.au/resources/australian-plant-pest-database/ (Accessed 15 May 2012).

Bateman, M. A. 1977. Dispersal and species interactions as factors in the establishment and success of tropical fruit flies in new areas. Proc. Ecol. Soc. Aust. 10: 106–112.

Bateman, M. A. 1991. The impact of fruit flies on Australian Horticulture. Horticultural Policy Council Report No. 3. ISBN 0 642 16110 0.

Blay, S. and B. Yuval. 1999. Oviposition and fertility in the Mediterranean fruit fly (Diptera: Tephritidae): effects of male and female body size and the availability of sperm. Ann. Entomol. Soc. Am. 92: 278–284.

Bonizzoni, M., C. R. Guglielmino, C. J. Smallridge, M. Gomulski, A. R. Malacrida, and G. Gasperi. 2004. On the origins of Medfly invasion and expansion in Australia. Mol. Ecol. 13: 3845–3855.

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

Caldwell, N. E. H. and A. W. S. May. 1943. Fruit fly luring investigation. Qld. Agric. J. 57: 166–168.

Campbell, A. J., A. J. Lynch, B. Dominiak, and H. I. Nicol. 2009. Effects of radiation, dye, day of larval hopping and vibration on eclosion of Queensland fruit fly Bactrocera tryoni (Froggatt) (Diptera: Tephritidae). Gen. Appl. Entomol. 38: 49–53.

Campbell, B. 2011. Seasonal climate summary southern hemisphere (autumn 2010): rapid decay of El Nino, wetter than average in central, northern and eastern Australia and warmer than usual in the west and south. Aust. Meteorol. Oceanog. J. 61: 65–76.

Christensen, L. D. and R. H. Foote. 1960. Biology of fruit flies. Ann. Rev. Entomol. 5: 171–192.

Clarke, A. R., Powell, K. S., Weldon, C. W., and P. W. Taylor. 2011. The ecology of Bactrocera tryoni (Diptera: Tephritidae): what do we know to assist pest management? Ann. Appl. Biol. 158: 26–55.

G.A. Wilkes and W.A. Krebs (eds.). 1982. Collins Concise Dictionary of the English Language. Collins , Sydney.

Debach, P. 1966. Competitive displacement and coexistence principles. Ann. Rev. Entomol. 11: 183–212.

Dominiak, B. C., T. D. Rafferty, and I. M. Barchia. 2000. A survey of travellers carrying host fruit of Queensland fruit fly, Bactrocera tryoni (Froggatt), into a fruit fly free area in 1996/97. Gen. Appl. Entomol. 29: 39–44.

Dominiak, B. C., H. S. Mavi, and H. I. Nicol. 2006. Effect of town microclimate on the Queensland fruit fly, Bactrocera tryoni. Aust. J. Exper. Agric. 46: 1239–1249.

Dominiak, B. C., S. Sundaralingham, L. Jiang, A. J. Jessup, and I. M. Barchia. 2008. Production levels and life history traits of mass reared Queensland fruit fly Bactrocera tryoni (Froggatt) (Diptera: Tephritidae) during 1999/2002 in Australia. Plant Prot. Q. 23: 131–135.

Dominiak, B. C. and N. M. Coombes. 2009. Fruit carrying characteristics of travellers into a quarantine zone in New South Wales in 1999/2000. Plant Prot. Q. 24: 14–19.

Dominiak, B. C. and N. M. Coombes. 2010. Review of the impact of the TriState community fruit fly awareness program on road travellers—1999/2000. Plant Prot. Q. 25: 2–8.

Dominiak, B. C., D. Daniels, and R. Mapson. 2011. Review of the outbreak threshold of Queensland fruit fly (Bactrocera tryoni Froggatt). Plant Prot. Q. 26: 141–147.

Dominiak, B. C. 2012. Review of dispersal, survival, and establishment of Bactrocera tryoni (Diptera: Tephritidae) for quarantine purposes. Ann. Entomol. Soc. Am. 105: 434–446.

Dominiak, B. C. and D. Daniels. 2012. Review of the past and present distribution of Mediterranean fruit fly (Ceratitis capitata Wiedemann) and Queensland fruit fly Bactrocera tryoni Froggatt) in Australia. Aust. J. Entomol. 51: 104–115.

Dominiak, B. C., B. Wiseman, C. Anderson, B. Walsh, M. McMahon, and R. Duthie. 2015. Definition of and management for areas of low pest prevalence for Queensland fruit fly Bactrocera tryoni Froggatt. Crop Prot. 72: 41–46.

Drew, R. A. I. 1989. The tropical fruit flies (Diptera: Tephritidae) of the Australasian and Oceanian regions. Mem. Qld. Mus. 26: 1–521.

Duyck, P. F. and S. Quilici. 2002. Survival and development of different life stages of three *Ceratitis* spp. (Diptera: Tephritidae) reared at five constant temperatures. Bull. Entomol. Res. 92: 461–469.

Edwards, B. A. B. 1961. The fruit fly problem in Australia. Outlook Agric. 3: 116–122.

Ekesi, S., M. K. Billah, P. W. Nderitu, S. A. Lux, and I. Rwomushana. 2009. Evidence for competitive displacement of ceratitis cosyra by the invasive fruit fly bactrocera invadens (Diptera: Tephritidae) on mango and mechanisms contributing to the displacement. J. Econ. Entomol. 102: 981–991.

FAO. 2015. International Standards for Phytosanitary Measures: ISPM 26. Establishment of pest free areas for fruit flies (Tephritidae). Publication No. 26. Secretariat of the International Plant Protection Convention, Food and Agriculture Organisation of the United Nations, Rome. p. 56.

Fisher, K. 1996. Queensland fruit fly (Bactrocera tryoni): eradication from Western Australia, pp. 535–541. *In* McPheron and Steck (eds.), Fruit fly pests. A world assessment of their biology and management. St Lucas Press, FL.

Fitt, G. P. 1984. Oviposition behaviour of two tephritid fruit flies, *Dacus tryoni* and *Dacus jarvisi*, as influenced by the presence of larvae in the host fruit. Oecologia. 62: 37–46.

Fletcher, B. S. and M. A. Bateman. 1983. Combating the fruit fly problems in Australia: the current situation and future prospects, pp. 555–563. *In* R. Cavalloroand and A. A. Balkema Rotterdam (eds.), Fruit flies of economic importance. ISBN 90 6191 503 1. A.A. Balkema, Rotterdam, Netherlands.

French, C. 1907. Fruit flies. J. Agric. 13: 301–312.

Froggatt, W. W. 1910. Notes on fruit flies (Trypetidae) with descriptions of new species. Linn. Soc. N. S. W. 35: 862–872.

Gillespie, P. 2003. Observations on fruit flies (Diptera: Tephritidae) in New South Wales. Gen. Appl. Entomol. 32: 41–47.

Gurney, W. M. B. 1910. Fruit flies and other insects attacking cultivated and wild fruit in New South Wales. Agric. Gaz. N. S. W. 31: 423–433.

Gurney, W. M. B. 1925. The control of fruit fly. Agric. Gaz. N. S. W. 31: 879–887.

Imielska, A. 2011. Seasonal climate summary southern hemisphere (summer 2010–2011): second-wettest Australian summer on record and one of the strongest La Nina events on record. Aust. Meteorol. Oceanog. J. 61: 241–251.

Jessup, A. J., B. C. Dominiak, B. Woods, C. P. F. De Lima, A. Tomkins, and C. Smallridge. 2007. Area-wide management of fruit flies in Australia, pp. 685–697. *In* M. J. B. Vreysen, A. S. Robinson, and J. Hendrichs (eds.), Area-wide control of insect pests: from research to field implementation. Springer, Dordrecht, The Netherlands.

Kaspi, R., Taylor, P. W., and B. Yuval. 2000. Diet and size influences sexual advertisement and copulatory success of males in Mediterranean fruit fly leks. Ecol. Entomol. 25: 279–284.

Lloyd, A. C., Hamacek, E. L., Kopittke, R. A., Peek, T., Wyatt, P. M., Neale, C. J., Eelkema, M. and H. Gu. 2010. Area-wide management of fruit flies (Diptera: Tephritidae) in the Central Burnett district of Queensland, Australia. Crop Prot. 29: 462–469.

Liu, H., C. Zhang, B. H. Hou, G. C. Ou-Yang, and J. Ma. 2017. Interspecific competition between *Ceratitis capitata* and two *Bactrocera* spp. (Diptera: Tephritidae) evaluated via adult behavioral interference under laboratory conditions. J. Econ. Entomol. 110: 1145–1155.

Martin, L. 2014. Seasonal climate summary southern hemisphere (winter 2013): Australia's third warmest winter on record. Aust. Meteorol. Oceanog. J. 64: 67–85.

May, A. W. S. 1944. Fruit fly control. Qld. Agric. J. 67: 224–229.

May, A. W. S. 1962. The fruit fly problem in Eastern Australia. Aust. J. Entomol. 1: 1–4.

May, A. W. S. 1963. An investigation of fruit flies (Trypetidae: Diptera) in Queensland. Qld. J. Agric. Sc. 20: 1–81.

Meats, A., A. Clift, and M. Robson. 2003. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Aust. J. Exp. Agric. 43: 397–406.

Meats, A. M., H. A. C. Fay, and R. A. I. Drew. 2008. Distribution and eradication of an exotic tephritid fruit fly in Australia: relevance of invasion theory. J. Appl. Entomol. 132: 406–411.

Mziray, H. A., R. H. Makundi, M. Mwatawala, A. Maerere, and M. De Meyer. 2010. Host use of *Bactrocera latifrons*, a new invasive tephritid species in Tanzania. J. Econ. Entomol. 103: 70–76.

O'Loughlin, G. T. 1964. The Queensland fruit fly in Victoria. J. Agric. Victoria. 62: 391–402.

O'Loughlin, G. T. 1983. Queensland fruit fly in Victoria—a synopsis of observations on its biology and control. Research Project Series No 177. Department of Agriculture, Melbourne, Victoria.

Permkan, S. and D. L. Hancock. 1994. Australian *Ceratitinae* (Diptera: Tephritidae). Invertebr. Taxon. 8: 1325–1341.

Plant Health Australia. 2014. The National Plant Health Status Report. Plant Health Australia, Canberra, ACT. p. 211.

Smith, E. S. C. 2000. Internal and external fruit fly quarantine in Australia, pp. 171–177. *In* N. S. Price and I. Seewooruthum (eds.), Proceedings, Symposium: Indian Ocean Commission Regional Fruit Fly Symposium June 2000. Indian Ocean Commission, Mauritius.

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

Sproule, R. S. 1975. Queensland fruit , p. 37. New South Wales Department of Agriculture, South Western Region

Sproul, A., S. Broughton, F. De Lima, D. Hardie, N. Monzu, and B. Woods. 2001. The fight against fruit flies in Western Australia. Bracks-Burns, M., Walker, C., and B. Woods (eds.), Department of Agriculture, Western Australia, Bulletin No. 4504, October 2001. researchlibrary.agric.wa.gov.au/bulletins/106/.

Stange, G. 1999. Carbon dioxide is a close-range oviposition attractant in the Queensland fruit fly Bactrocera tryoni. Naturwissenschaften. 86: 190–192.

Tryon, H. 1926. Queensland fruit flies (Trypetidae), Series 1. Proc. Royal Soc. Qld. 38: 176–223.

Veitch, R. 1934. Queensland fruit fly control. Qld. Agric. J. 42: 672–673.

Vera, M. T., R. Rodriguez, D. F. Segura, J. L. Cladera, and R. W. Sutherst. 2002. Potential geographic distribution of the Mediterranean fruit fly, Ceratitis capitata (Diptera: Tephritidae), with emphasis on Argentina and Australia. Environ. Entomol. 31: 1099–1022.

Waterhouse, D. F. and D. P. A. Sands. 2001. Classical biological control of arthropods in Australia. ACIAR Monograph No 77. 560 pages. aciar.gov.au/publication/mn077.

Webb, M. A. 2012. Seasonal climate summary southern hemisphere (summer 2011–12): a mature La Nina, strongly positive SAM and active MJO. Aust. Meteorol. Oceanog. J. 62: 335–349.

White, I. M. and M. M. Elson-Harris. 1992. Fruit flies of economic significance: their identification and bionomics. CAB International, Oxon, UK.

White, C. J. and P. Fox-Hughes. 2013. Seasonal climate summary southern hemisphere (summer 2013–13): Australia's hottest summer on record and extreme east coast rainfall. Aust. Meteorol. Oceanog. J. 63: 443–436.

Yonow, T. and R. W. Sutherst. 1998. The geographical distribution of the Queensland fruit fly, Bactrocera (Dacus) tryoni, in relation to climate. Aust. J. Agric. Res. 49: 935–953.

Zalucki, M. 2016. From natural history to continental scale perspectives: an overview of contributions by Australian entomologists to applied ecology—a play in three acts. Austral Entomol. 54: 231–245.

Downloaded from https://academic.oup.com/jee/article/110/6/2459/4431202 by SA Health Library Service user on 05 September 2025

PIRSA

South Australia's Biosecurity Policy

2024 – 2025

SOUTH AUSTRALIA

Government of South Australia

Department of Primary Industries and Regions

Acknowledgement of Country

We acknowledge and respect the Aboriginal peoples of South Australia as the first peoples and nations of South Australia.

We recognise them as the traditional owners and occupants of land and waters in South Australia and that their spiritual, social, cultural, and economic practices come from their traditional lands and waters. We recognise that they maintain their cultural and heritage beliefs, languages, and laws, which are of ongoing importance. We recognise that they have made, and continue to make, a unique and irreplaceable contribution to the State.

The PIRSA Reconciliation artwork by Ngarrindjeri artist, Jordan Lovegrove, is part of a broader piece which shows PIRSA and our central purpose: to advance the prosperity and sustainability of South Australia's primary industries and regional communities. PIRSA is represented by the large central meeting place, surrounded by our priorities, which are symbolised by the 'U' shaped people. The families and communities we help are represented by the dot pattern throughout the artwork. Our core business is shown by the different sections around the artwork. Our worksites across South Australia are represented by the smaller white meeting places.

Minister's Foreword

Every resident and those visiting our great State have a shared responsibility to protect South Australia from biosecurity risks and maintain the productivity of our primary industries. The decisions we make today in relation to biosecurity measures will have a profound impact on future generations, lifestyles, livelihoods, and our unique environments.

Surrounded by oceans, Australia is fortunate to maintain effective biosecurity systems. However, climate change, globalisation, changes to the way we travel, trade and logistics pose increased risks and threats from exotic pests and diseases. In recent years, we have seen a significant growth in awareness of emerging risks that are on our doorstep and threaten our way of life. With confirmed outbreaks of foot-and-mouth disease, African swine fever and lumpy skin disease detected in neighbouring countries, it is imperative that we are prepared to ensure our State, industries and irreplaceable habitats remain pest and disease free.

There is no room for complacency when it comes to how South Australia responds to biosecurity threats. Every person residing in or visiting our State has a critical role to safeguard our primary industries and keep the lands and waters that traditional owners have protected for thousands of years free from exotic disease and pests. A combined commitment from Government, industry and the wider community is required to prepare and implement a biosecurity management system that is effective and responsive.

Since the release of the 2020–2023 South Australian Biosecurity Policy, the Department of Primary Industries and Regions has responded to over 15 events relating to floods, bushfires, food safety incidents and incursions from pests and diseases. These occurrences have had devastating impacts to natural habitats, livelihoods, and significant economic implications for our State.

The revised South Australian Biosecurity Policy will continue to provide guidance on how to prevent the entry and establishment of pests and diseases, ensure food safety and support responsible agricultural chemical use.

The policy identifies 6 priority areas:

- Securing primary production and food safety
- Detection and response to new pests and diseases
- Minimising the economic, social and environmental impacts of pests and diseases
- Government, industry, and the community working together to enhance biosecurity
- Biosecurity technical expertise
- Modern fit-for-purpose infrastructure

Through agency partnerships, industry and the community, and State Government projects, we will prepare and respond to biosecurity threats in South Australia. The Dog Fence rebuild, providing protection from wild dogs, is over half-way completed with the remaining 650km of fence to be completed in 2025. The National Sterile Insect Technique (SIT) Facility in Port Augusta was expanded in September 2023, doubling the production capability to provide 40 million sterile Queensland fruit flies per week.

The National Transition to Management Plan for Varroa mite will be one of significant importance in preparing South Australian beekeepers to manage Varroa.

As South Australia works towards modernising Biosecurity legislation to protect South Australia, the Department of Primary Industries and Regions will commence the development of South Australia's Biosecurity Strategy. The Strategy, expected to be released in 2025, will ensure South Australia has a flexible and responsive biosecurity system. Partnerships and consultation are key to the development of the Strategy, providing a foundation and guiding principles on how we partner to achieve our biosecurity goals, and deliver a better future for all South Australians and our primary industries sector for generations to come.

The Hon. Clare Scriven

Minister for Primary Industries and Regional Development; Minister for Forest Industries

Key Policy Highlights

Securing primary production and food safety

- Progressed the development of a new Biosecurity Bill for South Australia to develop a modern and consistent framework for the state's biosecurity systems.
- Amended the *Livestock Act 1997* to strengthen South Australia's ability to respond swiftly to an emergency animal disease outbreak.
- Commenced the Priority Weeds Program to support South Australian croppers and graziers to prioritise and undertake weed control activities.
- Applied appropriate measures in the Riverland to support production, market access and eradication of fruit fly.
- Supported the development of the National Transition to Management Plan for Varroa mite and commenced development of the South Australian plan.
- Secured government and industry funding and commenced construction of the $25 million rebuild of 1,600 km of the Dog Fence.
- $15 million, 10-year Wild Dog Eradication Program.
- $14 million, 10-year Feral Deer Eradication Program.
- $5.8 million Kangaroo Island Feral Pig Eradication Program with the permanent removal of all feral pigs from the island imminent.

Detection and response to new pests and diseases

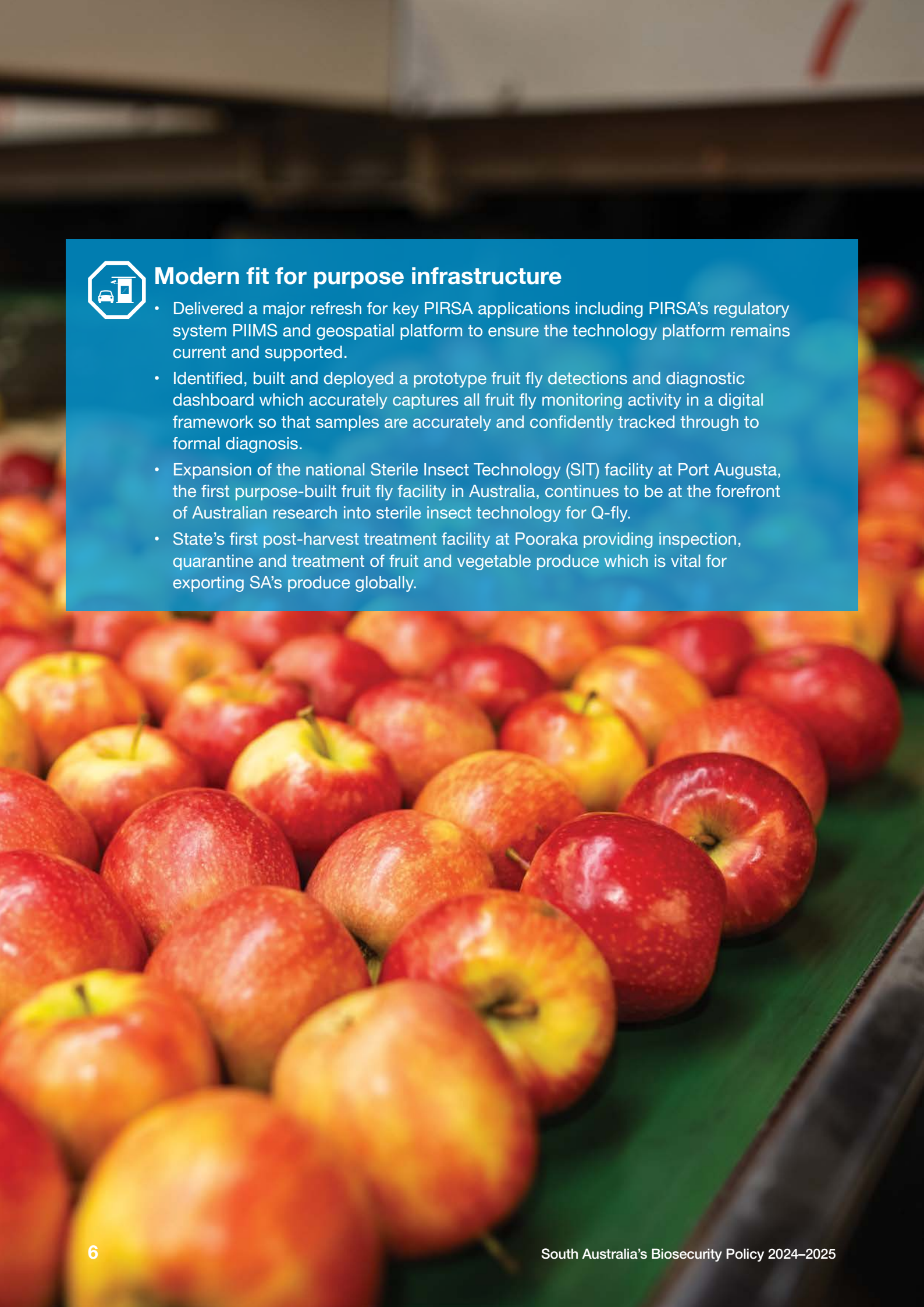
- $6.8 million to provide preparedness activities and to increase our response capabilities to emergency animal diseases.
- $3.7 million implementation to combat Varroa destructor (Varroa mite), Electric Ants and Polyphagous Shot-hole Borer (beetle).
- $25 million to undertake emergency fruit fly response activities.
- A new suite of controls never used before in the South Australian Riverland were implemented including using three new attract and kill devices, implementing an area-wide rolling carpet approach to SIT release and deploying a new online portal to register growers to apply baits and traps on their own properties.
- Successful eradication of fruit fly outbreaks across the state, including 12 in metropolitan Adelaide.

Minimising the economic, social and environmental impacts of pests

- Maintained the South Australian Dog Fence through coordination of all on-ground activities of PIRSA's $25 million Dog Fence Rebuild Project and the ongoing maintenance of the 2,150-kilometre South Australian Dog Fence which continues to support the $1.3 billion sheep industry in South Australia.
- Delivered the lens snail eradication program in partnership with Grains Producers SA to eradicate the pest from four sites in Largs North.
- Maintained market access through the implementation of animal disease surveillance systems and traceability compliance programs to underpin animal health assurances and product integrity.
- Maintained the state's fruit fly free status to protect the $1.3 billion horticulture industry by applying an effective response program.
- Increased surveillance and education about livestock, weeds, freight and fodder movements for Kangaroo Island (KI) continued in 2022–23. Since this project commenced, more than 100,000 cars, heavy machinery and boats have been inspected at Cape Jervis reducing the risk of biosecurity incursions on KI.

Government, industry and the community working together to enhance biosecurity

- Delivered engagement and capacity building activities with Aboriginal communities to support their management of Weeds of National Significance and other pest weeds on Aboriginal managed lands in South Australia.
- Delivered industry funded disease management programs for the South Australian sheep and cattle industries, covering footrot and lice in sheep and Johne's disease in cattle and sheep.
- Facilitated the development of an industry action plan for emergency animal disease preparedness for government – industry partnership, including communication, contingency planning, training and surveillance.
- Facilitated the delivery of Liaison – Livestock Industry training to enable industry participation in control centres during an emergency animal disease response.
- A survey was undertaken to identify the current level of on-farm biosecurity practices and preparedness across South Australian commercial pig farms. Respondents represented 76% of the South Australian sow herd and 23% of the national sow herd.
- Development of a $50 million biosecurity facility with South Australian Produce Market, based in Pooraka.



Modern fit for purpose infrastructure

- Delivered a major refresh for key PIRSA applications including PIRSA's regulatory system PIIMS and geospatial platform to ensure the technology platform remains current and supported.
- Identified, built and deployed a prototype fruit fly detections and diagnostic dashboard which accurately captures all fruit fly monitoring activity in a digital framework so that samples are accurately and confidently tracked through to formal diagnosis.
- Expansion of the national Sterile Insect Technology (SIT) facility at Port Augusta, the first purpose-built fruit fly facility in Australia, continues to be at the forefront of Australian research into sterile insect technology for Q-fly.
- State's first post-harvest treatment facility at Pooraka providing inspection, quarantine and treatment of fruit and vegetable produce which is vital for exporting SA's produce globally.

Principles

The State Biosecurity Policy is guided by the following principles:

1. Collaboration is central to our approach and there is an understanding of the accountabilities between governments, industries, communities, and individuals.
2. Development, implementation, monitoring and review of biosecurity programs is underpinned by science.
3. Detection and identification of new pests, diseases or contamination sources is both rapid and accurate.
4. Preparedness, prevention, and early intervention form the central focus of our activities.
5. Our biosecurity systems evolve as new knowledge and technologies become available to meet ever changing pest and disease threats.
6. Cost of biosecurity programs is shared equitably where feasible, between beneficiaries and risk creators.
7. We take a collaborative and integrative approach to human, animal, and ecosystem health.

Securing primary production and food safety

To maintain domestic and international market access, the South Australian Government works to minimise and manage high-priority biosecurity threats to the integrity and reputation of our primary produce and food by:

- designing biosecurity programs in partnership with industry sectors to manage priority food safety and contaminant risks.
- undertaking traceability and surveillance activities to support market access, such as the Japanese Encephalitis and Riverland fruit fly response and providing proof of freedom certification for agricultural produce.
- partnering with industry to develop market-driven systems for on-farm biosecurity such as 'One Biosecurity' for livestock production.
- promoting awareness across all primary industries for improved biosecurity including clarity of roles and responsibilities.
- undertaking preparedness and surveillance activities for pests and diseases such as foot and foot and mouth, lumpy skin, African swine fever, varroa mite and exotic plant pest species that may enter through import pathways into Australia.
- managing established priority pests that have significant impacts on primary production including feral deer, feral pigs and wild dogs.
- investigating reports of chemical misuse and excess residue levels in food products.
- enforcing strict quarantine requirements for plant and animal entry to South Australia, including zero tolerance at Yamba Quarantine Station.

Detection and response to new pests and diseases

Border quarantine and post border procedures help prevent the introduction and establishment of exotic pests and diseases. While biosecurity at South Australia's international borders is the responsibility of the Australian Government, incursions of pests and diseases that breach the international border are managed in collaboration with the State Government.

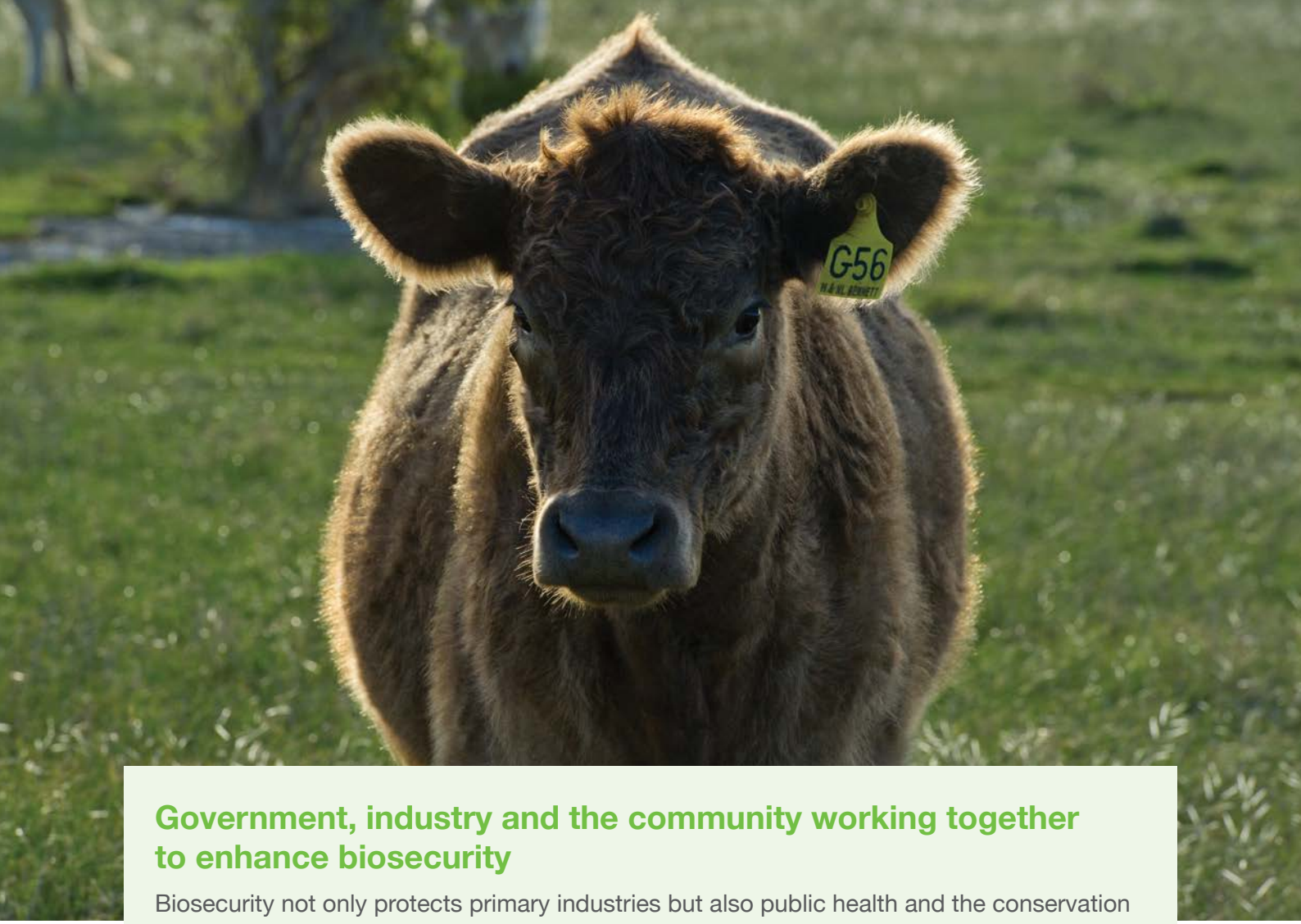
Systems for the early detection and containment of new pest and disease incursions are implemented by the South Australian Government to enable eradication, where feasible, by:

- establishing surveillance programs for the early detection of new threats to industry, the environment and the community.
- developing, implementing and exercising pest and disease response plans.
- building and maintaining an emergency response system to deliver whole-of-government responses to incursions as required.
- conducting emergency response and recovery to incursions in a rapid, professional manner, as achieved with the recent chocolate band snail and Riverland fruit fly eradication responses.
- building capacity and capability with funding to prepare for emergency animal diseases.

Minimising the economic, social and environmental impacts of pests and diseases

The South Australian Government minimises and manages the entry, spread and impacts of pests and diseases within the state by:

- partnering with the Australian, state and territory governments, along with industry, to develop and implement pre-border and border quarantine controls.
- developing and implementing management plans and programs aimed at detecting, containing and reducing the impacts of established priority pests and diseases, such as wild dogs, feral deer and goats, rabbits and varroa mite.
- supporting research into new and improved control tools promoting their adoption by end-users.
- applying containment protocols for the display or commercial use of potentially invasive organisms.
- partnering with land, fisheries and natural resource managers in managing established priority pests and diseases.



Government, industry and the community working together to enhance biosecurity

Biosecurity not only protects primary industries but also public health and the conservation and tourism benefits of the state's natural environments. As part of this, South Australian Government agencies work with industry and the community to enhance biosecurity by:

- establishing and maintaining stakeholder advisory groups, such as the Riverland Fruit Fly Committee, and the SA Varroa Industry Advisory Committee for priority biosecurity issues.
- engaging strongly with industry around other priorities such as spray drift.
- establishing institutional arrangements that engage relevant government agencies, industries, community groups and advisory boards.
- creating behavioral and cultural change through education to build a culture of shared responsibility to biosecurity and, raising awareness of people's responsibilities in preventing the arrival, establishment and spread of pests and diseases.
- partnering with universities to build skill and capability to support a wider and more robust biosecurity system for South Australia.
- engaging industry and the community in surveillance, detection, incursion responses and recovery plans.
- partnering with First Nations peoples to participate in biosecurity matters that impact or are important to them.
- expanding Port Augusta's Sterile Insect Technology (SIT) facility and releasing one billion sterile fruit flies over the Riverland region to combat outbreaks.
- partnering with PorkSA to deliver the Pig Biosecurity Project, a jointly funded initiative to strengthen supply chain biosecurity to increase preparedness for emergency animal diseases and support market access.

Biosecurity technical expertise

The South Australian Government provides a coordinated biosecurity system aimed at preventing and reducing pest and disease impacts, maintaining food safety and ensuring responsible agricultural chemical use by:

- introducing a new Biosecurity Bill to Parliament for the protection of South Australia from pests and diseases by combining several biosecurity related Acts.
- building biosecurity preparedness through registration and traceability systems to help prevent the spread of pests and diseases ensuring a consistent approach in SA and nationally e.g. through the National Livestock Identification System and National Property Identification Codes.
- assessing and prioritising biosecurity risks for industry sectors, the environment and public amenity.
- building epidemiology and preparedness teams to prepare and respond to emergency animal diseases.
- coordinating government capabilities, both intra and interstate, including laboratory diagnostic and research capacities.
- developing and maintaining an effective biosecurity system with a focus on science, innovative technologies, risk assessment, information management, planning, training and communication.
- contributing to legislative and regulatory reform relating to biosecurity at a state and national level.

Modern fit for purpose infrastructure

The South Australian Government maintains and upgrades its facilities and infrastructure to ensure it can support the work to reduce pest and disease threats, by:

- upgrading the infrastructure for entry points to the state, such as the Yamba Quarantine Station.
- upgrading the national Sterile Insect Technology facility to produce 40 million sterile Queensland fruit flies per week and in 2024–2025 production will include Medfly.
- maintaining signage for travelers entering the state, including rest stops.
- funding the construction of a post-harvest biosecurity treatment and inspection facility at the SA Produce Market site.
- continuing the South Australian Dog Fence upgrade to prevent wild dog incursions inside the fence and protect the livestock industry.

Case Study

Foot-and-mouth Disease

Biosecurity remains a key priority for South Australia as we continue to face ever increasing pest and disease challenges. We remain on high alert to the risk posed by exotic diseases such as foot-and-mouth disease, PIRSA is partnering with livestock industries along with the Australian, state and territory governments to enhance our preparedness. Exploring the potential impacts of a foot-and-mouth disease outbreak to South Australia using disease modelling software.

Foot-and-mouth disease (FMD) is a highly contagious viral disease affecting a range of cloven-hoofed (two-toed) animal species. Although Australia maintains FMD-free status, the interconnected global trade network and increased human mobility heighten the risk of introducing the virus into Australia. South Australia has a thriving agricultural industry, which would be devastated by an outbreak of FMD. The South Australian sheep and beef industries are prominent exporters, and those vital markets would be lost due to trade bans and restrictions in response to an FMD outbreak. The impacts of an outbreak would disrupt the entire supply chain, affecting businesses beyond the agricultural sector, including transportation, processing, and distribution, leading to economic downturns in related industries. Communities heavily reliant on agriculture would bear the brunt of the outbreak, facing economic hardship and social distress.

As part of state preparedness for a potential FMD outbreak, the PIRSA Animal Biosecurity team is utilising disease modelling to understand how an outbreak of FMD might unfold in South Australia. The Australian Animal Disease Spread (AADIS) model has been used to generate a reasonable worst-case scenario for an outbreak of FMD in South Australia. A reasonable worst-case scenario is a disease modelling outcome that is serious, yet still plausible, capturing the majority of potential ways that the outbreak could unfold. This can be used to understand and communicate the potential size, scale, and consequences of an outbreak, as well as to explore the effect of various control measures and interventions, and plan for the most effective response. This work has shown that a serious outbreak of FMD in South Australia may directly infect up to more than 90 farms, resulting in the culling of up to almost 100,000 animals, with thousands of farms impacted by the response. Control of such an outbreak could take up to six months to achieve.

Continuing to strengthen state biosecurity measures, including enhanced surveillance and monitoring, is crucial for early detection and prevention of FMD. Rapid response can contain the outbreak, minimising its impact.

Case Study

Wild Dog Trapper Program

Protecting the state's $4.3 billion livestock industry from wild dogs, tracker and trapper Ronald Boland is an Aboriginal man with a close affinity with the pastoral country of South Australia. Ronald applies his finely tuned skills for tracking and controlling hard to catch wild dogs. Ronald acquired his tracking skills over decades of close observation and learning from his father and Elders as well as throughout his working life on pastoral stations throughout South Australia.

South Australia's Wild Dog Trapper Program provides eligible land managers, with the services of a skilled and experienced dog trapper. More than 800 wild dogs have been controlled under the program to date.

Wild dogs are a declared pest inside South Australia's Dog Fence and are a key threat to the state's livestock industry, with several properties in impacted areas losing 2,000 or more sheep to dogs last year.

Trapping wild dogs requires a large amount of skill and bush craft; in addition to controlling dogs, the trappers also work with land managers to increase their skills and capacity to trap and manage wild dogs themselves.

During this four-year program (2018–2022), PIRSA has delivered many trapper training courses for land managers, utilising the expertise of the trappers like Ron.

PIRSA Biosecurity

Phone: (08) 8207 7900
Email: PIRSA.BiosecuritySA@sa.gov.au
GPO Box 1671, Adelaide SA 5001
pir.sa.gov.au/biosecurity

Hotlines

Emergency Animal Disease – 1800 675 888
Emergency Pest Alert – 1800 084 881
Fishwatch – 1800 065 522
Fruit Fly – 1300 666 010

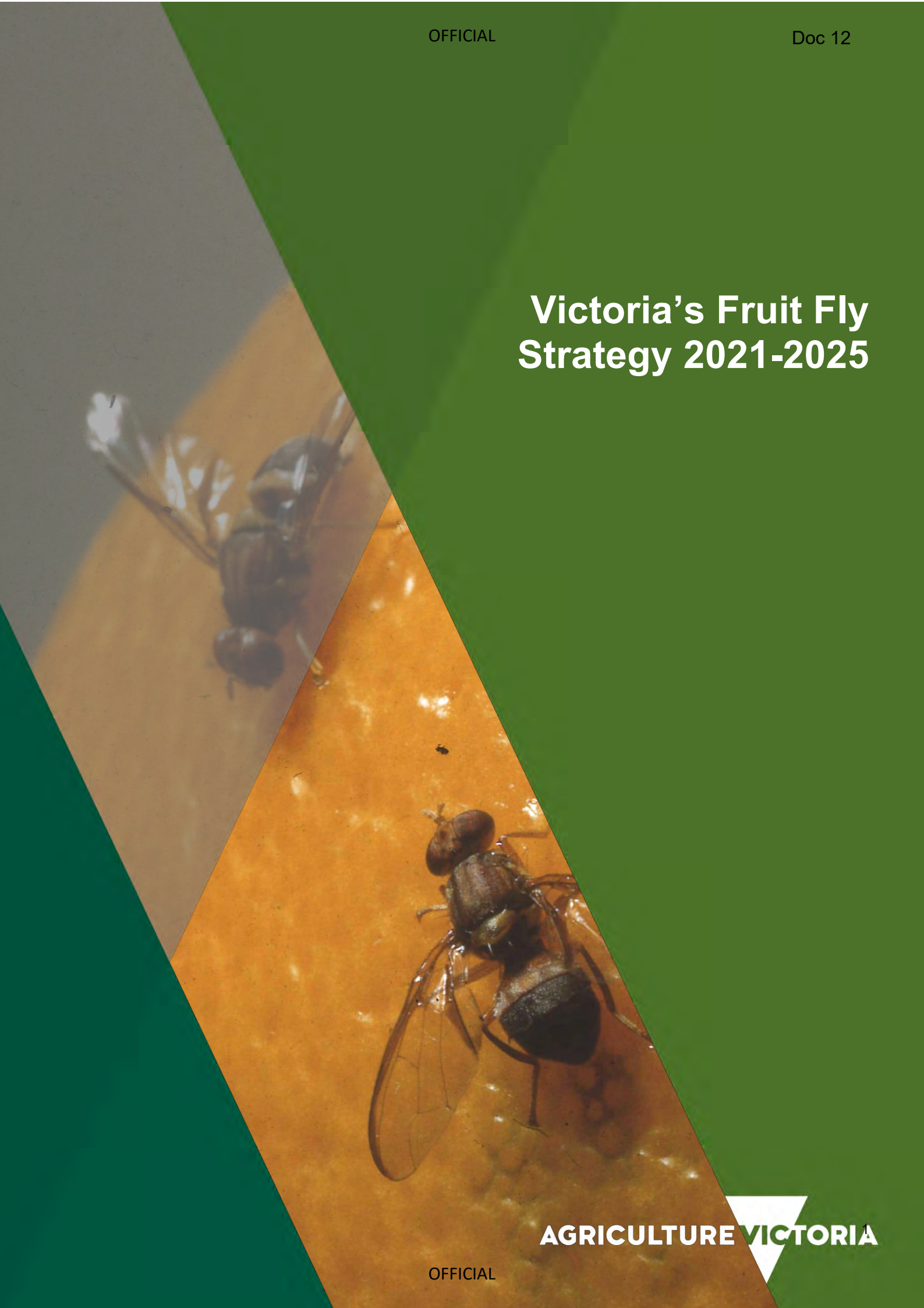
Disclaimer

PIRSA and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability and currency or otherwise. PIRSA and its employees expressly disclaim all liability or responsibility to any person using the information or advice.

SOUTH AUSTRALIA

Government of South Australia
Department of Primary Industries and Regions

Victoria's Fruit Fly Strategy 2021-2025



AGRICULTURE VICTORIA

CONTENTS

INTRODUCTION 4

FRUIT FLY 4

HORTICULTURE IN VICTORIA 5

THREAT OF EXOTIC FRUIT FLY TO VICTORIA 5

QUEENSLAND FRUIT FLY IN VICTORIA 6

POLICY POSITION 6

STRATEGIC OBJECTIVE AND ACTIVITY AREAS 8

ACTIVITY AREA 1: MAINTAIN VICTORIA'S FREEDOM FROM EXOTIC FRUIT FLY SPECIES (INCLUDING MEDFLY) 9

ACTIVITY AREA 2: CONTRIBUTE TO NATIONAL SYSTEMS AND RESEARCH THAT PROTECTS AUSTRALIA AND VICTORIA FROM EXOTIC FRUIT FLY AND FACILITATE MARKET ACCESS 11

ACTIVITY AREA 3: SUPPORT INDUSTRY AND COMMUNITY LED MANAGEMENT OF QUEENSLAND FRUIT FLY AND STRENGTHEN INDUSTRY SURVEILLANCE CAPABILITY 13

REFERENCES 15

APPENDIX 1: NATIONAL FRUIT FLY STRATEGY PRIORITY AREAS 16

Published by Agriculture Victoria, Department of Jobs, Precincts and Regions, 1 Spring Street Melbourne Victoria 3000
Telephone (03) 9651 9999

July 2021

© Copyright State of Victoria 2021

This publication is copyright. No part may be reproduced by any process except in accordance with provisions of the *Copyright Act 1968*.

Authorised by the Victorian Government, Melbourne.

Except for any logos, emblems, trademarks, artwork, and photography this document is made available under the terms of the Creative Commons Attribution 3.0 Australia license.

Disclaimer

This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication. While every effort has been made to ensure the currency, accuracy, or completeness of the content we endeavour to keep the content relevant and up to date and reserve the right to make changes as required. The Victorian Government, authors and presenters do not accept any liability to any person for the information (or the use of the information) which is provided or referred to in the report.

If you would like to receive this publication in an accessible format, such as large print or audio, telephone 1300 502 656 or email info@agriculture.vic.gov.au.

ACKNOWLEDGEMENT OF COUNTRY

We acknowledge the traditional Aboriginal owners of country throughout Victoria, their ongoing connection to this land and we pay our respects to their culture and their Elders past, present and future.

INTRODUCTION

Victoria's Fruit Fly Strategy 2021-2025 (the Strategy) spans a four-year period from 2021-2025. It is based on best practice biosecurity principles and studies. This Strategy does not replicate, but rather, complements existing national strategies including the *National Fruit Fly Strategy 2020-2025*.

The Strategy also aligns with key themes detailed in Victoria's Agriculture Strategy: Strong, Innovative, Sustainable: A New Strategy for Agriculture in Victoria (2020). This includes focussing on protecting and enhancing the future of agriculture by ensuring it is well-placed to respond to a range of threats including pest species.

The management of risks and impacts of fruit fly is critical for a thriving horticulture industry. How Victoria manages fruit fly has implications not just for Victoria but for other jurisdictions and for Australia's horticulture exports more generally. While Victorian industries and communities work locally in the three key horticultural regions of Sunraysia, Goulburn Murray Valley and Yarra Valley, Victoria is part of a national system that collectively supports domestic and international market access opportunities.

Victoria is party to and supports a range of initiatives that address fruit fly issues of national importance, including research, development, and extension activities.

This Strategy emphasises shared responsibility for the management of fruit fly with government investing in, and leading work on exotic species, providing the regulatory tools to support market access opportunities for trade impacted by fruit fly and supporting industry and communities in the area-wide management of fruit fly.

FRUIT FLY

Fruit fly is a horticultural pest

Fruit flies cause damage to produce when a female fly 'stings' a piece of fruit in order to lay her eggs. Larvae feeding on the fruit weaken the fruit structure which promotes rotting and dropping. The original sting site may also allow the introduction of bacteria and other pests, which can further damage the fruit.

Fruit fly species

There are more than 50 exotic and established species of fruit fly that are of potential economic significance or quarantine concern to Victoria[1]. However, the most significant species are Mediterranean fruit fly (Medfly) and Queensland fruit fly (QFF). At present Victoria remains free of Medfly despite its presence elsewhere in Australia. QFF is an established pest in Victoria.

Fruit fly host plants

Fruit flies have the potential to impact a broad range of horticultural crops. Individual species may be host specific or have multiple hosts. This broad host range, which includes some native species, makes management challenging. The key horticultural crops affected by fruit fly in Victoria include stonefruit (e.g. apricots, peaches, and cherries), pomefruit (e.g. apples, pears), citrus (e.g. oranges, mandarins), grapes, berries and tomatoes.

[1] Agriculture Victoria generally considers established species to be those that are widespread and beyond eradication, as is the case with Queensland fruit fly.

HORTICULTURE IN VICTORIA

There are approximately 5,000 horticulture producers in Victoria, employing around 11,000 people. The horticulture industry in Victoria is worth over $3 billion and exports are worth $1.6 billion per year. At least $1 billion of these export crops are fruits and vegetables that are susceptible to fruit fly.

The *Victorian Food and Fibre Export Performance Report 2019-20* stated that the 2019-20 Victorian horticulture season to be its most valuable year. A summary is provided in Table 1. Key achievements include:

- Fruit exports increased by $84 million (10 per cent) to be valued at $904 million in 2019-20. China was the major market for Victorian horticultural exports with a total value of $646 million.
- Table grapes recorded the largest growth in export value, increasing by $59 million (12 per cent) to a record $562 million. Export volumes increased by four (4) per cent.
- The value of citrus and stone fruit exports increased by nine (9) per cent and four (4) per cent respectively.

Table 1. Victorian horticulture exports since 2015-16[2]

Produce	2015-16		2016-17		2017-18		2018-19		2019-20	
	$ million	'000 tonnes	$ million	'000 tonnes	$ million	'000 tonnes	$ million	'000 tonnes	$ million	'000 tonnes
Table grapes	340	110	349	109	351	110	504	145	562	152
Dried grapes	16	4	16	4	18	5	24	5	29	5
Citrus	105	84	120	89	147	104	162	104	177	118
Stone fruit	53	14	46	12	68	17	102	23	106	22
Pome fruit	24	14	15	9	24	16	22	13	21	13
Other fruit	8	3	9	3	8	3	6	2	9	2
Processed fruit	4	1	4	1	10	2	11	2	8	2

THREAT OF EXOTIC FRUIT FLY TO VICTORIA

Exotic fruit fly being introduced and becoming established in Victoria would have a detrimental impact on horticultural production and market access, affecting produce quality, and leading to increased production costs.

Victoria's trade of fruit fly hosts is based on freedom from several fruit fly species which although present in Australia, are not present in the state of Victoria. These species include:

- Mediterranean fruit fly (*Ceratitis capitate*)
- North-Australian fruit fly (*Bactrocera aquilionis*)
- Jarvis fruit fly (*Bactrocera jarvisii*)
- Lesser Queensland fruit fly (*Bactrocera neohumeralis*)

True 'exotic' species from a national perspective which Victoria maintains freedom from include:

- Oriental fruit fly (*Bactrocera dorsalis*)
- Carambola fruit fly (*Bactrocera caramboloe*)
- Mexican fruit fly (*Anastrepha ludens*).
- Spotted wing drosophila (*Drosophila suzukii*)

There are a number of ways that exotic fruit flies arrive in Australia. The most likely scenario is via transport in imported fruits or vegetables. To address this risk of introduction into Australia, the Department of Agriculture, Water and the Environment (DAWE) assesses risks and regulates pathways and commodities for the importation of fruit fly hosts. Approved treatments are applied if required. In addition, public awareness campaigns, passenger declarations and border inspections for international travellers address the risk of individuals bringing fruit fly infested fruits and vegetables into Victoria.

[2] Extract from the *Victorian Food and Fibre Export Performance Report 2019-20*

Domestically, Victoria also has preparedness strategies in place to ensure that Medfly and other species exotic to Victoria are not introduced into the state from other jurisdictions. From a Victorian perspective and for the purpose of this Strategy, Medfly which is established in Western Australia, and under eradication in South Australia is considered an exotic species.

QUEENSLAND FRUIT FLY IN VICTORIA

Queensland fruit fly is a sub-tropical species which is native to Queensland that has established across New South Wales and Victoria. There have also been increasing detections of QFF in South Australia.

Prior to 2013, QFF work was focused on eradication efforts. As a result of ongoing and increasing outbreaks of QFF in Victoria, on 1 July 2013, in consultation with industry bodies, the Victoria Government deregulated the movement of QFF host material into and within the state, with the exception of the Greater Sunraysia Pest Free Area (GSPFA). This change was implemented in recognition of the high cost of eradication, the associated impact of regulation for horticulturalists and recognition that QFF could not be eradicated from Victoria and was therefore considered to be established.

Since 2013 Victoria has been transitioning from government-led regulation and eradication efforts to a shared responsibility model. Under this model industry and community work in partnership with government to manage the impacts of fruit fly in their local region. Resources have been provided to support industry in the delivery of area-wide management programs to improve market access and reduce management costs to growers.

Beyond the horticulture industry, fruit fly also impacts home and community gardens, limiting the ability of individuals to enjoy some home-grown horticultural produce. Equally, urban host plants / trees that are not effectively managed can be a source of fruit fly populations that impact neighbouring horticultural areas. Management of QFF across all properties, including backyards, remains a significant and important challenge for some local communities.

POLICY POSITION

Agriculture Victoria's current policy is based on best practice biosecurity principles and has been informed by a range of analyses. To establish the policy position Agriculture Victoria considered key factors including:

- existing national strategies and intergovernmental agreements
- the status of fruit fly in Victoria and across Australia
- the threat of exotic fruit fly
- the impacts of fruit fly as a horticultural pest, including on-farm and impacts on trade and market access
- co-investment with industries in research and development for the management of QFF
- the benefits and beneficiaries of regional area-wide management
- industry and government’s ability / capacity to respond to fruit fly incursions.

Fundamental principles

- Management of fruit fly in Victoria is a shared responsibility between the Victorian government, fruit fly impacted industries and the broader community.
- Agriculture Victoria's priority responsibilities are leading responses to exotic species (i.e. prevention, preparedness, surveillance for early detection, containment, and eradication) and facilitating domestic and international market access. This aligns with the *National Framework for the Management of Established Pests and Diseases of National Significance.*
- Management of established pests, such as QFF, is primarily the responsibility of land managers. Established pest management is most effective where industry and community work collectively; government may invest where a commitment to collective action is demonstrated.
- Delivery of on-farm and community actions for established fruit fly species is best led by fruit fly impacted industries, local councils, and community stakeholders.
- Agriculture Victoria has a responsibility to contribute to the national fruit fly system.
- The priorities for the Victorian government’s fruit fly trapping network are early detection of exotic species and support for area freedom claims.
- An effective state-wide fruit fly management system requires contributions (including activity delivery) from all stakeholders in a coordinated manner so there is minimal duplication and all efforts are recognised.
- Government funding decisions must consider return on investment, risk creators and beneficiaries.

Key assumptions

- The extensive host range of QFF, degree of host susceptibility and timing of harvests present unique management needs in different regions.
- Implementation of the *Managing Fruit Fly in Victoria Action Plan 2015-2020* has raised awareness and helped establish structures that support area-wide management of QFF off-farm in the broader community.
- The regionally specific action plans showed a significant, tangible benefit in the off-farm management of QFF.
- Fruit fly can be managed effectively on-farm and through pre- and post-harvest treatments, as demonstrated by increasing horticultural exports despite QFF being established in Victoria. It is noted that pest pressure levels can differ across seasons and can impact management options and outcomes.
- The utilisation of effective pre- and post-harvest treatment protocols has also enabled produce from the Greater Sunraysia region to continue to be traded successfully despite the GSPFA not being recognised by international export markets as a pest free area.
- Industry and other stakeholder surveillance for exotic and established species may be integrated with government data to support market access.

STRATEGIC OBJECTIVE AND ACTIVITY AREAS

Overview

This Strategy guides Victoria's approach to the management of fruit fly. It provides for Agriculture Victoria's focus on managing the risk of exotic incursions by prioritising preparedness and prevention activities and strengthening shared responsibility in the management of QFF. To develop the Strategy, Agriculture Victoria considered:

- the performance of the horticulture sector
- the threat posed by fruit fly species exotic to Victoria and Australia (including Medfly)
- the established status of QFF in Victoria
- principles of best practice biosecurity
- related national strategies and agreements
- information provided by studies and analyses
- the local, national, and international landscapes including biosecurity and market access expectations
- stakeholder relationships.

The Strategy strongly aligns with the *National Fruit Fly Strategy 2020-2025*. This is important because Victoria operates as part of a national system to support domestic and international trade and market access.

The strategic objective and activity areas are outlined in Figure 1.

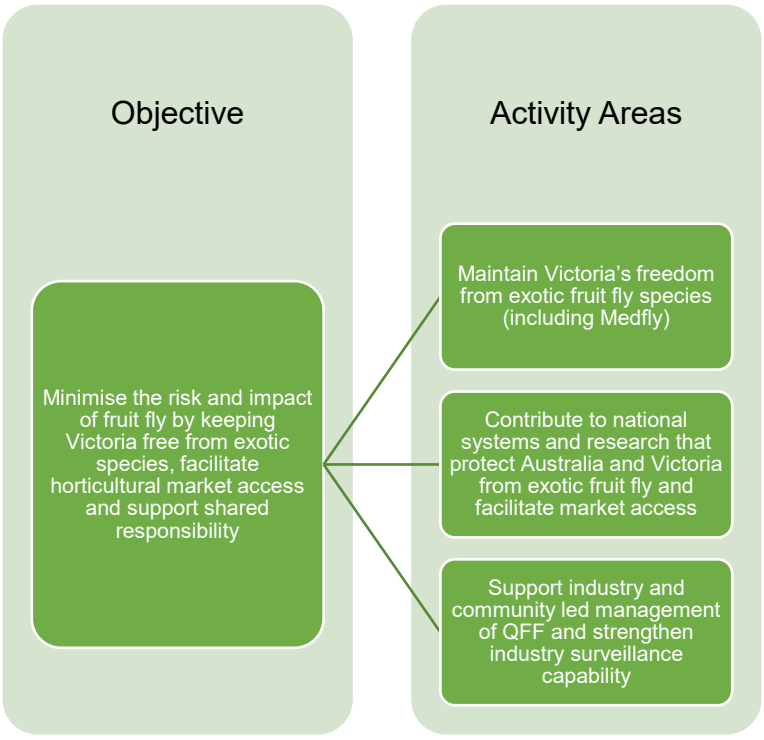


Figure 1. Outline of strategic objective and three activity areas

ACTIVITY AREA 1: MAINTAIN VICTORIA'S FREEDOM FROM EXOTIC FRUIT FLY SPECIES (INCLUDING MEDFLY)

The outcomes and activities under Activity Area 1 are led by government with support from stakeholders. It should be noted that Agriculture Victoria's core business includes a broad range of activities that will achieve the outcomes of Activity Area 1, which are already being delivered to minimise the risk and impact of fruit fly on Victorian horticulture. These activities along with new strategic projects will contribute to the overarching strategic objective.

These activities align with the NFFS Priority Areas 1, 3, 5, 6 and 7 (Appendix 1).

Preparedness and Response

Outcome: Victoria is able to effectively respond to exotic fruit flies and maintain market access

Diagnostic Services	Victoria's technical expertise and equipment capability is maintained and improved.
Reference Collections	Victoria's insect collection maintains relevant specimens to facilitate diagnosis and support market access requirements.
Simulation Exercises	Victoria's response systems and people are 'mission ready' and regularly tested and practiced through functional activities.
Contingency Plans	Appropriate contingency plans are in place for all significant fruit fly species for Victoria to ensure a consistent and effective response.
Medfly Planning	Victoria has an agreed response strategy in place and resources determined to enable an effective response to a Medfly detection.
Torres Strait Exotic Fruit Fly Eradication	Victoria provides financial and technical contributions to the national eradication of exotic fruit flies from the Torres Strait to protect Australian industries.

Surveillance

Outcome: Early detection of exotic species facilitates effective response and claims of pest status are validated

Trapping Network	Victoria's trapping network provides confidence for early detection of exotic species and supports pest status claims for market access.
Investigating Public Reports	Reports of suspect exotic fruit flies are encouraged, and Agriculture Victoria effectively and rapidly undertakes appropriate investigations.
National Plant Health Surveillance (NPHS)	The Victorian component of the NHPS program (targeted to ports of entry / high risk sites) is effectively delivered.
Urban Plant Health Network	Biosecurity awareness in urban environments is enhanced to facilitate increased reporting of suspect pests, including fruit fly.

Strategic Project - Future of the Greater Sunraysia Pest Free Area (GSPFA)

Outcome: Victoria is able to make an informed decision about the future of the GSPFA

The GSPFA was established in 2007. By 2013 there were a significant number of outbreaks in the area, resulting in the suspension of area freedom status by trading partners. Eradication is highly unlikely now that QFF is established and it is no longer the best use of resources for maintaining market access. Industries in the region trade under non-PFA protocols. Resources should be directed to managing fruit fly and its impacts to ensure market access is supported.

Note: Agriculture Victoria is leading a collaborative project with the New South Wales Department of Primary Industries, DAWE, and industry to determine the regulatory future of the GSPFA.

Strategic Project - Optimising the Victorian Fruit Fly Trapping Network

Outcome: Victoria is able to make informed decisions to optimise the trapping network to strengthen surveillance for exotic species

The current trapping network in Victoria has evolved to meet changing levels of risk, needs of stakeholders and status of pest freedom across regions and meets the requirements of the NHPS program.

Agriculture Victoria is undertaking a review of the fruit fly trapping network. The review was initiated in the interests of best practice and continuous improvement. The objective is to ensure that Victoria's trapping network is fit for purpose and provides the best outcomes for Victoria.

Any re-design of the trapping network will continue to be primarily focussed upon achieving early detection of exotic fruit flies, including the increasing threat of Medfly, as well as providing data to assist in the management of established fruit fly species. The requirements of the NPHS will be maintained under any re-design of Victoria's trapping network.

Note: This review is due to be completed during 2021 and is subject to consultation with stakeholders.

ACTIVITY AREA 2: CONTRIBUTE TO NATIONAL SYSTEMS AND RESEARCH THAT PROTECTS AUSTRALIA AND VICTORIA FROM EXOTIC FRUIT FLY AND FACILITATE MARKET ACCESS

The outcomes and activities under Activity Area 2 will be predominantly led by government with participation from stakeholders, particularly for the domestic quarantine and market access outcomes. It should be noted that Agriculture Victoria's core business includes a broad range of activities that will achieve the outcomes of Activity Area 2, which are already being delivered to minimise the risk and impact of fruit fly on Victorian horticulture. These activities along with research projects already underway and new strategic projects will contribute to the overarching strategic objective.

These activities align with the NFFS Priority Areas 1, 3, 4, 5, 6, 7, 8 (Appendix 1).

Domestic Quarantine and Market Access

Outcome: Treatment and movement of plant and plant products into, out of and within Victoria is effectively regulated

Domestic Market Access	Victoria delivers an effective and efficient market access program including Interstate Certificate Assurance; administration of the online Plant Quarantine Manual and industry notification processes.
Proof of Freedom	Victoria delivers an area freedom program for Medfly covering market access requirements, awareness, surveillance, and corrective action.
Regulatory Framework	Agriculture Victoria maintains a regulatory framework supporting the market access program.

International Market Access

Outcome: International market access is actively facilitated by Agriculture Victoria

Manage Relationships	Victoria builds and maintains relationships with DAWE, peak industry bodies, and trading partners.
Facilitate Trade	Victoria supports DAWE in making technical assessments to facilitate trade.
National Partnerships	Victoria works collaboratively with the Commonwealth and State and Territory governments, industry, and community stakeholders.

Research Projects - Projects underway at Agriculture Victoria Research

Outcome: Surveillance, diagnostics and management are improved through development and application of new technologies and practices
A national biocontrol program to manage pest fruit flies in Australia
Parasitoids for the management of fruit flies in Australia
Queensland fruit fly trapping in table grapes
New Integrated Pest Management tools for insect pests of biosecurity significance
Phenology, demography, and distribution of fruit flies (Metabarcoding and LAMP)
Post factory pilot for SITPlus
Boosting diagnostics for plant production industries (Spotted Wing Drosophila)

ACTIVITY AREA 3: SUPPORT INDUSTRY AND COMMUNITY LED MANAGEMENT OF QUEENSLAND FRUIT FLY AND STRENGTHEN INDUSTRY SURVEILLANCE CAPABILITY

The outcomes and activities under Activity Area 3 will be most appropriately led by industry, community, and local government with support from the state government. These activities along with proposed strategic projects may contribute to addressing regional and local priorities and the overarching strategic objective.

These activities align with the NFFS Priority Areas 2, 3, 5, 7 and 8 (Appendix 1).

Government Funding

The Victorian Government is providing funding over the life of the Strategy for Regional Coordinators and area-wide management programs in the three key horticultural areas of the Goulburn Murray Valley, the Yarra Valley and the Greater Sunraysia region. Agriculture Victoria will work with the Regional Coordinators and Governance Groups of these regions to develop implementation plans to ensure funding is utilised effectively and efficiently to meet agreed outcomes specified in the Strategy Implementation Plan.

Sustainable Funding

A key outcome of the implementation plan to be developed in consultation with industry is the investigation of sustainable funding mechanisms available for industries to secure funds for biosecurity activities. Agriculture Victoria will work with industry to explore sustainable future funding opportunities.

Regional Programs

Outcome: Industry and community have ownership of area-wide management priorities and have capability to deliver regional programs

Area-wide Management	Support regional stakeholders to continue best practice area-wide management programs.
Sustainable Funding	Facilitate access to a sustainable funding model for regional priorities.

Community Awareness

Outcome: Increase community awareness of fruit fly risks, impacts and management

Statewide Awareness Campaign	Develop and promote education materials for off-farm and private garden management.

Strategic Project - Sustainable Funding for Regional Programs

Outcome: The horticulture industry in Victoria has a sustainable funding model that provides for shared contribution to area-wide management of QFF across the three key horticulture regions of Greater Sunraysia, Goulburn Murray Valley and Yarra Valley

In response to the Managing Fruit Fly in Victoria Action Plan 2015-2020 Evaluation Report and the Transition Plans provided by the Governance Groups of the three key horticultural areas around the value of regional area-wide management programs, Agriculture Victoria is committed to supporting industry and local government to establish a sustainable funding model. The model may include both financial and in-kind resources that support area-wide management objectives for the regions.

Note: This project is subject to consultation with stakeholders.

Strategic Project - Industry Surveillance Model

Outcome: The horticulture industry has a surveillance system that increases the identification and reporting of fruit fly (and other plant pests) by horticulturalist and primary producers to deliver a biosecurity service that protects the horticulture industry

In response to findings from independent analyses, Agriculture Victoria is proposing to develop an industry surveillance model for horticulture. The independent analyses highlighted the importance of a trapping network that covers production areas to help support management decisions, and the inherent value of strengthening exotic surveillance.

The program would be delivered by Agriculture Victoria, in collaboration with major horticultural companies, a network of private consultants and primary producers. The program would build upon existing methods of reporting including the biosecurity hotline.

Note: This project is subject to a feasibility study and consultation with stakeholders. Development would likely commence in 2022.

REFERENCES

National Fruit Fly Strategy 2020-25, National Fruit Fly Council (2020), Plant Health Australia

Victorian Food and Fibre Export Performance Report 2019-20 (2020), State Government of Victoria

Strong, Innovative, Sustainable: A New Strategy for Agriculture in Victoria (2020), State Government of Victoria

APPENDIX 1: NATIONAL FRUIT FLY STRATEGY PRIORITY AREAS

1. **Market access**

   Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures, is legally enforceable and technically justified.

2. **Management of established fruit fly**

   Build and promote efficient and effective methods to manage established fruit fly species, to reduce the impact on production and facilitate access to sensitive markets.

3. **Prevention, preparedness, and response**

   Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

4. **Research**

   Maintain and enhance fruit fly research capability, capacity and resources, pursuing research and extension that focuses on nationally agreed priorities.

5. **Surveillance**

   Ensure a nationally consistent surveillance framework that provides clarity around fruit fly distribution, prevalence, and control.

6. **Diagnostics**

   Maintain and enhance rapid diagnostic capability and capacity, to support responses to incursions or outbreaks and to confirm area freedom.

7. **Communication and engagement**

   Adopt systems and mechanisms for the efficient and effective communication, training, extension, and uptake of fruit fly information across a broad range of audiences.

8. **Cooperation**

   Maintain and enhance engagement processes that serve to coordinate, progress and improve fruit fly management systems.

PLANT HEALTH ACT 2009

SECTION 7(2)

Prohibition on Introducing Pest Affected Plants or Plant Related Products

Pursuant to Section 7(2) of the *Plant Health Act 2009*, I, Clare Scriven, Minister for Primary Industries and Regional Development, prohibit the importation or introduction of the classes of plant or plant related products listed in Schedule 1 to prevent the introduction into South Australia or the spread of a pest.

This notice revokes all previous notices made pursuant to Section 7 of the *Plant Health Act 2009*.

DEFINITIONS

In this notice:

"the Act" means the *Plant Health Act 2009.*

"soil" means the upper, outermost layer of soil, usually the top 20 centimetres consisting of rock and mineral particulates that may be mixed with organic matter and in which plants grow or are grown.

"the Standard" means the document prepared and published by the Department of Primary Industries and Regions South Australia entitled the "Plant Quarantine Standard South Australia".

SCHEDULE 1

1. A prohibition applies to the importation or introduction into the State of the following:
   (a) any pest declared under Section 4 of the Act;
   (b) any fruit, plant or soil affected by such a pest;
   (c) packaging in which any fruit or plant affected by such a pest has been packed;
   (d) goods with which any fruit or plant affected by such a pest has come into contact.
2. The items below must not be imported or introduced into the State unless the provisions of the Standard have been complied with:
   (a) the following host fruits of fruit flies being, in my opinion, fruit of species that are likely to introduce fruit fly into the State:

Common Name	Scientific Name
Abiu	*Pouteria caimito*
Acerola	*Malpighia glabra*
Achachairu	*Garcinia humilis*
Almond	*Prunis dulcis*
Apple	*Malus domestica*
Apricol	*Prunus armeniaca*
Avocado	*Persea americana*
Babaco	*Carica pentagona*
Banana	*Musa acuminata*
Blackberry	*Rubus fruiticosus*
Black Sapote	*Diospyros ebenum*
Blueberry	*Vaccinium corymbosum*
Brazil Cherry	*Eugenia uniflora*
Breadfruit	*Artocarpus altilis*
Caimito	*Chrysophyllum cainito*
Cape Gooseberry	*Physalis peruviana*
Capsicum	*Capsicum annuum var. grossum*
Carambola	*Averrhoa carambola*
Cashew Apple	*Anacardium occidentale*
Casimiroa	*Casimiroa edulis*
Cherimoya	*Annona cherimolia*
Cherry	*Prunus avium*
Chilli	*Capsicum annuum var. acuminatum*
Citron	*Citrus medica*
Coffee berry	*Coffea* species
Custard apple	*Annona squamosa*
Date	*Phoenix dactylifera*
Dragon Fruit	*Hyloscereus undatus*
Durian	*Durio zibethinus*
Eggplant	*Solanum melongena*
Feijoa	*Feijoa sellowiana*
Fig	*Ficus carica*
Gourd, bitter	*Momordica charantia*
Gourd, bottle	*Langenaria siceraria*
Granadilla	*Passiflora quadrangularis*
Grapefruit	*Citrus* x *paradisi*
Grapes	*Vitis* species
Grumichama	*Eugenia braziliensis*
Guava	*Psidium* species
Hog Plum	*Spondias mombin*
Jaboticaba	*Myrciaria cauliflora*
Jackfruit	*Artocarpus heterophyllus*
Jambu Jujube	*Syzygium cumini Ziziphus* spp
Kiwifruit	*Actinidia deliciosa*
Kumquat	*Fortunella japonica*
Lemon, including Meyer lemon	*Citrus limon* or *Citrus* x *meyeri* (hybrids)
Lime	*Citrus aurantiifolia* or *C. latifolia* or *C. limettoïdes* or *C. australasica* or *C. excelsa* or *C. medica* x *C. reticulata*
Loganberry	*Rubus loganobaccus*
Longan	*Euphoria longan*

Common Name	Scientific Name
Loofa, Smooth	*Luffa cylindrica*
Loquat	*Eriobotrya japonica*
Lychee	*Litchii chinensis*
Mandarin	*Citrus reticulata*
Mango	*Mangifera indica*
Medlar	*Mespilus germanica*
Mangosteen	*Garcinia mangostana*
Mulberry	*Morus nigra*
Nashi	*Pyrus pyrifolia var. culta*
Nectarine	*Prunus persicae var. nectarina*
Olive	*Olea europaea*
Orange	*Citrus aurantium* or *Citrus sinensis*
Passionfruit	*Passiflora spp.*
Papaw	*Carica papaya*
Peach	*Prunus persica*
Peacharine	*Prunus nucipersica*
Pear	*Pyrus communis*
Pepino	*Solanum muricatum*
Persimmon	*Diospyros kaki*
Plum (including Davidson and Japanese)	*Prunus domestica* *Prunus salicina* *Davidsonia spp.*
Plumcot	*Prunus domestica* x *Prunus armeniaca*
Pomegranate	*Punica granatum*
Prickly Pear	*Opuntia stricta* or *O. ficus indica*
Pummelo	*Citrus grandis*
Quandong	*Santalum acuminatum*
Quince	*Cydonia oblonga*
Rambutan	*Nephelium lappaceum*
Raspberry	*Rubus idaeus*
Rollinia	*Rollinia deliciosa*
Rose Apple	*Syzygium jambos*
Santol	*Sandoricum indicum*
Sapodilla	*Manilkara zapota*
Sapote	*Sapote*
Soursop	*Annona muricata*
Strawberry	*Fragaria ananassa*
Sweetsop	*Annona squamosa*
Tamarillo	*Cyphomandra betacea*
Tangelo	*Citrus reticulata* x *C. paradise*
Tangor	*Citrus reticulata* x *C. sinensis*
Tomato	*Lycopersicon esculentum*
Water Apple	Syzygium samarangense
Wax Jambu	*Eugenia jambos*

(b) the following other fruit, vegetables, plants and plant products being, in my opinion, fruit, vegetables, plants and plant products of species that are likely to introduce a pest into the State:

Allium spp (onion, spring onion, garlic, chives, leek, shallots, etc)
Apple (fruit and plants)
Avocado (fruit and plants)
Babaco
Banana
Beans
Capsicum
Chilli
Carambola
Casimiroa (white sapote)
Citrus (fruit and plants)
Cucumbers
Cucurbits
Custard apple
Cut Flowers
Date Palm (fruit and plants)
Dragon fruit
Durian
Eggplant
Feijoa
Fig
Fire Blight hosts
Fodder/Hay
Gourd, bitter
Grapes and grape products (marc, must and juice)
Grapevines (cuttings, rootlings, plants/plant parts and tissue cultures)
Guava
Jackfruit
Kiwi fruit (Chinese gooseberry)
Leaf vegetables
Lettuce
Loofa (smooth)

Longan
Loquat
Lychee (or Litchi or Lichi)
Maize seed
Mango
Mangosteen
Medlar
Melons (watermelon, rockmelon, honeydew, etc)
Miscellaneous host fruits of fruit flies (Tephriditae family)
Myrtaceae Family (Eucalypts, guava etc)
Okra
Olive
Passionfruit
Papaw (or pawpaw or papaya)
Peas
Persimmon
Pinus plants
Plant nursery stock
Pome fruit (apple, pear, loquat, medlar, quinces, nashi pear)
Pomegranate
Potatoes (tubers and plants)
Prickly pear
Pumpkin
Quince
Rambutan
Raspberry
Rooted plants and cuttings
Root vegetables
Sapodilla
Sapote, black
Silverbeet
Soursop
Spinach
Squash
Star apple
Stone fruit (peach, nectarine, plum, apricot, cherry, peacharine, plumcot)
Strawberry
Tamarillo
Timber
Tobacco
Tomato
Turf

(c) soil;

(d) any plant growing in soil or to which soil is adhering;

(e) any equipment (including, but not restricted to) any harvester, machinery, tools, bulk bins, containers or posts that has been used in the production or manipulation of grapes or grapevines in the States of New South Wales, Queensland or Victoria;

(f) any used agricultural machinery;

(g) plant diagnostic samples.

(i) Sub-paragraph (2) does not apply in relation to any item for which importation or introduction is prohibited under sub-paragraph (1).

Dated: 30 May 2024

HON CLARE SCRIVEN MLC
Minister for Primary Industries and Regional Development

ROADS (OPENING AND CLOSING) ACT 1991

SECTION 24

NOTICE OF CONFIRMATION OF ROAD PROCESS ORDER

Road Closure—Old Coach Road, Gulnare

By Road Process Order made on 21 November 2023, the Northern Areas Council ordered that:

1. Portion of Old Coach Road, Gulnare, situated adjoining Sections 204E, 203 and Allotment 775 in Filed Plan 188097, Hundred of Yackamoorundie, more particularly delineated and lettered 'A', 'B' and 'C' in Preliminary Plan 22/0045 be closed.
2. Transfer the whole of the land subject to closure lettered 'A' to Neil Andrew Ferme in accordance with the Agreement for Transfer dated 13 September 2023 entered into between the Northern Areas Council and Neil Andrew Ferme.
3. Transfer the whole of the land subject to closure lettered 'B' and 'C' to Trevor Rodney Keech in accordance with the Agreement for Transfer dated 7 September 2023 entered into between the Northern Areas Council and Trevor Rodney Keech.

On 12 June 2024 that order was confirmed by the Minister for Planning conditionally upon the deposit by the Registrar-General of Deposited Plan 132565 being the authority for the new boundaries.

Pursuant to Section 24(5) of t*he Roads (Opening and Closing) Act 1991*, notice of the Order referred to above and its confirmation is hereby given.

Dated: 13 June 2024

B. J. SLAPE
Surveyor-General

2022/16848/01

PLANT HEALTH ACT 2009

SECTION 4

Declaration of Pests

PURSUTANT TO sections 4(3) and 8(3) of the *Plant Health Act 2009,* I, Clare Scriven, Minister for Primary Industries and Regional Development revoke the previous section 4 and 8 notices made by the Chief Inspector on 4 December 2023 and published on 7 December 2023 on page 4076.

PURSUANT to Section 4 of the *Plant Health Act 2009*, I, Clare Scriven, Minister for Primary Industries and Regional Development, hereby declare the following pests specified by common name or scientific name are declared to be pests for the purposes of the Act:

Common Name(s)	**Scientific Name(s)**
African citrus psyllid	*Trioza erytreae*
American serpentine leaf miner	*Liriomyza trifolii*
Anthracnose of Brassica crops	*Colletotrichum higginsianum*
Asian citrus psyllid	*Diaphorina citri*
Asian longicorn beetle	*Anaplophora glabripennis*
Asian subterranean termite	*Cryptotermes gestroi*
Australian plague locust	*Chortoicetes terminifera*
Bacterial wilt of potato	*Ralstonia solanacearum* Race 3
Barley stem gall midge	*Mayetiola hordei*
Barley stripe rust	*Puccinia striiformis* f. *sp. hordei*
Blueberry rust	*Thekopsora minima*
Boil smut of maize	*Ustilago maydis*
Brown marmorated stink bug	*Halyomorpha halys*
Browsing ant	*Lepisiota frauenfeldi*
Burning moth	*Hylesia nigricans*
Caracollina lenticula	*Caracollina lenticula*
Ceratocystis wilt	*Ceratocystis manginecans, Ceratocystis* spp. (exotic species)
Chestnut blight	*Cryphonectria parasitica*
Chickpea leaf miner	*Liriomyza cicerina*
Chocolate-band snail	*Eobania vermiculata*
Citrus blight	(unknown causal agent)
Citrus canker	*Xanthomonas citri* subsp. *citri*
Citrus longicorn beetle	*Anaplophora chinensis*
Citrus red mite	*Panonychus citri*
Citrus tristeza virus – sweet orange stem pitting strain	Citrus tristeza closterovirus – sweet orange stem pitting strain
Citrus variegated chlorosis	*Xylella fastidiosa*
Columnea latent viroid (CLVd)	Columnea latent viroid
Cucumber fruit mottle mosaic virus (CFMMV)	Cucumber fruit mottle mosaic tobamovirus
Cucumber green mottle mosaic virus (CGMMV)	Cucumber green mottle mosaic tobamovirus
Drywood termite	*Cryptotermes dudleyi*
Electric ant	*Wasmannia auropunctata*
European House Borer	*Hylotrupes bajulus*
Exotic gypsy moth	*Lymantria* spp. (*L. dispar* and sub-species, *L. monacha*)
Fire blight	*Erwinia amylovora*
Fruit flies	Pest species of Tephritidae family
Fusarium wilt of tomatoes	*Fusarium oxysporum* f.sp. *lycopersicon* Race 3
Giant African snail	*Lissachatina fulica*
Giant pine scale	*Marchalina hellenica*
Glassy-winged sharpshooter	*Homalodisca vitripennis*
Golden apple snail	*Pomacea canaliculata*
Grape phylloxera	*Daktulosphaira vitifolliae*
Grapevine leaf rust	*Phakopsora euvitis*
Grapevine red blotch-associated virus	Grapevine red blotch-associated geminivirus
Green snail	*Cantareus apertus*
Guava Root Knot Nematode	*Meloidogyne enterolobii*
Harlequin lady beetle	*Harmonia axyridis*
Hessian fly	*Mayetiola destructor*
Huanglongbing disease of citrus	'*Candidatus liberibacter*' spp.
Karnal bunt	*Tilletia indica*
Khapra beetle	*Trogoderma granarium*
Kyuri green mottle mosaic virus (KGMMV)	Kyuri green mottle mosaic tobamovirus
Melon necrotic spot virus (MNSV)	Melon necrotic spot carmovirus
Melon thrips	*Thrips palmi*
Myrtle rust	*Puccinia psidii* (syn. *Uredo rangelii*)

Common Name(s)	Scientific Name(s)
Myrtle rust (exotic strains)	*Austropuccinia psidii* (syn. *Puccinia psidii, Uredo rangelii*) – exotic strains
Parlatoria date scale	*Parlatoria blanchardi*
Pepino mosaic virus (PepMV)	Pepino mosaic potexvirus
Pepper chat fruit viroid (PCFVd)	Pepper chat fruit viroid
Phoney peach disease	*Xylella fastidiosa*
Phytophthora blight	*Phytophthora kernoviae*
Pierce's disease of grapevines	*Xylella fastidiosa*
Pine wilt nematode	*Bursaphelenchus spp.* including *B. xylophilus*
Pitch canker	*Fusarium circinatum*
Polyphagous shot hole borer	*Euwallacea fornicatus*
Polyphagous shot hole borer-associated fusarium wilt	*Fusarium euwallaceae*
Potato blackleg and soft rot	*Dickeya spp. Including D. dianthicola, D. dadantii and D. solani*
Potato cyst nematode	*Globodera pallida*
Potato cyst nematode	*Globodera rostochiensis*
Potato late blight	*Phytophthora infestans* (A2 mating type)
Potato mop top virus (PMTV)	*Pomovirus solani*
Potato spindle tuber viroid (PSTVd)	Potato spindle tuber pospiviroid
Pyriform scale	*Protopulvinaria pyriformis*
Red imported fire ant	*Solenopsis invicta*
Sawyer beetles	*Monochamus spp.* including *M. alternatus, M. galloprovincialis, M. scutellatus, M. titillator*
Serpentine leaf miner	*Liriomyza huidobrensis*
Sharka	Plum pox potyvirus
Small plague grasshopper	*Austroicetes cruciata*
Spotted-winged drosophila (fruit fly)	*Drosophila suzukii*
Strawberry latent ringspot virus (SLRSV)	Strawberry latent ringspot virus
Stubborn disease of citrus	*Spiroplasma citri*
Subterranean termite	*Coptotermes formosanus*
Sudden oak death	*Phytophthora ramorum*
Tarnished plant bug	*Lygus lineolaris*
Teratosphaeria canker	*Teratosphaeria destructans* and *T. zuluensis*
Tomato apical stunt viroid (TASVd)	Tomato apical stunt viroid
Tomato black ring virus (TBRV)	Tomato black ring nepovirus
Tomato brown rugose fruit virus (ToBRFV)	Tomato brown rugose fruit tobamovirus
Tomato chlorotic dwarf viroid (TCDVd)	Tomato chlorotic dwarf viroid
Tomato leaf miner	*Liriomyza bryoniae*
Tomato mottle mosaic virus (ToMMV)	Tomato mottle mosaic tobamovirus
Tomato planta macho viroid (TPMVd)	Tomato planta macho viroid
Tomato-potato psyllid	*Bactericera cockerelli*
Tropical fire ant	*Solenopsis geminata*
Vegetable leaf miner	*Liriomyza sativae*
Watermelon green mottle mosaic virus (WGMMV)	Watermelon green mottle mosaic tobamovirus
West Indian drywood termite	*Cryptotermes brevis*
Western plant bug	*Lygus hesperus*
Wheat stem rust (exotic strains)	*Puccinia graminis* f. sp. *tritici* (exotic strains)
Wheat stem sawfly	*Cephus* spp. (*C. cinctus*, *C. pygmeaus*)
Yellow crazy ant	*Anoplolepis gracilipes*
Zebra chip of potatoes, 'yellows' and other diseases of solanaceous and apiaceous plants	'*Candidatus* Liberibacter solanacearum' (all Haplotypes)
Zucchini green mottle mosaic virus (ZGMMV)	Zucchini green mottle mosaic tobamovirus

In this Notice:

- "the Act" means the *Plant Health Act 2009*.

This Notice will remain in force until revoked by subsequent Notice.

Dated:

HON CLARE SCRIVEN MLC
Minister for Primary Industries and Regional Development

PLANT HEALTH ACT 2009

SECTION 8

Declaration of Quarantine Areas

PURSUANT to Section 8 of the *Plant Health Act 2009*, I, Clare Scriven, Minister for Primary Industries and Regional Development, hereby declare the portions of the State listed in Part 1 of this notice to be quarantine areas for the purposes of the Act.

Part 1

1.1 The following portions of the State are declared to be quarantine areas:

(1) the whole of Kangaroo Island with respect to the declared pests of potatoes. This quarantine area is to be known as the 'Kangaroo Island Protected Production Area'.

(2) with respect to pest fruit flies, for the purposes of control and eradication, a "Controlled Movement Zone" (as defined in Part 2 of this Notice).

(3) with respect to pest fruit flies, for the purpose of excluding fruit flies from the Riverland of South Australia ("Riverland Pest Free Area"), the:

(i) County of Hamley; and

(ii) Hundreds of Bookpurnong, Cadell, Gordon, Holder, Katarapko, Loveday, Markaranka, Moorook, Murtho, Parcoola, Paringa, Pooginook, Pyap, Stuart, Waikerie, Eba, Fisher, Forster, Hay, Murkbo, Nildottie, Paisley, Ridley and Skurray.

(4) with respect to *Caracollina lenticula*, the following are declared to be quarantine areas:

(i) 9 Creswell Road, Largs North, Certificate of Title Volume 5781 Folio 919; and

(ii) 10 Creswell Road, Largs North, Certificate of Title Volume 5208 Folio 532; and

(iii) 1- 4 / 2 Elder Road, Largs North, Certificates of Title Volume 6129 Folio 124 and Volume 6129 Folio 125.

(5) with respect to *Cantareus apertus*, for the purposes of control and eradication, the following is declared a quarantine area and will be known as the 'Green Snail Quarantine Area':

(i) the area extending outwards for 2 km from the parcel boundary of the place known as Ferguson Conservation Park located on Hallett Road, Stonyfell, Certificate of Title Volume 5772 Folio 813.

1.2 Measures to be taken in Quarantine Areas

(1) The owner or occupier of any premises within the 'Kangaroo Island Protected Production Area' established under Part 1 1.1(1) must take the measures prescribed in the Standard for eradication of the declared diseases of potatoes.

(2) For the purposes of control and eradication of fruit flies, unless permitted within the Standard, host fruit grown in or introduced into a Controlled Movement Zone must not be moved within or removed from the Controlled Movement Zone without approval from the Chief Inspector or delegate; and

(3) the owner or occupier of any premises within a portion of the State declared to be a:

(i) Delimitation Zone (as defined in Part 2 of this Notice) must take the measures prescribed in the Standard for the control and eradication of such flies from a fruit fly outbreak zone; and

(ii) Corrective Action Zone (as defined in Part 2 of this Notice) must take the measures prescribed in the Standard for the control and eradication of such flies from a fruit fly outbreak area; and

(iii) Export Assurance Zone (as defined in Part 2 of this Notice) must take the measures prescribed in the Standard for the control and eradication of such flies from a fruit fly suspension area.

(4) Measures for the exclusion of fruit flies from the Riverland of South Australia ("Riverland Pest Free Area"):

(i) Introduction of host fruits, as specified under Section 7 of the Act, into the Riverland Pest Free Area is prohibited unless:

a) in transit through the Riverland Pest Free Area; or

b) if the host fruit was produced in a State or Territory other than South Australia or interstate Fruit Fly Pest Free Area (FF-PFA): the host fruit complies with the treatments described within Part 1, paragraph 1.2(4)(iii) below and is accompanied with plant health certification; or

c) if the host fruit was produced in any part of South Australia outside the Riverland Pest Free Area, the host fruit has been certified by an inspector as having been either;

i. grown in an area free of fruit flies as defined by the Standard; or

ii. treated in compliance with the treatments described in Part 1, paragraph 1.2(4)(iii) below; or

d) moved under an accreditation arrangement as approved by the Minister under Part 4 Division 2 of the Act and Regulation 7 of the *Plant Health Regulations 2022*; or

e) accompanied by an itemised retail purchase docket applicable to that produce and issued by an Approved PFA suitable retail store.

(ii) if the host fruit was originally produced in the Riverland Pest Free Area or an interstate Fruit Fly Pest Free Area, but has moved outside that area and is now proposed to be re-introduced,

or introduced for the first time as the case may be, into the Riverland Pest Free Area, the produce must be;

a) maintained under secure conditions throughout the duration that it was outside the Riverland Pest Free Area or interstate Fruit Fly Pest Free Area; and

b) labelled in accordance with the *Plant Health Regulations 2022* and accompanied with documentation demonstrating the origin and destination of the host fruit; or

c) moved under an accreditation arrangement as approved by the Minister under Part 4 Division 2 of the Act and Regulation 7 of the *Plant Health Regulations 2022*; or

d) Treated in compliance with the treatments described in Part 1, paragraph 1.2(4)(iii) below and is accompanied with plant health certification.

(iii) The following treatments are prescribed for the purpose of moving produce into the Riverland Pest Free Area:

a) Treatment in accordance with Condition 9 (Area Freedom for fruit flies / secure transportation) as described in the Standard

b) Treatment in accordance with Condition 10.1 (Hard green or similar condition for Fruit Fly) as described in the Standard

c) Treatment in accordance with Condition 11 (Disinfestation by Cold Storage) as described in the Standard

d) Treatment in accordance with Condition 12 (Disinfestation using Dimethoate – Queensland fruit fly) as described in the Standard

e) Treatment in accordance with Condition 12E (Winegrapes Secure Transportation – Queensland Fruit Fly / Mediterranean Fruit Fly – Systems Approach – ICA 33) as described in the Standard

f) Treatment in accordance with Condition 13 (Disinfestation by Methyl Bromide fumigation) as described in the Standard

g) Treatment in accordance with Condition 14 (Disinfestation by Irradiation) as described in the Standard

h) Treated or consigned under conditions approved by the Chief Inspector.

(5) The owner or occupier of any premises within the quarantine area with respect to *Caracollina lenticula*, must take the following measures

(i) all outdoor areas must be treated with the following molluscicide bait treatments in accordance with label specifications:

a) a metaldehyde-based bait (e.g. Metarex Inov Slug and Snail Bait, Axcela Slug and Snail Bait) at least once during the months of March, April, May, September, October and November; and,

b) an iron-based bait (e.g. Protect Us Snail and Slug Killer, Eradicate Snail and Slug Bait) at least once during the months of June, July and August of each year.

c) bait applications must occur at regular intervals over the twelve months (e.g. every 30 days plus (+) or minus (–) 3 days).

(ii) all annual vegetative ground cover must be destroyed but retained within the premises.

a) any item from the quarantine area that may harbour *Caracollina lenticula* is prohibited from leaving the quarantine area unless it meets the conditions laid out in Part 1, paragraphs 1.2(5)(ii)a) to 1.2(5)(ii)d) below:

b) the item is inspected by an inspector and the inspector is satisfied that the item is free of *Caracollina lenticula*; or

c) a staff member nominated by the affected business who is authorised by an inspector to do the inspections is satisfied that the item is free of *Caracollina lenticula*, and,

d) if *Caracollina lenticula* are found during inspection, or the item cannot be inspected to satisfy that the item is free of *Caracollina lenticula*, the item must be cleaned or treated in a method approved by the Department of Primary Industries and Regions, South Australia, and,

e) the item is removed from the quarantine area immediately upon being inspected in accordance with Part 1, paragraph 1.2(5)(ii)a) or b) above; or immediately upon being cleaned or treated in accordance with Part 1, paragraph 1.2(5)(ii)c) above.

(6) With respect to Green Snail, (*Cantareus apertus*) the owner or occupier of any premises within the Green Snail Quarantine Area must take the following measures:

(i) Any host item located on a property within the Green Snail Quarantine Area which may harbour *Cantareus apertus* is prohibited from leaving the property unless it meets the conditions laid out in Part 1, paragraphs 1.2(6)(i)a) to d) below:

a) The host item is inspected by an inspector and the inspector is satisfied that the item is free of *Cantareus apertus*; and

b) if *Cantareus apertus* are found during inspection, or the item cannot be inspected to satisfy that the host item is free of *Cantareus apertus*, the host item must be cleaned or treated using a method approved by the Chief Inspector; and

c) the host item is removed from the Green Snail Quarantine Area immediately upon being inspected in accordance with Part 1, paragraph 1.2(6)(i)a) or b) above; or

immediately upon being cleaned or treated in accordance with Part 1, paragraph 1.2(6)(i)c) above; or,

d) in the case of residential garden waste, host items must be disposed of by placing inside a green waste bin located on the residential property which is kept closed when not in use and is placed for collection on the designated local government area collection day; or,

e) is otherwise consigned under conditions prescribed by the Chief Inspector.

ii. One of the following prescribed treatments must be applied before moving host items out of the Green Snail Quarantine Area:

a) treatment in accordance with Condition 23 (Hosts of Green Snail) as described in the Standard; and,

b) accompanied with Plant Health Certification issued by a Plant Health Inspector certifying the host items meets Condition 23 of the Standard; or,

c) moved under an accreditation arrangement as approved by the Minister under Part 4 Division 2 of the Act and Regulation 7 of the *Plant Health Regulations 2022*; and,

d) is accompanied with a Plant Health Assurance Certificate issued by a business accredited under the Act; or

e) is otherwise consigned under conditions prescribed by the Chief Inspector.

Part 2

In this Notice:

- "the Act" means the *Plant Health Act 2009*.
- "annual vegetation" means plants that grow for only a single year and not purposely grown for amenity reasons.
- "Approved PFA suitable retail store" means a retail store who holds an accreditation arrangement as approved by the Minister under Part 4 Division 2 of the Act and Regulation 7 of the *Plant Health Regulations 2022*, and as having verified systems for the management and traceability of host fruit, and does not receive, display or sell any host fruit that does not meet the requirements of Part 1, paragraph 1.2(4)(iii) of this Notice.
- "Controlled Movement Zone" (also known as the *Fruit Fly Affected Area*) means the entire area within a circle of pre- determined radius surrounding a fruit fly outbreak centre Epicentre in which area freedom status is suspended and movement controls are applied.
    - Unless otherwise determined by the Chief Inspector, the pre-determined radius of the Controlled Movement Zone is 15 kilometres in the case of an outbreak of Queensland fruit fly.
    - Unless otherwise determined by the Chief Inspector, the pre-determined radius of the Controlled Movement Zone is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly.
- "Corrective Action Zone" (also known as the *fruit fly outbreak area*) means an area within 1.5 kilometres radius of a fruit fly outbreak centre Epicentre, unless otherwise determined by the Chief Inspector.
- "Delimitation Zone" (also known as the *fruit fly outbreak zone*) means all of the land within a 200-metre radius around each fruit fly Discovery Point once the outbreak trigger has been met, unless otherwise determined by the Chief Inspector.
- "Discovery Point" means the physical location where:
    - One or more suspect adult flies have been collected during a single inspection of a trap (regardless of whether the detection triggers and outbreak or not); or
    - Host material containing fruit fly larvae was grown.
- "Export Assurance Zone" (also known as the *fruit fly suspension area*) means the area starting at the outer boundary of the Corrective Action Zone to the pre-determined radius surrounding an Epicentre in which area freedom status is suspended and movement controls are applied.
    - The pre-determined radius of the fruit fly Export Assurance Zone is 15 kilometres in the case of an outbreak of Queensland fruit fly, unless otherwise determined by the Chief Inspector.
    - he pre-determined radius of the fruit fly Export Assurance Zone is 7.5 kilometres in the case of an outbreak of Mediterranean fruit fly, unless otherwise determined by the Chief Inspector.
- "Epicentre" (also known as the *fruit fly outbreak centre*) means the means the location related to each single detection or grouping of detections that triggers an outbreak. An Epicentre may be:
    - the Discovery Point where the first larvae or gravid female was detected; or
    - a location between a grouping of male flies that precipitated the outbreak.
- "fruit fly outbreak trigger" means the detection of fruit fly larvae in locally grown fruit, the detection of one gravid female fruit fly, or the detection of a predetermined number of male fruit flies or non-gravid female fruit flies within a 1- kilometre radius within a consecutive fourteen-day period
    - The pre-determined number of male fruit flies or non-gravid female fruit flies is five for Queensland fruit fly
    - The pre-determined number of male fruit flies or non-gravid female fruit flies is three for Mediterranean fruit fly.
- "host fruit" means the host fruits of fruit flies as specified under Section 7 of the Act.
- "host item" for the purposes of *Cantareus apertus* means
    - Soil originating from within the Green Snail Quarantine Area;

- Machinery or equipment that has been used within the Green Snail Quarantine Area which is capable of carrying adherent soil; or
- Any plant material originating from within the Green Snail Quarantine Area, including, but not limited to leafy vegetables, peas, beans, asparagus, strawberries, strawberry plants, cut flowers, turf, hay straw, fodder and potted plants generally, provided that such plants or plant products have been grown or remained within the Green Snail Quarantine Area, and excluding defoliated cuttings of all plants and bare rooted plants or bare rooted trees, provided they have no leaves or fruit.

- "inspector" means an inspector appointed pursuant to Section 41 of the Act
- "interstate Fruit Fly Pest Free Area" means an area outside of South Australia certified by the Commonwealth Government department responsible for agriculture as a Fruit Fly Pest Free Area.
- "introduced into", for the purposes of control and eradication of fruit flies only, excludes host fruit in transit.
- an "item that may harbour *Caracollina lenticula*" includes any vehicle, machinery or equipment, whether or not it is a plant-related product.
- "the Minister" means the Minister for Primary Industries and Regional Development.
- "molluscicide" means a pesticide that will kill snails and slugs.
- "plant-related product" has the same meaning as in the Act.
- "plant health certification" means assurance certificate or plant health certificate certifying the consignment as treated with the requirements described in Part 1, paragraph 1.2(4)(iii).
- "quarantine area" means the area described in Part 1 of this Notice.
- "retail purchase docket" means a sale provided by an Approved PFA suitable retail store for fruit or fruiting vegetables sold to the public for personal consumption rather than for resale.
- "the Standard" means the document prepared and published by the Department of Primary Industries and Regions entitled the "Plant Quarantine Standard South Australia".
- "transiting" or "in transit" means the movement of securely contained plant product, either directly through South Australia or through another quarantine area for a plant pest, that is accompanied by documentation that can demonstrate both the origin and destination of product, and, whilst in South Australia or another quarantine area, is not subject to off- loading, reloading or storage.
- "securely contained" means transported in a manner that prevents infestation of product with a quarantine pest and/or release of a quarantine pest and, for fruit fly purposes, meets the requirements of Condition 9 of the Standard.

This Notice will remain in force until revoked by subsequent Notice.

Dated:

HON CLARE SCRIVEN MLC
Minister for Primary Industries and Regional Development

REPRODUCTIVE CAPACITY OF QUEENSLAND FRUIT FLY *BACTROCERA TRYONI* FROGGATT IN DIFFERENT HOST FRUIT – A FIELD ASSESSMENT IN SOUTHERN NEW SOUTH WALES.

Bernard C. Dominiak[1], Brett Kerruish[2] and Daryl Cooper[3]

[1] NSW Department of Primary Industries, The Ian Armstrong Building, 105 Prince Street, Orange NSW 2800, Australia.
[2] NSW Department of Primary Industries, Biosecurity Compliance and Food Safety, Orange Agricultural Institute, 1447 Forest Road, Orange, NSW, 2800, Australia.
[3] NSW Department of Primary Industries, Biosecurity Compliance and Food Safety, 2198 Irrigation Way East, Yanco NSW 2703. Australia.

Corresponding author: E-mail: bernie.dominiak@dpi.nsw.gov.au

Summary

Tephritid fruit flies are major economic pests and are an impediment to trade. Different host fruits are known to vary in their capacity for fruit flies to complete their life cycle. However, currently there are few reports that identify the capacity for Queensland fruit fly (Qfly) (*Bactrocera tryoni* (Froggatt)) to complete their life cycle in different hosts. Here, we harvested backyard fruit from infested areas and assessed how many adult flies could be produced from a kilogram of fruit after field infestation. We found loquat, kumquat, peaches and nectarines (in that order) produced the highest number of Qfly adults (>175 adults per kg). This knowledge will assist pest managers and the development of trade standards.

Key words: trade, market access, management, fruit flies

INTRODUCTION

The fruit fly family (Tephritidae) contains some of the world's most serious economic pests (Vargas *et al*. 2015). In eastern Australia, Queensland fruit fly (Qfly) (*Bactrocera tryoni* (Froggatt)) is the most economically important fruit fly pest for market access and fruit production (Dominiak and Mapson 2017). Qfly infests 117 hosts from 49 plant families (Hancock *et al*. 2000). There is little published knowledge on the capacity of Qfly to complete their life cycle. Hancock *et al*. (2000) examined historical records and databases in a review of host status (host or non-host) but made no attempt to rank different hosts. Bateman (1991) broadly categorised fruit into three categories, high, medium or low risk status. A better defined fruit-host ranking may be a useful component of risk mitigation in a systems approach (Dominiak 2019a; van Klinken *et al*. 2020) because there are some fruits that are intrinsically poor hosts. Some host fruit have a high capability to produce large numbers of adult Qfly and need to be managed differently from fruit which produce low Qfly populations.

The capacity of fruit fly to complete their life cycle depends on characteristics of the fruit. In their search for fruit, Qfly are drawn to colours and tree shapes (Meats 1983). After Qfly have detected fruit, Qfly must penetrate fruit skin to lay eggs and start the life cycle. Characteristics such as fruit size, peel toughness, pericarp thickness and Brix level influence oviposition (Muthuthantri and Clarke 2012; Unahawutti *et al*. 2014). Utilisation of fruit and survival of larvae may depend, at least partly, on the water-soluble carbohydrates (Dominiak and Fanson 2017). Given all these variables, there may be considerable variation of oviposition preference within host families (Balagawi *et al*. 2013) and the fruit flies' ability to complete their life cycle. Additionally, there are losses in each life stage before Qfly adults appear in the environment. For Qfly management and trade, there is a need to be able to compare the flies' reproductive potential in different fruit.

A three-tiered assessment was proposed by Cowley *et al*. (1992) involving laboratory cage tests with (1) intact and (2) punctured fruit, and (3) field cage tests with intact fruit attached to the tree. Each fruit would be assessed by counting the number of pupae and adults per kg of fruit. This measure (adults per kg) was used to assess host utilization by *B. invadens* (Drew, Tsura & White, 2005) (Mwatawala *et al.* 2006). Similarly, the susceptibility of hosts was ranked by Lloyd *et al*. (2013) based on the number of fruit flies produced per gram of fruit subjected to an infestation rate of one egg per gram of fruit. In our paper, we used a ranking similar to those suggested by Cowley *et al*. (1992) and Mwatawala *et al.* (2006).

We found that loquat (*Eribotrya japonica* (Thunb.) Lindl.) and kumquats (*Citrus japonica* Thunb.) were most able to support Qfly reproductive capacity with >200 adults per kg (A/kg). Peaches (*Prunus persica* L. (Batsch)) and nectarines (*Prunus persica* var. *nucipersica*) produced up to 175 A/kg. Guava (*Psidium guajava* L.) supported about 100 A/kg. Apricots (*Prunus armeniaca* L.), feijoa (*Acca sellowiana* (O. Berg) Burret), pears (*Pyrus communis* L.), grapes (*Vitis vinifera* L.) and quince (*Cydonia oblonga* Mill.) supported up to about 50 A/kg.

MATERIALS AND METHODS

There were many Qfly outbreaks in the Riverina during 2010 and 2012 (Dominiak and Mapson 2017), and backyard fruit were inspected for Qfly

damage as part of the outbreak response. Fruit suspected of being stung by Qfly were collected opportunistically from trees in urban areas in Balranald, Griffith, Leeton, Deniliquin and Yanco, and sent to the Orange Agricultural Institute. Fallen fruit was not sampled because of the state of degradation. A total of 102.3 kg of fruit was collected with an average sample weight of 1.1kg. Sample size (excluding small fruit such as grapes, cherries and olives) ranged from one nashi pear to 104 quandongs. On receipt, fruit was weighed and placed in growth cabinets. Each sample was held separately to identify insects that emerged. Fruit was held above vermiculite (1-4 cm deep) in a constant growth cabinet set at 26ºC (+/- 5ºC) and 80% (+/- 20%) relative humidity for 3 weeks to enable pupation and eclosion of adults. The adult flies were identified morphologically and the numbers counted. The number of adults per kg (A/kg) of fruit was calculated for each sample. The numbers were recorded in Table 1 with the lowest numbers on the left and the highest on the right side for each fruit.

RESULTS AND DISCUSSION

In 2010, there were 54 fruit samples submitted and 24 were infested with Qfly. In 2011, there were 88 samples submitted with 65 samples supporting Qfly adult development Many hosts supported less than 100 A/kg. Orange, peach and nectarine supported between 100 and 200 A/kg. Kumquat supported >200 A/kg. Loquat appeared to be an ideal host supporting a maximum of >300 A/kg (Table 1).

Historically, fruit were described as hosts or not hosts. Little allowance was made for any gradation of fruit-host capacity to support the Qfly life cycle. Bateman (1991) was the first to rank fruit into three levels: high, medium and low risk status. Novotny *et al*. (2005) found that fruit flies infested fruit at densities of 0-110 A/kg with a median of 0-12 A/kg. Lloyd *et al*. (2013) noted that there was no international standard to determine host susceptibility for fruit fly including Qfly. They reported on infestations based on adults per gram: we converted their results to A/kg and we compared our results on the A/kg basis. Our program collected 89 infested fruit while Lloyd *et al.* (2013) collected 66 infested fruit. Loquats were the most frequently fruit sampled in both surveys.

It is important to place the sequence of fruit in context for fruit fly management. Some citrus are left hanging on trees over winter and provide a winter host. Loquats are usually the first ripe fruit after winter in late August to mid-September. Grapefruit usually follow the loquat and then the early apricots. Stone fruit is usually ripe from early summer and grapes are a late season host.

We collected 26 samples of infested loquat with a maximum of 323.5 A/kg. Bateman (1991) ranked loquat as high risk status and Lloyd *et al.* (2013) reported loquat as their fourth highest risk host with a mean of 148 A/kg. Peaches and nectarines also were ranked as high pest status by Bateman (1991) but not reported by Lloyd *et al.* (2013). We found the maximum A/kg of 178.9 and 176.0 respectively. Peaches and nectarines would support a population increase, particularly at mid-season when these were ripe. We found ten infested samples of apricot with a maximum of 62.5 A/kg. We also found two infested samples of pears with a maximum of 55.9 A/kg. Bateman (1991) ranked apricots and pears as high pest status.

Bateman (1991) ranked capsicum, cherry, custard apple, feijoa, grapefruit, mandarin, pomegranate, tomatoes and walnuts with a medium risk status. We found none of these fruit exceeded 50 A/kg with two exceptions (Table 1). Quince supported up to 63.3 A/kg. We found orange supported up to 141.8 A/kg. Generally, based on our results, the difference between Bateman's medium and high pest status is about 50 A/kg, but there are some exceptions to this estimate. If we examine the rankings by Lloyd *et al*. (2013) in relation to the medium pest status in Bateman (1991), five of seven samples in the medium risk status category had a mean of <35 A/kg. The exceptions were Seville oranges and mulberry (*Morus nigra* L.) with a means of 237 A/kg and 209 A/kg respectively.

Grapes were considered to be a low pest status by Bateman (1991) and were treated as a non-host for many years. However, grapes have since been identified as a host (Dominiak 2011). Our work has verified that grapes are a host with >50 A/kg in two samples. Grape growers need to recognize that grapes can support Qfly populations at a level similar to feijoa or pears. Prickly pears and feral olives are weeds in the Riverina and are frequently found close to fruit production areas. We found one sample of prickly pear with a Qfly infestation (6.1 A/kg) equivalent to grapefruit. Dominiak *et al*. (2019) reported olives could produce up to 32.5 A/kg. Therefore, prickly pears and feral olives need to be managed particularly where these weeds occur near commercial fruit production. If fruit such as olives and loquats are grown in homestead gardens on orchards, these hosts need to be managed to prevent Qfly moving from these hosts into the commercial orchard.

There were no other dacine fruit flies found in our samples. This is consistent with the range of *B. neohumeralis* (Hardy) and *B. jarvisi* (Tryon) and these species were not expected in the Riverina (Dominiak and Worsley 2016, 2017). *Dacus newmani* (Perkins) were not detected in our fruit samples and are not known to infest commercial fruit despite high populations in the Riverina

(Dominiak 2019b). We detected metallic-green tomato fly, *Lamprolonchaea brouniana* (Bezzi) (Diptera: Lonchaeidae) in six very ripe fruit. *Lamprolonchaea brouniana* occurs in ripe or damaged fruit and is not a serious primary invader (Blacket and Malipatil, 2010). We also reared a *Diachasmimorpha kraussii* (Fullaway) (Hymenoptera: Braconidae) from two samples, and five parasitoids from two other samples. Therefore, four of our 89 infested samples had parasitoids (4.5%). Our results are similar to those of Spinner *et al.* (2011) who reported 9% of samples supporting parasitoids. They also detected *D. kraussii* (known parasitoid of Qfly) in districts adjacent to our surveyed area.

Results from our work should be treated with caution where the number of samples was small (e.g. feija, lemons, prickly pear). The A/kg in our paper should be treated as an indicator of the maximum. More fruit sampling will need to be done to verify our findings. For trade, importing countries are only interested in the size of the threat posed from potentially imported fruit and therefore we did not calculate variance or other statistics. More work needs to be done on a standard or system of ranking host risk and the ability of Qfly to reproduce in different fruit. Fruit ranking is likely to be used in future systems approaches for trade (Dominiak 2019a; van Klinken *et al.* 2020).

ACKNOWLEDGEMENTS

We thank the many staff at Orange Agricultural Institute who received and processed the fruit samples and compiled the reports, particularly Michelle Rossetto, Chris Bloomfield, Rosy Kerslake and Catherine Phillips. David Troldahl and Andrew Creek provided useful comments on an earlier version of this manuscript. We thank the anonymous journal reviewers who reviewed and improved an earlier draft of this manuscript.

REFERENCES

Balagawi, S., Vijaysegaran, S., Drew, R.A.I. and Raghu, S. (2005). Influence of fruit traits on oviposition preference and offspring performance of *Bactrocera tryoni* (Froggatt) (Diptera : Tephritidae) on three tomato (*Lycopersicon lycopersicum*) cultivars. *Australian Journal of Entomology* **44**: 97-103.

Balagawi, S., Drew, R.A.I. and Clarke, A.R. (2013). Simultaneous tests of the preference-performance and phylogenetic conservatism hypothesis: is either theory useful? *Arthropod-Plant Interactions* **7**: 299-313.

Bateman, M.A. (1991). The impact of fruit flies on Australian Horticulture. Horticultural Policy Council Report No. 3. ISBN 0 642 16110 0.

Blacket, M.J. and Malipatil, M.B. (2010). Redescription of the Australian metallic-green tomato fly, *Lamprolonchaea brouniana* (Bezzi) (Diptera: Lonchaeidae), with notes on the Australian *Lamprolonchaea* fauna. *Zootaxa* **2670**: 31–51

Cowley, J.M., Baker, R.T. and Harte, D.S. (1992). Definition and determination of host status for multivoltine fruit fly (Diptera: Tephritidae) species. *Journal of Economic Entomology* **85**: 312-317.

Dominiak, B.C. (2011). Review of grapes *Vitis* sp. as an occasional host for Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). *Crop Protection* **30**: 958-961.

Dominiak, B.C. (2019a). Components of a systems approach for the management of Queensland fruit fly *Bactrocera tryoni* (Froggatt) in a post dimethoate fenthion era. *Crop Protection* **116**: 56-67.

Dominiak, B.C. (2019b). Review of the biology and distribution of Newman fruit fly *Dacus newmani* (Perkins) (Diptera: Tephritidae), a cryptic Dacinae species from the dry inland of Australia. *General and Applied Entomology* **47**: 17-24.

Dominiak, B.C. and Fanson, B.G. (2017). Assessing the proportion of nutrients removed from larval diet by Queensland fruit fly (*Bactrocera tryoni*) at a mass-rearing facility and possible uses of spent media. *General and Applied Entomology* **45**: 71-75.

Dominiak, B.C. and Mapson, R. (2017). Revised distribution of Queensland fruit fly (*Bactrocera tryoni* Froggatt) in eastern Australia and effect on possible incursions of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann): Development of Australia's eastern trading block. *Journal of Economic Entomology* **110**: 2459-2465.

Dominiak, B.C. and Worsley, P. (2016). Lesser Queensland fruit fly *Bactrocera neohumeralis* (Hardy) (Diptera: Tephritidae: Dacinae) not detected in inland New South Wales or south of Sydney. *General and Applied Entomology* **44**: 9-15.

Dominiak, B.C. and Worsley, P. (2017). Review of the southern boundary of Jarvis fruit fly *Bactrocera jarvisi* (Tryon) (Diptera: Tephritidae: Dacinae) and its likely southern distribution in Australia. *General and Applied Entomology* **45**: 1-7.

Dominiak, B.C., Semeraro, L., Blacket, M.J., Englefield, A.C. and Mellberg, A. (2019). Olive fruit (*Olea europaea* L.) as a host of Queensland fruit fly *Bactrocera tryoni* (Froggatt) in South Eastern Australia. *General and Applied Entomology* **47**: 1-6.

Hancock, D.L., Hamacek, E.L., Lloyd, A.C. and Elson-Harris, M.M. (2000). The distribution and host plants of fruit flies (Diptera: Tephritidae) in Australia. Queensland Department of Primary Industries. ISSN 0727-6273.

Lloyd, A.C., Hamacek, E.L., Smith, D., Kopittke, R.A. and Gu, H. (2013). Host susceptibility of citrus cultivars to Queensland fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology* **106**: 883-890.

Muthuthantri, S. and Clarke, A.R. (2012). Five commercial citrus rate poorly as hosts of the polyphagous fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) in laboratory studies. *Australian Journal of Entomology* **51**: 289-298.

Mwatawala, M.W., De Meyer, M., Makundi, R.H. and Maerere, A.P. (2006). Seasonality and host utilisation of the invasive fruit fly, *Bactrocera invadens* (Dipt., Tephritidae) in central Tanzania. *Journal of Applied Entomology* **130**: 530-537.

Meats, A. (1983). The response of the Queensland fruit fly, *Dacus tryoni*, to tree models. Proceedings of the CEC/IOBC International Symposium, Athens, Greec, November 1982. Fruit flies of economic importance. Commission of the European communities, A.A. Balkema/Rotterdam/1983. 285-289.

Novotny, V., Clarke, A.R., Drew, R.A.I., Balagawi, S. and Clifford, B. (2005). Host specialization and species richness of fruit flies (Diptera: Tephritidae) in a New Guinea rain forest. *Journal of Tropical Ecology* **21**: 67-77.

Spinner, J.E., Cowling, A.M., Gurr, G.M., Jessup, A.J. and Reynolds, O.L. (2011). Parasitoid fauna of Queensland fruit fly, *Bactrocera tryoni* Froggatt (Diptera: Tephritidae)

in inland New South Wales, Australia and their potential for use in augmentative biological control. *Australian Journal of Entomology* **50**: 445-452.

Unahawutti, U., Intarakumheng, R., Oonthonglang, P., Phankum, S. and Follett, P.A. (2014). Nonhost status of mangosteen to *Bactrocera dorsalis* and *Bactrocera carambolae* (Diptera: Tephritidae) in Thailand. *Journal of Economic Entomology* **107**: 1355-1361.

Van Klinken, R.D., Fielder, K., Kingham, L., Collins, K. and Barbour, D. (2020). A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. *Crop Protection* **129**: 104994.

Vargas, R.I., Pinero, J.C. and Leblanc, L. (2015). An overview of pest species of *Bactrocera* fruit flies (*Diptera: Tephritidae*) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific Region. *Insects* **6**: 297-318.

Table 1. Reproductive capacity of different fruit based on adult *Bactrocera tryoni* flies successfully completing their life cycle per kilogram of fruit harvested at Griffith, Leeton, Yanco and Balranald. Lowest numbers are on the left, progressing to highest numbers on the right for each row (fruit).

Fruit	**Adult emerged per kg fruit (A/kg)**
Acca sellowiana (O. Berg) Burret, Feijoa	45.8,
Annona reticulata L., Custard apple	25.9,
Capsicum annuum L., Capsicum	17.4, 24.3,
Citrus japonica Thunb., Kumquat	33.6, 35.2, 37.8, 233.8,
Citrus limon (L.) Osbeck, Lemon Lisbon	3.3,
Citrus x paradisi Macfad., Grapefruit	0.6, 2.1, 2.7, 2.9, 4.7,
Citrus reticulata Blanco 1837, Mandarin	43.3,
Citrus sinensis L., Orange	11.5, 34.6, 141.8,
Cydonia oblonga Mill., Quince	1.4, 1.5, 1.9, 2.2, 4.7, 63.3,
Eribotrya japonica (Thunb.) Lindl., Loquat	6.9, 10.4, 14.7, 28.6, 31.1, 33.6, 37.5, 38.1, 46.7, 57.1, 57.3, 72.7, 72.7, 79.8, 97.2, 97.3, 99.8, 108.6, 109.2, 115.4, 115.9, 147.1, 182.4, 199.6, 314.9, 323.5,
Juglans regia L., Walnut	14.1
Malus domestica (Borkh), Apple	12.0,
Mangifera indica L., Mango	4.2
Opuntia sp. Prickly pear	6.1,
Prunus avium L., Cherry	8.2, 8.9,
Prunus armeniaca L., Apricot	1.4, 6.0, 8.8, 12.1, 12.3, 17.5, 44.1, 48.1, 51.3, 62.5,
Pyrus communis L., Pear	13.9, 55.9,
Pyrus pyrifolia (Burm.) Nak, Nashi pear	13.9, 72.7,
Prunus persica L. (Batsch), Peach	<1, 5.0, 8.8, 18.8, 20.7, 178.9,
Prunus persica var. *nucipersica*, Nectarine	2.0, 3.2, 4.4, 25.8, 70.9, 176.0
Psidium guajava L., Guava	92.4,
Punica granatum L., Pomegranate	4.1
Solanum lycopersicum L., Tomato	<1,
Vitis vinifera L., Grapes	1.6, 7.9, 50.0, 52.6,

Crop Protection 138 (2020) 105341

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Current quarantine and suspension distances are excessive for incipient populations of Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) (Diptera: Tephritidae) in southern New South Wales, Australia

Bernard C. Dominiak [a,*], Benjamin G. Fanson [b]

[a] New South Wales Department of Primary Industries, 161 Kite Street, Orange, NSW, 2800, Australia
[b] School of Life and Environmental Sciences, Deakin University, Geelong, VIC, 3216, Australia

ARTICLE INFO

Keywords:
Flight distance
Trade
Invasions
Epicentre

ABSTRACT

The Queensland fruit fly (Qfly; *Bactrocera tryoni* Froggatt) is a major horticultural pest species in Australia and considered a serious quarantine concern, both domestically and internationally. When a Qfly outbreak is declared in the main horticultural regions of southeast Australia, a 15 km radius suspension zone is established (area of 707 km^2) around the epicentre of the outbreak. This suspension radius was originally adopted in the early 1990s. Here, we analysed trapping data in New South Wales (Australia) from 2002 to 2010 to evaluate the suitability of the 15 km suspension radius. There were 439 Qfly incursions recorded in Qfly-free zones, but only 9.9% of these incursions resulted in a declared outbreak. For these outbreaks, we conducted two distinct analyses. First, we modelled the distribution of infestation radii from the outbreaks and predicted the suspension distance using multiple levels of risk protection (e.g. probit 8.7, probit 9). Second, we fitted various probability distributions to individual fly trapping data and then estimated upper confidence limits for suspension distances, based on dispersal patterns of Qfly. Overall, the predicted suspension radii were substantially smaller than the current 15 km radius. Our results concur with other studies suggesting that Qfly are relatively poor colonisers. We propose that the current 15 km could be reduced substantially to 3 or 4 km.

1. Introduction

Tephritid fruit flies are significant pests of fruit production in most continents of the world. Different species have evolved in different regions (Krosch et al., 2012) and modern large scale trade has the potential to transport species into fruit fly free areas. For instance, Mediterranean fruit fly (Medfly) (*Ceratitis capitata* Wiedemann) originated in sub-Saharan Africa and has spread to every continent except for Antarctic (Malacrida et al., 2007). Hence, importing countries are understandably sensitive to the possible importation of fruit fly infested produce.

Horticultural products represent a significant contribution to Australia's economy. In Australia, more than $1 billion worth of products are traded domestically and are vulnerable to fruit fly pests. Furthermore, the total average export value for Australia's top 25 commodities that were fruit fly hosts has been estimated at $432 million (Plant Health Australia, 2009). The major threat to this horticultural economy is the native Queensland fruit fly (Qfly) (*Bactrocera tryoni* Froggatt).

Qfly originated in southern Queensland, but has now become distributed along the entire eastern Australian coast (Dominiak and Daniels, 2012). Also, Qfly became distributed inland into the main horticultural production areas along the Murray River. Following the wet seasons in the late 1990s, individual farm control programs were considered unsuccessful to access international trade and a regional management program was developed. The resulting zone became known as the Fruit Fly Exclusion Zone (FFEZ) and managed by a standard set of rules (Sutherst and Yonow, 1998). The initial design of proposed rules for this pest free area was reported by Bateman (1991). The "Code of Practice for the Management of Queensland fruit fly" (the Code) used the findings of Bateman (1991) as a basis. The Code became the universal management rules for all domestic trade and became the basis for international trade with 28 countries (Anonymous, 1997). Some rules such as the threshold for an outbreak have since been reviewed and verified (Dominiak et al., 2011). However other rules such as the reinstatement period and the suspension distance (sometimes called a quarantine distance) have not been reviewed to include research

* Corresponding author.
E-mail addresses: bernie.dominiak@gmail.com, bernie.dominiak@dpi.nsw.gov.au (B.C. Dominiak).

https://doi.org/10.1016/j.cropro.2020.105341
Received 15 May 2020; Received in revised form 27 July 2020; Accepted 30 July 2020
Available online 4 August 2020
0261-2194/© 2020 Elsevier Ltd. All rights reserved.

results since 1991.

In the early 1990s, many countries imposed a suspension distance for Qfly of 80 km, presumably based on one report of long distance flight (Macfarlane et al., 1987). In the review of data for suspension distances for outbreaks, Bateman (1991) reviewed 24 Qfly outbreaks over 11 years. Bateman (1991) found a mean radius of detections from these outbreaks of 0.2 km and a maximum recorded dispersal of 0.73 km. Using the formula for the area of a circle, these distances equate to an infested area of 0.13 and 1.5 sq km respectively. Bateman (1991) claimed "that suspension over a 10–15 km would afford a very generous margin of protection …". Regulators chose the more conservative 15 km; however, the reasons for this choice were not recorded. Simplistically, 15 km is about 20 times longer or about 470 times larger (based on area) than the worst dispersal distance. Perhaps the radius reduction from 80 km (about 20,114 sq km) to 15 km (about 707 sq km) was probably seen as a radical enough reduction but a reduction to 10 km (about 314 sq km) was too radical. The 15 km distance was implemented in 1993 and has been operational since then. The area within the suspension zone is 707 sq km: all produce within this area must be subjected to a disinfestation treatment before export to a fruit fly sensitive market. This was a vast improvement compared to 20,114 sq km associated with an 80 km suspension zone.

However, research since the early 1990s has challenged the validity of the 15 km rule. Several studies using the release of sterile flies have found that flies dispersed only hundreds of metres, not kilometres (e.g. Dominiak and Webster, 1998; Dominiak et al., 2003b; Weldon and Meats, 2007; Meats and Edgerton, 2008). Dominiak (2012) reviewed dispersal distances for Qfly from 21 studies showing that the 15 km suspension distance was very conservative. However, how to calculate a new quarantine distance standard is problematic.

Two distinct methods for estimating quarantine distances for Qfly have been proposed (see Meats et al. (2003), Meats and Edgerton (2008) and Dominiak (2012)). These methods approach suspension distances from very different directions. The first approach (population-level) analyses previous outbreaks, recording the furthest distance a fly is trapped and then fits a statistical model (e.g. linear regression) to predict the probability that a future outbreak has a fly dispersal beyond a specified distance. For instance, using historical data of outbreaks from 1974 to 2000 across Australia, Meats et al. (2003) analysed the relationship between maximal dispersal distances of adult flies and the size of the outbreak, as determined by capture rates in the epicentre during the first two weeks. Then they used regression models to predict the probability a fly disperses more than a specified distance. Meats et al. (2003) suggested that quarantine distances be determined by the probit 9 criteria.

Alternatively, quarantine distances can be estimated by understanding the underlying distribution of dispersal distances (aka individual-level). Much theoretical and empirical work has been conducted on describing patterns in animal movements (e.g.Viswanathan and Afanasyevt, 1996; Kokko and López-Sepulcre, 2006; Benhamou, 2007), including Qfly (Meats et al., 2006; Weldon and Meats, 2007; Meats and Edgerton, 2008; Gilchrist and Meats, 2012). If the underlying distribution is well-described, then distributional theory can be used to estimate the probability that an animal will disperse beyond a specified distance.

The distribution models are part of the suspension zone issue. The second consideration is an appropriate level of protection. Probit offers a range of standards (e.g. 9.0, 8.7, 8.1) however probit is used as a dose response measurement or to assess the percentage of a pest killed by a pesticide. Bliss (1934) proposed transforming the percentage killed into a "probability unit" or probit, and usually the number of treated insects is known or predetermined. Surveillance does not apply a dose to a fruit fly population being surveyed and the number of insects in the field is not known. Therefore, probit analysis is inappropriate for surveillance. However, many regulators are familiar with probit standards. Probit 9 was originally used for disinfestation (Cannon, 1998). Disinfestation often requires the treatment of 30,000 fruit fly. Surveillance of adults for outbreaks often involves less than 10 individuals. Probit 9 is a measure of mortality (RAP Pub, 2004/23). Pest risk pertains to the number of survivors and to an appropriate level of protection (ALOP). This is related to risk of entry, survival rate, reproductive potential and establishment, and not a mortality measure. Probit 9 could be too stringent in cases where the natural rate of pest infestation in the field is low (eg, early stages of incursion) and the chances of survival and reproduction are poor (RAP Pub, 2004/23). Subsequently probit 8.7 was used for disinfestation work in the Pacific area (RAP Pub, 2004/23). Meats and Clift (2005) claimed that 0.001 (probit 8.1) was an appropriate level of confidence for surveillance of domestic fruit flies but that probit 9 might be appropriate for exotic flies.

The goal of this study is to assess proposed suspension formulas for Qfly by reviewing Qfly outbreaks using historical trapping in New South Wales (NSW) from 2002 to 2010. We identified Qfly incursions at inland regions that had no permanent Qfly populations. There was a series of large outbreaks between 1998 and 2001 when many outbreaks merged (flies from adjacent outbreaks overlapped) and the data for each outbreak were too difficult to define into separate outbreaks. Also, the 2010–2011 period was the wettest two year period on record (Imielska, 2011; National Climate Centre, 2012) and again, detections for each individual outbreak overlapped and it became too difficult to maintain our assumptions and hence to analyse the dispersal data. For the 2002–2010 outbreaks, we calculate suspension distances using previously proposed methods and then evaluate the concordance of the predicted suspension distances. A range of confidence levels are examined.

2. Materials and methods

2.1. Surveillance protocol and Code of Practice

As part of the National Fruit Fly Surveillance Program in Australia, trapping grids were established across the export focused area in NSW, Australia. The density of the traps varied from 0.4 km (6.25 traps/km^{-1}) in urban areas to 1 km (1 trap/km^{-1}) in production areas. Traps comprise cuelure that attract male Qfly, and the killing agent maldison (Dominiak et al., 2003c). Traps were cleared fortnightly (June to October), weekly (November to May) or sooner during outbreaks (Anonymous, 1997).

The Code of Practice (CoP) were established in 1993 to provide a consistent approach for the management of Qfly infestations (Anonymous, 1997). This code indicated the triggers/responses required for different levels of fruit fly detection. The response depends on the number and frequency of trapped Qfly. If only 1 male Qfly was trapped within a radius of 1 km in a 2-week period, no action was taken. If 2 male flies were caught within 1 km in a 2-week period, this triggered the deployment of supplementary traps. These supplementary traps were set within 200 m of the primary trap and were checked biweekly. If ≥ 5 male flies were caught within 1 km and within a 2-week span, an outbreak was declared. At this point and not before, two types of localised chemical spraying for 12 weeks commenced, usually entailing protein bait spraying twice weekly within 200 m of the epicentre and weekly between 200 m and 1.5 km. Cover sprays with dimethoate or fenthion were used on infested trees as an immediate response. The soil under infested trees was treated with chlorpyrifos (Anon. 1997). In urban areas, fruit on suspect or infested trees was stripped and destroyed. As part of the clean-up programme, sterile insects may be released for 8–12 weeks after chemical treatment had stopped as these treatments will also kill sterile Qfly.

An outbreak was also declared if a gravid female Qfly was caught in a trap or Qfly larvae are discovered in locally grown fruit. Once an outbreak was declared, a 15-km suspension zone was established and remained in place for a minimum of 12 weeks (the reinstatement date) (see CoP for more information Anonymous (1997)). This reinstatement

period begins after the last fly is trapped. By default, 12 weeks or 84 days is the minimum period for reinstatement.

2.2. Experimental protocol.

We obtained data from the NSW Department of Primary Industries (DPI) by assessing the departmental database "PestMon" (Dominiak et al., 2007). These data sets consisted of trapping data between 2002 and 2010 and restricted to the main horticultural production areas in centre of NSW (Fig. 1). These production areas were considered to have no resident Qfly populations and hence all Qfly caught in these areas most likely represent incursions due to transport of infested fruit (Gilchrist et al., 2004). After 2010, uncharacteristic high levels of rainfall resulted in a rapid increase of Qfly outbreaks, making it impossible to tease apart incursions from newly established breeding populations (see Dominiak and Mapson, 2017).

The trapping data comprised geographical locations of trap (postal address or GPS coordinates), date of trap clearance and number of male and female Qfly caught. From these data, we extracted the following information:

1) Identification of all Qfly detections and determined if that detection was followed by an outbreak based on CoP criteria of larvae in locally grown fruit, one gravid female or 5 males within 1 km over 2 weeks.
2) Determination of the epicentre of the incursion, which was defined as the trap with the highest capture rates when an outbreak is declared (if multiple traps, then the average location).
3) Calculation of reinstatement date based on 12 weeks or 1 generation +28 days since last fly was caught, whichever is longer (Anonymous, 1997).
4) For every trapped fly from start of an outbreak to the reinstatement date, we calculated the shortest distance to the epicentre.
5) Trap location was used to identify if the trap was on a 400 m surveillance grid (urban area) or 1 km grid (orchard).

A complicating issue with this analysis was defining when a trapped fly should be considered from the same incursion. In general, outbreaks were well-defined with occasional exceptions. Therefore, we adopted the approach of Meats et al. (2003) for identifying separate incursions. Briefly, a trapped fly was considered a separate infestation if the fly is trapped more than 2 km from the epicentre and the distance from the epicentre is twice the distance of the next furthest fly detection, which indicates a large spatial gap between catches (Meats et al., 2003).

Fig. 1. Map of New South Wales showing locations of the outbreaks between 2002 and 2011.

Another complicating issue is that during an outbreak, supplementary traps (16 wet food lure MacPhail traps and 16 cuelure baited Lynfield traps) were deployed within 200 m of the epicentre. For these supplemental traps, exact geographical locations were not recorded as many traps remained in place for usually only a few weeks. Therefore, we used a conservative approach of adding 200 m to the distance from the primary trap site to the epicentre. Finally, for each outbreak, we assessed the trapping coverage. Only outbreaks that had sufficient trapping coverage were kept for the suspension analyses.

2.3. Data analysis

2.3.1. Unsuccessful Incursions Analysis

For all incursions, we calculated the number of fly detections that did not lead to an outbreak. A fly incursion was considered unsuccessful if $<$ 5 flies were captured and no more flies were caught within 1 km in the next 2 weeks (Anonymous, 1997).

2.3.2. Population-Level Analysis

We adopted the approach from Meats et al. (2003) which used trapping data from 1974 to 2000. For the population-level approach, we recorded the furthest distance a fly is trapped for each outbreak and then fitted a general linear model to predict the probability that a future outbreak will have a single fly disperse beyond a specified distance. We also included capture totals for the first 2 weeks, grid type (0.4 km or 1 km) and production area type as predictor variables in the model. We then calculated the prediction intervals for multiple levels of protection (0.001 (probit 8.1), 0.0001 (probit 8.7), 0.00003 (probit 9)). The upper limit of these prediction intervals indicates the probability that a fly in a future outbreak will disperse further than the suspension distance.

2.3.3. Individual-level analysis

Another approach to estimating suspension distances was to use probability distributions to model the dispersal of flies during outbreaks. We tested six types of probability distributions; Cauchy, power, exponential, inverse square rule, normal, and shifted normal. The Cauchy and power distribution are 'fat' tailed distributions. For the power distribution, the standard approach was that dispersal pattern decay inverse to the square of the distance (Fletcher, 1974). The Cauchy distribution has previously been shown to fit dispersal patterns in sterile flies released from a central location, though its characteristic 'fat' tail at longer distances may be biologically inaccurate (Meats and Edgerton, 2008). Therefore, we compared the Cauchy with two other distributions that have 'skinnier' tails: the exponential and normal distributions. Both distributions have also been used to describe dispersal patterns (Chapman et al., 2007). The normal and the exponential distributions were both similar (depending if the scale factor was large or small, respectively) to the Cauchy near the release sites. However, both the normal and exponential have tails that were much skinnier and may better reflect actual dispersal limitations of flies. Finally, Dominiak (2012) argued for shifting the normal distribution from the epicentre. Thus, we included the shifted normal, which was just the normal distribution shifted by mean dispersal distance.

To fit the distributions, we estimated for each trapping grid type (orchard vs. urban) the characteristic parameters for each distribution using all male trapping results (averaged by trap numbers) within 5 weeks of the outbreak. For both the Cauchy and normal distributions, we assumed the location parameters were zero – in other words, centred on the epicentre. For the Cauchy distribution, the scale parameter can be estimated using the IQR range (Krishnamoorthy, 2010), but since dispersal distances were all positive due to the method of calculation, we estimated the scale parameter using the median of the dispersal distances (location of 50% of the data). The variance estimate for the normal distribution was calculated by obtaining the standard deviation assuming mean was zero. The shifted normal was estimated using mean dispersal data and the standard deviation based on that mean. For the

power distribution (defined by exponent and x_{min} (Clauset et al., 2009),), we used an exponent of 2 following Fletcher's inverse square law and estimated the x_{min} as 0.1 km. Finally, the exponential was calculated using mean dispersal distances.

Next, to assess the fit of the distribution, we estimated the expected number of trapped flies for each distribution at 0.4 km intervals (or 1 km for orchard) and then calculated the goodness-of-fit (χ^2) for each model. Additionally, we used the probability distributions to estimate the suspension distances for multiple levels of protection (probit 8.1, 8.7, and 9). This suspension distance was interpreted as the probability that a single fly will disperse beyond the suspension distance.

Finally, since the individual-level only estimated the probability that a single fly exceeds a certain distance, we estimated the quarantine distance required such that only 1% and 0.1% of outbreaks have one more flies disperse past the quarantine distance. Using the exponential distribution, we calculated these quarantine distances based on the level of protection, outbreak size, and mean dispersal distance for Qfly.

It is known that a mating requires two flies, therefore we repeated this analysis for the case where 2 or more flies (assuming that at least one is a male and one is a female (Clarke and Dominiak, 2010)) exceed the quarantine distances. The range of outbreak sizes were determined from the data and included all flies caught from start of incursion until the reinstatement date.

2.3.4. Practical implications

We examined the practical implications for different suspension distances by estimating the areas associated with each distance. We compared different areas (rather than distances) to demonstrate levels of protection.

3. Results

3.1. Unsuccessful incursions

To calculate the percentage of incursions that failed to cause an outbreak, we used all 439 fly incursions, of which 48 led to an outbreak. Overall, 90.1% of the Qfly incursions died out without any intervention (movement restrictions) or eradication measures (e.g. chemical spraying, SIT). The majority were 1-fly incursions (76.4%), followed by 2-fly (13.5%), 3-fly (7.8%) and 4-fly (2.3%) (Fig. 2).

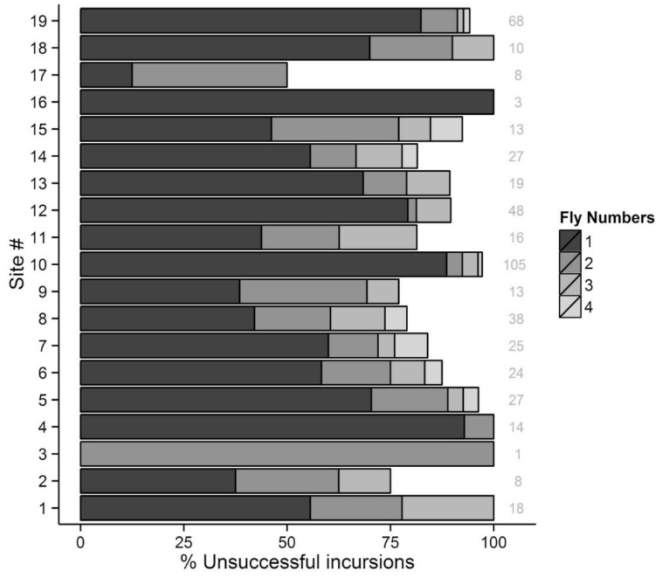


Fig. 2. Percentage of incursions resulting in an outbreak by location. Grey numbers indicate sample sizes (total number of flies caught) for each location. Different colours indicate max biweekly catch rate.

3.2. Population-Level Analysis

The linear model found no significant effect of total flies captured on maximum distance of male flies caught ($F_{1,26} = 2.55$, $p = 0.12$), production zone ($F_{2,26} = 0.13$, $p = 0.88$), or grid type ($F_{1,26} = 0.48$, $p = 0.49$) on maximum dispersal distance (Fig. 3). Since no predictors were significant, we re-ran the linear model with just the intercept and obtained upper prediction intervals of 6.2 km, 7.3 km and 7.8 km for probit 8.1, 8.7, and 9, respectively (Table 1).

3.3. Individual-level analysis

Overall, the exponential distribution fitted the dispersal distances the best, having the lowest goodness-of-fit scores (16.9 and 50.2 for the urban and orchard grids; Table 2). The next best fitting distributions were the normal, Cauchy, shifted normal, and finally power (Table 2). For the urban grid, the largest lack of fit for the exponential distribution was between 400 and 800 m in which the exponential distribution overestimated capture rates (Fig. 4). For the orchard, the main lack of fit was at the 3–4 km distance group, in which the exponential underestimated the capture rate. Using the estimated exponential parameters for the urban results (0.58 km) and the orchard (0.71 km) results, we estimated suspension distances of 4.0/4.8 km (urban/orchard) for probit 8.1, of 5.3/6.5 km for probit 8.7, and 6.0/7.3 km for probit 9 (Table 1).

However, statistical testing of the goodness-of-fit for the exponential results found that the trapping data were significantly different from the exponential distribution (urban, $df = 6, \chi^2 = 16.9$, $p = 0.01$; orchard, $df = 4, \chi^2 = 50.2$, $p < 0.0001$; Table 2), suggesting that dispersal pattern in Qfly do not exactly match the exponential distribution. Therefore, we estimated suspension distances for all distributions to better understand the sensitivity of any suspension estimates based on the exponential distribution (Table 1). The most notable difference among the distributions was the Cauchy distribution which had impracticably long suspension distances (e.g. 4244 km for probit 9), due to the fat tail of the distribution. The other distributions predicted significantly shorter suspension distances (Table 1).

Next, we used the formula recommended in Dominiak (2012) for calculating suspension distances. This formula, $\sqrt{10}$ (mean dispersal + 3 (SD of dispersal), is based on the Shifted Normal. We estimated a

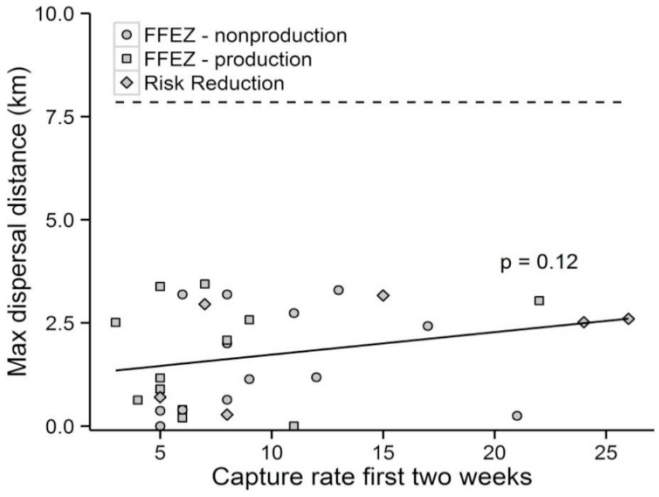


Fig. 3. Relationship between capture rates and maximum dispersal distance. Solid line shows the regression line; no significant effect of capture rates was found ($p = 0.12$). Dotted line is the upper prediction interval for $p = 3/100{,}000$. In the figure, "FFEZ – non production" indicates towns which had no production in their area but were within the FFEZ. "FFEZ – production" indicates towns in close proximity to fruit crops. "Risk Reduction" were towns in the area within 80 km of the FFEZ where Qfly populations were eradicated.

Table 1
Summary of quarantine distances. Mean quarantine distances (km) are listed at three levels of protection.

Method	Grid Type	Levels of Protection (km)		
		99.900% (probit 8.1)	99.990% (probit 8.7)	99.997% (probit 9)
Population level				
Regression	Combined	6.2	7.3	7.8
	Urban	5.7	6.7	7.2
	Orchard	24.7	51.4	75.9
Individual level				
Cauchy	Combined	127.3	1273	4244
Power	Combined	10.1	31.6	57.6
Exponential	Combined	4.3	5.8	6.5
	Urban	4.0	5.3	6.0
	Orchard	4.8	6.5	7.3
Normal	Combined	3.2	3.7	4.0
	Urban	2.7	3.2	3.4
	Orchard	3.8	4.5	4.8
Shifted normal	Combined	2.9	3.3	3.6
	Urban	2.3	2.7	2.9
	Orchard	3.5	4.1	4.4
$\sqrt{10}$* (Mean + 3SD)	Combined			8.9[a]
	Urban	NA	NA	7.2[a]
	Orchard			11.0[a]

[a] Actual level of protection is substantially higher than probit 9.

suspension distance of 7.2 and 11.0 km for 0.0001 and probit 9, respectively (Table 1).

Since we used outbreak data, we calculated quarantine distances based on different outbreak sizes (Table 3). A quarantine distance between 4.7 and 5.9 km (or 6.2–7.3 km) will result in 99% (or 99.9%) of the outbreaks having no flies exceeding the quarantine distance (Table 3). Since mating involves two flies of opposite sex to produce offspring, we also calculated quarantine distances for 2 or more flies, which gave ranges of 3.1–4.2 km (or 3.8–4.9 km) for 99% (or 99.9%).

4. Discussion

4.1. Qfly as poor colonizer

We found that only 9.9% of all Qfly incursions led to an outbreak. Furthermore, it also is likely that we missed other incursions, as Qfly lures are only effective for sexually-mature males 6–10 days post-eclosion (Perez-Staples et al., 2007). Therefore, at least some incursions were very likely to fail before males reached sexual maturity. Therefore, the 9.9% was likely a conservative estimate.

Our results were lower than the 29% outbreak rate by Meats et al. (2003) for trapping records from 1974 to 2000. The difference in incursion rates possibly reflects difference in geographical regions (climatic conditions) and the frequency of transport of infested fruits (Dominiak et al., 1998). Though the estimates differed, both estimates suggested that Qfly were poor colonizers. For instance, the Medfly had an estimate 82% successful outbreak rates (Meats et al., 2003). The lower colonization rates for Qfly were possibly due to the extended sexual maturation period (up to 10 days; Dominiak, 2012) and the shorter dispersal distances of Medfly. Also, other studies suggested that Qfly were poor colonizers (Bateman, 1972; Edge et al., 2001; Weldon, 2007).

4.2. Population-Level Analysis

Meats et al. (2003) conducted a similar analysis with outbreak data from 1974 to 2000 that included 262 incursions (75 outbreaks) in Adelaide region of South Australia (SA). Overall, our mean maximum dispersal was substantially longer than Meats et al. (2003) (1.8 km vs. ~0.5 km). Furthermore, our maximum dispersals were more variable than Meats et al. (2003). Consequently, Meats et al. (2003) found much shorter suspension distances for their regression model, around 2.0 km, in contrast to our analysis that estimated suspension distance of 7.8 km based on probit 9. Finally, our results found a lack of an effect of initial capture rates on maximum dispersal distance in the global model; whereas, Meats et al. (2003) found a significant positive relationship.

These differences may in part reflect the different methods of analysis. Since we were only interested in outbreak cases, we dropped non-outbreak incursions that were included by Meats et al. (2003). Since these small incursions appear to strongly influence the regression line in Meats et al. (2003), excluding these incursions likely explains why we found no significant effect of total capture rates on maximal dispersal distance. Furthermore, including these smaller incursions will also likely dampen the variance estimate.

However, the large differences in the average maximum dispersal distances (and hence suspension estimates) likely reflect actual differences. These differences can not to be explained solely by location effects (i.e. Adelaide vs. inland NSW). However, Reynolds et al. (2012) found differences in SIT results between SA and NSW but could not easily explain why. Meats et al. (2003) conducted a secondary analysis (though not clearly explained in the paper) that included incursion data from SA, Victoria (VIC), and NSW, and showed similar results among the states. Therefore, it appears that temporal differences (e.g. climatic

Table 2
Predicted values for each distribution for urban (0.4 km) and orchard (1.0 km) grids. Each row shows predicted number of flies caught for a given distance interval (km) for each distribution. χ^2 estimates are shown in parentheses. Bold shows best fitting distribution.

Distance group	Observed	Predicted Number (Deviance)				
		Cauchy	Power	Exponential	Normal	Shifted Normal
Urban Grid (0.4 km)						
[0.0,0.4)	174	221.3 (10.1)	251.2 (23.7)	157.2 (1.8)	118.7 (25.8)	105.3 (44.8)
[0.4,0.8)	54	43.7 (2.4)	27.9 (24.4)	78.5 (7.6)	93.5 (16.7)	97.1 (19.2)
[0.8,1.2)	44	16.0 (49.3)	10.7 (103.1)	39.2 (0.6)	58.1 (3.4)	68.2 (8.6)
[1.2,1.6)	24	8.2 (30.8)	5.7 (59.0)	19.6 (1.0)	28.4 (0.7)	31.9 (2.0)
[1.6,2.0)	10	4.9 (5.2)	3.5 (11.9)	9.8 (0.0)	11.0 (0.1)	9.5 (0.0)
[2.0,2.4)	3	3.3 (0.0)	2.4 (0.2)	4.9 (0.7)	3.3 (0.0)	1.8 (0.9)
[2.4,2.8]	5	2.4 (2.9)	1.7 (6.2)	2.4 (2.7)	0.8 (22.1)	0.2 (112.5)
[2.8,Inf)	0	7.1 (7.1)	11.2 (11.2)	2.4 (2.4)	0.2 (0.2)	0.0 (0.0)
Cumulative χ^2		(107.9)	(239.7)	(16.9)	(69.0)	(187.9)
Orchard Grid (1.0 km)						
[0,1)	144	175.7 (5.7)	182.7 (8.2)	152.8 (0.5)	123.2 (3.5)	119.7 (4.9)
[1,2)	32	12.5 (30.4)	8.7 (62.4)	36.7 (0.6)	61.0 (13.8)	65.1 (16.9)
[2,3)	13	4.2 (18.1)	3.1 (31.8)	8.8 (2.0)	14.9 (0.2)	14.9 (0.2)
[3,4]	12	2.1 (45.9)	1.6 (68.6)	2.1 (46.4)	1.8 (58.1)	1.2 (96.4)
[4,Inf)	0	3.2 (3.2)	5.0 (5.0)	0.7 (0.7)	0.1 (0.1)	0.0 (0.0)
Cumulativeχ^2		(103.3)	(176.1)	(50.2)	(75.7)	(118.4)

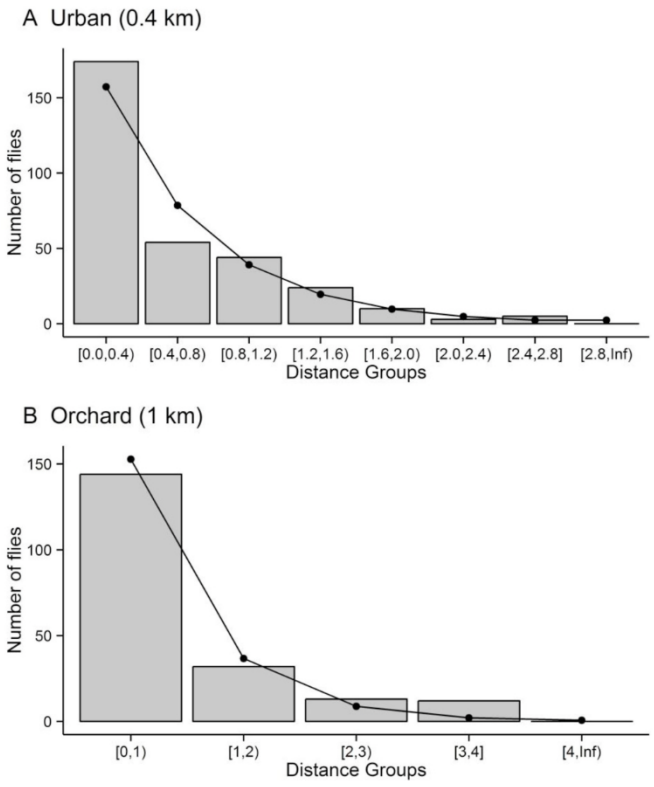


Fig. 4. Observed trapping rates compared to the predicted rates from the exponential distribution. Top plot shows urban trapping grid and the bottom plot is the orchard trapping grid. Bars show the actual trapping data and black line indicates predicted rate from the exponential distribution.

Table 3
Estimated quarantine distances based on outbreaks of different sizes. For varying outbreak sizes, we estimated the quarantine distance required such that only 1% and 0.1% of the outbreaks have one or more flies (and two or more flies) disperse past the quarantine distance.

Outbreak Size	Levels of Protection (km)			
	0.01 (1%)		0.001 (0.1%)	
	≥1 flies	≥2 flies	≥1 flies	≥2 flies
20	4.7	3.1	6.2	3.8
40	5.2	3.5	6.6	4.2
60	5.4	3.7	6.9	4.5
80	5.6	3.9	7.1	4.7
100	5.8	4.1	7.2	4.8
120	5.9	4.2	7.3	4.9

conditions, spraying methods for managing Qfly outbreaks, habitat structure) may be responsible for these differences.

4.3. Individual-level analysis

Exponential and normal distributions have been commonly used to describe animal movement in ecology, although some studies found that animal movements may be better described using distribution with 'fatter' tails (Viswanathan and Afanasyevt, 1996; Chapman et al., 2007; Meats and Edgerton, 2008). We found that the exponential distribution fitted the data better than other distributions for both grid types.

In a comparable analysis, Meats and Edgerton (2008) fitted a Cauchy distribution to short range dispersal of both sexually immature and mature flies (laboratory reared), and long range dispersal across multiple research studies. The Cauchy distribution fitted their trapping data well, though no comparison to the exponential was performed. The main difference between the Cauchy and the exponential is the fatness of the tail, and this is seen by the extreme large suspension estimate for the Cauchy (4244 km for probit 9). The Cauchy distribution arises when an animal moves with a mix of short and long trajectories.

Little is known about how individual flies move through their environment, though most flights are assumed to be short (reviewed in Dominiak, 2012). However, it would not be surprising due to environmental (e.g. wind storm) and/or human factors (e.g. vehicular transport), occasionally Qfly is transported a long distance in infested fruit. Some of these aspects are known. Regarding wind, Dominiak et al. (2003a), Dominiak et al. (2013), and Worsley et al. (2008) could not demonstrate any influence of wind on fruit fly distribution; however, additional research is needed to be more confident in this aspect. Regarding human transport, Dominiak et al. (1998) demonstrated that 18% of unregulated vehicle movements carried fruit. Community awareness and spot fines reduced fruit carriage to 5.4% (Dominiak and Coombes, 2009). However, there have been no studies on the accidental transport of wild flies. We cannot include or exclude any of these factors. If so, then it may be that fly movements actually follow more of a normal or exponential distribution (skinnier tail distribution), but these accidental transport modes result in a Cauchy-like distribution.

4.4. Quality of estimates

There are several caveats in using natural Qfly outbreaks. First, it is possible to misdiagnose a trapped fly as belonging to an outbreak when it was actually a separate incursion. The majority of Qfly outbreaks in the inland NSW towns were assumed to be caused by the introduction of infested fruit consignments. It is very possible that these infested fruit consignments may be divided, resulting in multiple infestations. Analysis of fruit carriage by the travelling public has demonstrated that families (the second highest carriage group) travel more frequently during school holidays and these periods are more likely to result in multiple incursions (Dominiak and Coombes, 2009).

Another important caveat was the sparseness of the trapping grids at further distances. Around epicentres, trapping locations were usually well populated. However, after a few kilometres, trapping locations often become sparse, occurring in distinct clumps. Therefore, we could be missing the majority of long-distance dispersers, although these may self-extinguish for lack of hosts, shelter and nutrition. The sparseness of the trapping grid would lead to underestimation of suspension distances. On the other hand, the opposite result could also be true. Trapping grids were mostly placed in town locations. If long distance Qfly movements were mainly due to human transport, we may be actually transporting Qfly directly from one trapping grid to another. Therefore, the surrounding environment may actually be at a much lower risk than the trapping evidence suggests. There are more humans per square kilometre in urban areas compared to horticultural production areas. Therefore, it is more likely that incursions will occur where more humans live, i.e. in urban areas.

Based on Table 3, there is little support for the 15 km rule, and there was even less support for the 30 km rule for large outbreaks. There appears to be no reasoning for the 30 km rule other than it was twice 15 km. In Table 3 for different outbreak size, an increase from 20 flies to 100 flies does not result in a five times increase in the dispersal distance. So how should a larger outbreak be handled? Whatever way is decided, doubling the suspension zone has no scientific support. Also, Table 3 highlights another aspect. If we examine the 20 fly outbreak at 0.001 level of protection, the data indicate that one fly might reach the 6.2 km distance. However, two flies (male and female) are needed for a mating, and we see that two flies might reach 3.8 km. However, if events were completely random, then these two flies would be distributed in the circumstance of a 3.8 km radius circle. This circumference was estimated to be nearly 24 km. If everything was random, then these two flies would be about 12 km apart (on opposite sides on the circumference) at mating time. Not surprisingly, flies near the epicentre would be closer.

Therefore, while we put forward the one and two fly calculation in Table 3, we ponder if this has any merit based on the mean and maximum dispersal distance, other than to demonstrate the lack of support for doubling the suspension distance.

4.5. The elephant in the room – levels of protection and surveillance efficiency

The major issue in our paper is the appropriate level of protection. There is an apparent absence of scientific peer reviewed papers of surveillance and levels of protection. We have been obligated to provide a range of protection levels at every step. One pressing need for the future is a consensus of surveillance and appropriate risk levels. Preferably, we need to establish the standard method to calculate the risk based on factors such as pest biology (dispersal) and efficiency of surveillance traps.

One approach for this is the statistical calculations (probit 9, etc), assuming the probit method is deemed appropriate. Another method is the more practical approach in Table 4. If countries (such as Australia) can demonstrate the dispersal distances of particular species (such as Qfly), and it is accepted that dispersal is based on area (not radius), then a simple level of protection could be applied based on area. Given that the calculation of mean dispersal is probably more reliable than the maximum dispersal distance, then a level of protection could be applied to mean dispersal distance such that it encompasses the maximum dispersal distance. This recognises that while a small number may disperse longer distances, these are invariable over dispersed, as demonstrated in the circumference example. Alternatively, the suspension zone could be based on a smaller multiplier of the area subjected to bait spray, knowing that the over-dispersed flies are further punished by the spray program. From Table 4, four times the baited area (7.1 sq km) would result in a suspension zone of 28.4 sq km, or a suspension distance of about 3 km.

The rationale for the current 15 km suspension distance is not explicitly clear nor statistically-based. Though our study has limitations, we provided a formal analysis that allows for a systematic evaluation of the suspension distance.

4.6. Practical implications

The practical implications of the choice of suspension distance is provided in Table 4. The mean and maximum dispersal are calculated from the data as described above. A breeding population must lie somewhere in between these two distances. There are no clear data to estimate the area occupied by a breeding population, so for simplicity to get one sq km, we estimate that the breeding population exists at 0.57 km from the epicentre. We actually think it is closer to the mean than the maximum however for the current paper, we postulate that the breeding population covers an area of one sq km. If this is so, the area requiring bait spray in seven times larger than the breeding population and the current suspension zone is 707 times larger than the proposed breeding area.

4.7. Recommendations

There are few definitive conclusions in our study. Accidental long distance transport of Qfly results in a Cauchy-like distribution. However, all other analyses indicate that the current 15 km suspension distance is excessive for natural dispersal. Additionally, there are no data to support a 10 km suspension distance. While there is support that suspension zones should be shorter than 10 or 15 km, the recommended suspension zone varied depending on the ALOP. Also, we recommend that the exponential distribution is used, however other countries or jurisdictions may choose a different distribution.

Many surveillance experts claim that probit 9 is inappropriate because it is a response dose statistic that is not readily adaptable to surveillance approaches. However, if the probit 9 standard or its equivalent is adopted using exponential distribution, then the rural/urban combined data result in a suspension distance of 6.5 km. Another option is to claim a different suspension distances for orchard (7.3 km) and urban (6.0 km) areas. These are likely to be the worst case scenario.

If probit 8.7 is chosen, then we predict that 5.8 km for the combined data or 6.5 km or 5.3 km for orchard and urban areas respectively. If the Meats et al. (2003) standard of probit 8.1 is used, then the distances become 4.3, 4.8 and 4.0 for each of these areas.

However, these suspension distances predict an ALOP for a single fly. Is this appropriate? Single flies are not reproductive - it takes a male and a female to become reproductive. Mated females stay near fruiting trees and therefore mated females are unlikely to travel these distances. However, even the two fly calculation is questionable as we demonstrated by the circumference example.

Table 4
The estimated areas requiring disinfestation for fruit fly sensitive markets based on different suspension distances.

Suspension radius (km)	Suspension area (sq km)	Characteristics
0.2	0.13	Mean dispersal
0.57	1.0	Possible breeding area
0.73	1.5	Maximum dispersal
1.5	7.1	Bait spraying in Anon. (1997)
3.0	28	
4.0	50.3	Proposed new suspension
5.0	78.6	
7.2	162.9	USA standard
7.5	176.8	Half the current Australian standard (Anon. 1997)
15	707	Current Australian standard (Anon. 1997)
30	2828	Current Australian standard for large outbreaks (Anon. 1997)
80	20,114	Quarantine distance before 1996

Author contribution

Both authors were involved in the original idea and manuscript construction. Bernie Dominiak accessed the data and Ben Fanson conducted the analysis. Fine tuning of final theories and presentation was conducted by both authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Inspectors who cleared the traps using the bar code readers to record information and sent samples for identification are gratefully acknowledged. The identification staff at Orange Agricultural Institute who identified wild and sterile flies greatly contributed to the program. Staff who maintained the NSW DPI PestMon database and the ICT links are gratefully acknowledged. Dr Pat Barkley made useful comments on an early version of this paper. This research was funded by the NSW Department of Primary Industries.

References

Anonymous, 1997. Code of Practice for the Management of Queensland Fruit Fly. In: Standing Committee on Agriculture and Resource Management. Canberra, Australia.
Bateman, M.A., 1972. The ecology of fruit flies. Annu. Rev. Entomol. 17, 493–518.
Bateman, M.A., 1991. The Impact of Fruit Flies on Australian Horticulture, vol. 3. Horticultural Policy Council Report, Canberra, (. Australia).

Benhamou, S., 2007. How many animals really do the Levy walk? Ecology 88, 1962–1969.
Bliss, C.I., 1934. The method of probits. Science 79, 38–39.
Cannon, R., 1998. Sampling to comply with a maximum pest limit. Biometrics 847–858.
Chapman, D.S., Dytham, C., Oxford, G.S., 2007. Modelling population redistribution in a leaf beetle: an evaluation of alternative dispersal functions. J. Anim. Ecol. 76, 36–44.
Clarke, A.R., Dominiak, B.C., 2010. Positive correlation of male and female *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae) catches in orange-ammonia traps. Gen. Appl. Entomol. 39, 9–13.
Clauset, A., Shalizi, C.R., Newman, M.E., 2009. Power-law distributions in empirical data. SIAM Rev. 51, 661–703.
Dominiak, B., Coombes, N., 2009. Fruit carrying characteristics of travellers into a quarantine zone in New South Wales in 1999/2000. Plant Protect. Q. 24.
Dominiak, B., Rafferty, T., Barchia, I., 1998. An analysis of travellers carrying fruit near Griffith, NSW, during Easter 1996 to assess the risk of Queensland fruit fly (Bactrocera tryoni Froggatt). Gen. Appl. Entomol. 28, 13–19.
Dominiak, B., Gillespie, P., Tom, G., 2007. Changes in data management and the impediments to change-a case study for fruit fly surveillance. Plant Protect. Q. 22, 95.
Dominiak, B.C., 2012. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Ann. Entomol. Soc. Am. 105, 434–446.
Dominiak, B.C., Webster, A., 1998. Sand bed release of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) at Young, NSW. Gen. Appl. Entomol. 28, 9–11.
Dominiak, B.C., Daniels, D., 2012. Review of the past and present distribution of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) and Queensland fruit fly (*Bactrocera tryoni* Froggatt) in Australia. Aust. J. Entomol. 51, 104–115.
Dominiak, B.C., Mapson, R., 2017. Revised distribution of Bactrocera tryoni in eastern Australia and effect on possible incursions of mediterranean fruit fly: development of Australia's eastern trading block. J. Econ. Entomol. 110, 2459–2465.
Dominiak, B.C., Westcott, A., Barchia, I., 2003a. Release of sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), at Sydney, Australia. Aust. J. Exp. Agric. 43, 519–528.
Dominiak, B.C., McLeod, L., Landon, R., 2003b. Further development of a low-cost release method for sterile Queensland fruit fly *Bactrocera tryoni* (Froggatt) in rural New South Wales. Aust. J. Exp. Agric. 43, 407–417.
Dominiak, B.C., Daniels, D., Mapson, R., 2011. Review of the outbreak threshold for Queensland fruit fly ('Bactrocera tryoni'Froggatt). Plant Protect. Q. 26, 141.
Dominiak, B.C., Worsley, P.M., Nicol, H., 2013. Release from a point source and dispersal of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt))(Diptera: Tephritidae) at Wagga Wagga. Plant Protect. Q. 28, 120.
Dominiak, B.C., Gilmour, A., Kerruish, B., Whitehead, D., 2003c. Detecting low populations of Queensland fruit fly, *Bactrocera tryoni* (Froggatt) with McPhail and Lynfield traps. Gen. Appl. Entomol. 32, 49–53.
Edge, V., Gardner, R., Green, A., Cook, K., Cornish, J., 2001. In: Technical Review of the Tri-state Strategy for Queensland Fruit Fly, p. 62. R. t. S. C. o. A. a. R. Management.
Fletcher, B.S., 1974. The ecology of a natural population of the Queensland fruit fly, *Dacus tryoni* V. The dispersal of adults. Aust. J. Zool. 22, 189–202.
Gilchrist, A.S., Meats, A.W., 2012. Factors affecting the dispersal of large-scale releases of the Queensland fruit fly, Bactrocera tryoni. J. Appl. Entomol. 136, 252–262.
Gilchrist, A.S., Sved, J.A., Meats, A., 2004. Genetic relations between outbreaks of the Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), in Adelaide in 2000 and 2002. Aust. J. Entomol. 43, 157–163.
Imielska, A., 2011. Seasonal climate summary southern hemisphere (summer 2010-2011): second-wettest Australian summer on record and one of the strongest La Niña events on record. Australian Meteorological and Oceanographic Journal 61, 241.
Kokko, H., López-Sepulcre, A., 2006. From individual dispersal to species ranges: perspectives for a changing world. Science 313, 789–791.
Krishnamoorthy, K., 2010. Handbook of Statistical Distributions with Applications. Taylor & Francis.
Krosch, M.N., Schutze, M.K., Armstrong, K.F., Graham, G.C., Yeates, D.K., Clarke, A.R., 2012. A molecular phylogeny for the Tribe Dacini (Diptera: Tephritidae): systematic and biogeographic implications. Mol. Phylogenet. Evol. 64, 513–523.
Macfarlane, J., East, R., Drew, R., Betlinski, G., 1987. Dispersal of irradiated Queensland fruit-flies, dacus-tryoni (Froggatt) (Diptera, Tephritidae), in southeastern Australia. Aust. J. Zool. 35, 275–281.
Malacrida, A., Gomulski, L., Bonizzoni, M., Bertin, S., Gasperi, G., Guglielmino, C., 2007. Globalization and fruitfly invasion and expansion: the medfly paradigm. Genetica 131, 1–9.
Meats, A., Clift, A., 2005. Zero catch criteria for declaring eradication of tephritid fruit flies: the probabilities. Anim. Prod. Sci. 45, 1335–1340.
Meats, A., Clift, A., Robson, M., 2003. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Anim. Prod. Sci. 43, 397–406.
Meats, A.W., Edgerton, J.E., 2008. Short- and long-distance dispersal of Queensland fruit fly, *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Agric. 48, 1237–1245.
Meats, A.W., Smallridge, C.J., Dominiak, B.C., 2006. Dispersion theory and the sterile insect technique: application to two species of fruit fly. Entomol. Exp. Appl. 119, 247–254.
National Climate Centre, 2012. Special Climate Statement 38: Australia's Wettest Two-Year Period on Record; 2010–2011. Australia's National Meteorological Service. Bureau of Meteorology.
Perez-Staples, D., Prabhu, V., Taylor, P.W., 2007. Post-teneral protein feeding enhances sexual performance of Queensland fruit flies. Physiol. Entomol. 32, 225–232.
Plant Health Australia, 2009. The National Plant Health Status Report 08/09. Plant Health Australia, Canberra (ACT, Australia).
RAP Pub, 2004/23. Rregional Standards for Phytosanitary Measures. RAP publication.
Reynolds, O.L., Smallridge, C.J., Cockington, V.G., Penrose, L.D., 2012. The effect of release method and trial site on recapture rates of adult sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. vol. 51, 116–126.
Sutherst, R.W., Yonow, T., 1998. The geographical distribution of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*, in relation to climate. Aust. J. Agric. Res. 49, 935–954.
Viswanathan, G., Afanasyevt, V., 1996. Lévy flight search patterns of wandering albatrosses. Nature 381, 30.
Weldon, C.W., 2007. Influence of male aggregation size on female visitation in *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 46, 29–34.
Weldon, C.W., Meats, A., 2007. Short-range dispersal of recently emerged males and females of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) monitored by sticky sphere traps baited with protein and Lynfield traps baited with cue-lure. Aust. J. Entomol. 46, 160–166.
Worsley, P.M., Dominiak, B.C., Gilmour, A.R., James, D.G., 2008. Pilot study at Cowra of intra-town dynamics of Queensland Fruit Fly (*Bactrocera tryoni* (Froggatt)) populations based on trap catch data. Plant Protect. Q. 23, 86–89.

Crop Protection 164 (2023) 106121

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Predicting point-source invasion success in the Queensland fruit fly (*Bactrocera tryoni*): An individual-based modelling approach

Bernard C. Dominiak [a,*], Benjamin G. Fanson [b]

[a] New South Wales Department of Primary Industries, Ian Armstrong Building, 105 Prince Street, Orange, NSW, 2800, Australia
[b] School of Life and Environmental Sciences, Deakin University, Geelong, VIC, 3216, Australia

ARTICLE INFO

Keywords:
IBM
Incipient populations
Pest management
Market access
Phytosanitary standards

ABSTRACT

Fruit flies are a major pest worldwide for fruit producing industries. Incursions into fly free areas usually occurs via infested fruit; however, little is reported about the size of a propagule to start a new establishment. Propagule pressure is an important predictor of the probability that an invasive species will establish a breeding population. Recently, individual-based model (IBM) became a valuable modelling tool for exploring invasive species. Here, we developed a spatially-explicit individual-based model (IBM) specifically parameterized for the Queensland fruit fly (Qfly) (*Bactrocera tryoni* Froggatt), a major horticultural pest species in Australia and a major quarantine concern worldwide. Usually, new establishments or incursions originate from the introduction of infested fruit and larvae must progress through several stages to become sexually mature adults. For a Qfly incursion to establish a breeding population, flies must avoid predators and survive long enough to become reproductively mature, find a mate, and find ripening fruit. Additionally, their offspring must survive and successfully reproduce. The IBM model simulated release of a fixed number of flies into a heterogeneous environment of varying suitability. We conducted simulations to delineate the contributions of demographic stochasticity and Allee effects (finding a mate in a spatial environment) on establishment probability. Our model delineated several key influential factors, especially tree density, extrinsic mortality and mating range. We performed sensitivity analyses to identity which biological and ecological mechanisms strongly affect establishment probability. Integrating the model's findings with information on transport of infested fruit helps explain why Qfly incursions are common, but yet most fail to establish. Our model predicted that circa 16 and 50 flies were required for a 50% and 99% chance of establishment respectively. Additionally, our model predicted the mating distance for Qfly was 16.1 m. The mean daily dispersal distance was 30 m. We discuss how this knowledge might be used to better manage Qfly by alterations in surveillance and male annihilation technique.

1. Introduction

The increase in global trade has resulted in many more opportunities for pests to be transported beyond their natural ranges (Bebber et al., 2014). The inadvertent translocation of pest species is a major threat to biological diversity and agricultural industries (Schmitz and Simberloff, 1997). Consequently, the process of biological invasions has become an increasingly studied area, expanding beyond descriptive studies to identifying mechanistic processes underlying invasions (Britton and Gozlan, 2013; Keitt et al., 2001; Kolar and Lodge, 2001; Memmott et al., 2005; Schmitz and Simberloff, 1997: Yonow et al., 2004). It may become possible to better predict invasion success, resulting in better pest management practices by delineating these biological processes (Lockwood et al., 2005).

A significant barrier to a biological invasion is the establishment of a reproducing population in a novel environment. Most species introductions fail to establish (Kolar and Lodge, 2001; Williamson et al., 1986), with many abiotic (e.g. environmental suitability) and biotic factors (e.g. species life history strategies) having been identified for affecting establishment probability for a species (Gozlan et al., 2010; Kolar and Lodge, 2001; Williamson et al., 1986). One of the most consistent predictors of invasion success is propagule pressure, which is a function of the total number of individuals ("propagule size") and the frequency of introductions ("propagule number") (Lockwood et al., 2009). Often, species with higher propagule pressures have increased invasion success (Lockwood et al., 2009).

* Corresponding author.
E-mail address: bernie.dominiak@dpi.nsw.gov.au (B.C. Dominiak).

https://doi.org/10.1016/j.cropro.2022.106121
Received 13 July 2022; Received in revised form 3 October 2022; Accepted 6 October 2022
Available online 22 October 2022
0261-2194/Crown Copyright © 2022 Published by Elsevier Ltd. All rights reserved.

The link between propagule number (frequency of introductions) and population success is intuitively straightforward; the more invasions attempts or larger invasions attempts both result in the higher the probability that at least one will be successful. From a management perspective, the best practice for dealing with propagule number is to decrease the frequency of propagule attempts but it is more difficult to alter the propagule size (larvae per consignment) which is frequently government by climate or host (Follett et al., 2021). However, the efficacy of this practice depends on the success probability for each propagule. The probability of invasion success is dependent on propagule size. Therefore, it is essential to understand the relationship between propagule size and invasion success (Britton and Gozlan, 2013; Gertzen et al., 2011; Leung et al., 2004; Memmott et al., 2005; Yonow et al., 2004).

Small populations are especially susceptible to demographic stochasticity (e.g. uneven sex ratios), environmental stochasticity (e.g. extreme climatic conditions), inbreeding depression, and Allee effects (any process leading to reduction in fitness at low population densities) (Boukal and Berec, 2002; Kolar and Lodge, 2001; Leung et al., 2004; Lux, 2014, 2018; Snyder, 2003; Stephens and Sutherland, 1999) and these factors can lead to population extinction. Consequently, the relationship between propagule size and probability of establishment often follows a dose-response-like curve (Britton and Gozlan, 2013; Gertzen et al., 2011; Memmott et al., 2005; Shea and Possingham, 2000). The identification of the shape of these curves can allow for informed management practices to minimise propagule pressure (Lockwood et al., 2005). However, quantification of dose-response curves is rare, particularly for highly invasive species in which logistical constraints often limit empirical studies (Brodland, 2015; Lewis et al., 2016). Consequently, the use of theoretical models parameterized for specific species can provide initial guidance for management decisions and allow for focused experiments.

Much of the current Australian management approaches are based on practices from the 1990's. Issues such as natural dispersal distances were recently re-examined and results have indicated shorter dispersal distances than previously assumed (Dominiak, 2012; Dominiak and Fanson, 2020). However, shorter quarantine distances have not been widely adopted. The recognition of shorter dispersal distances is becoming increasingly important as Australia moves away from large regional government sponsored fruit fly free areas. Increasingly, the "Systems Approach" for market access is being embraced (Dominiak, 2019; Jang, 2016; van Klinken et al., 2020), however the success of this approach is largely dependent on the recognition of shorter dispersal distances. The Systems Approach places the management of fruit flies clearly back with the producer, allowing them to choose fruit fly control strategies that suit their enterprise. However, surveillance protocols and the use of male annihilation technique (MAT) (as an exclusion technique on property boundaries) remain largely based on the knowledge from the 1990's, despite growing recognition of shorter dispersal distances (Meats et al., 2003; Meats and Leighton, 2004; Dominiak, 2012; Dominiak and Fanson, 2020; Caton et al., 2021).

Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) (Qfly) is the major Tephritid fruit fly pest in Australian horticulture, attacking most fruit and many vegetable crops (e.g., bananas, citrus, coffee, tomato pome fruit, stone fruit) (Clarke et al., 2011; Dominiak and Mapson, 2017; Hancock et al., 2000; Yonow and Sutherst, 1998). Generally, it is understood that Qfly incursions into Pest Free Areas (PFA) in Australia are most often the result of illegal transportation into, and the inappropriate disposal of infested host material within PFAs (Bateman, 1991; Dominiak et al., 2000; Dominiak and Coombes, 2009). Therefore, most new detections of Qfly are principally caused by entries of small parcels of relatively few immature fruit flies, and most fail to establish breeding populations. Previous research has found that 71% (Meats et al., 2003) to 90.1% (Dominiak and Fanson, 2020) of detected incursions self-extinguish without any interventions. However, these estimates represent lower bounds as some incursions likely self-extinguish before any flies are caught in traps and not all detected incursions lead to successfully breeding populations. Here, we utilize a spatially explicit individual-based model (IBM) to simulate incursions of the Qfly in PFAs. Recently, IBM was shown to be very useful to modelling pest dynamics across spatial scales (see Crespo-Perez et al., 2011; Lux, 2014; Lux, 2018).

Little empirical information exists about the initial founding population sizes for most Qfly detections. Similarly, almost nothing is known about which ecological and biological factors for Qfly might affect incursion success. For a Qfly incursion to produce a breeding population, larvae from infested fruit must successfully pupate, find suitable pupal habitat, and successfully eclose. Then the immature adults must disperse into the environment, find food (essential for reproductive maturation in Qfly) (Fanson and Taylor, 2012; Meats and Leighton, 2004; Perez--Staples et al., 2007; Prabhu et al., 2008) and water, avoid predators for about 2 weeks at which point the females become sexually mature (Taylor et al., 2013). Then, male and female flies must be within proximity to successfully mate during a 30min window during dusk (Tychsen, 1978). Because of all these steps, it is thought that the chances of a sexually mature male and female Qfly occurring in the same tree or group of trees is extremely low in pest free areas (Bateman, 1977; Fletcher, 1974; Meats, 1998; Weldon, 2007).

It has been hypothesized that the low establishment probability for Qfly is mainly due to the difficulty of finding a mate (i.e. an Allee effect) in a spatial environment (Bateman, 1977; Dominiak, 2012; Meats, 1998). We develop a spatially explicit IBM that has been parameterized for Qfly to provide a working framework. With this model, we ask the following questions: 1) what is the relationship between establishment probability and propagule size under just demographic stochasticity, under just Allee effects, or both; and 2) which ecological and biological factors most affect the relationship between population size and successful incursion? This knowledge can be used for making more informed management decisions.

2. Methods

2.1. Model description

The model is a spatially-explicit, individual-based model implemented in NetLogo v5.1.0 (Wilensky, 1999; freely downloadable from https://ccl.northwestern.edu/netlogo/). The model's code is available in the electronic supplementary material. Below, we follow the ODD (overview, design concepts and details) protocol for describing agent-based models recommended by Grimm et al. (2020).

Purpose - The purpose of this model is to explore the ecological and biological factors that influence the probability that a point-source invasion results in the establishment of a breeding population of Qfly.

State variables and scales – The principal agents in the model are flies, which are characterized by age (days), sex (male/female), and mating status (unmated/mated). The flies inhabit a 400 × 400 square grid (based on smallest trapping array for surveillance), in which each square ('patch'; 5 m × 5 m) represents either bare ground, non-fruiting tree, or a fruiting tree (Fig. 1). Each patch had a certain probability of being a tree, and if a tree, another probability of being a fruiting tree (Fig. 2). Each fruiting tree had the potential to be repeatedly infested and it could contain larva of different ages, not necessarily in the one piece of fruit. One time step in the model corresponds to one day and there are eight substeps in each day.

Process overview and scheduling – During every time step, a series of actions occur. First, trees with infested fruit are updated in which every larva ages one day. For larva reaching adulthood during the time step, they emerge as adult flies with a certain probability (see Table 1 for parameterization). After updating each patch, the model has each fly conduct a series of behaviours. First, each fly disperses to a new tree or remains in current tree based on a dispersal probability. This dispersal probability can differ between fruiting and non-fruiting trees. If a fly

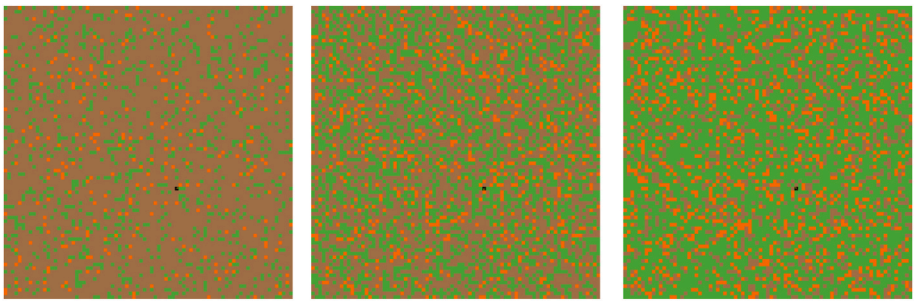


Fig. 1. Schematic of landscapes used in the models. Brown is non-tree patch. Green is a non-fruiting tree and orange is a fruiting tree. Landscapes left to right have increasing probability of trees of 0.1, 0.5, 0.8. Black dot is the origin of a point incursion. All landscapes have 0.2 chance of any given tree fruiting. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

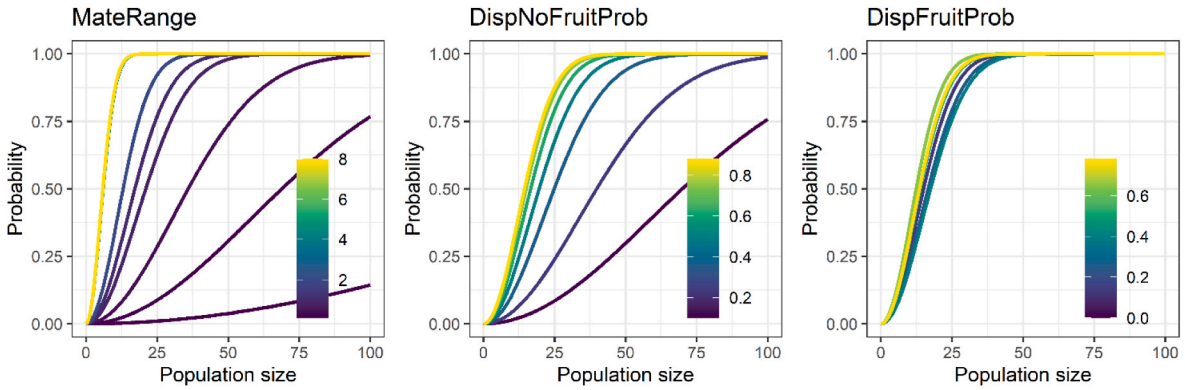


Fig. 2. Effects of mate range, dispersal probability on non-fruit trees and on fruit trees. For each plot, curves represent relationship between initial population size and establishment probability for varying levels of the parameter. Colour bar indicates parameter values. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

disperses, it moves through the landscape with a specified correlated movement (Fig. S1) until it hits another tree (including returning to the original tree), if it survives. Each movement is associated with a mortality risk. Second, if the fly is a mated female and inhabits a fruiting tree, she will lay eggs in a fruit. Then every fly again has a chance to disperse. This dispersal/movement sequence repeats 8 times per day, giving each fly multiple chances to move in a single day. Flight movements appear relatively rare in Qfly, spending ~0.6% of their time flying (Weldon et al., 2010) but multiple movements in a day are likely. At the last time step (the eighth step in any one day), the mating routine occurs (matching dusk mating in Qfly). In this routine, every female that is not mated and is sexually mature (e.g. age >10 days) has the opportunity to mate. If there is a mature male within a specified distance (within same patch), then the female becomes mated and can lay fertilized eggs for remaining lifespan. The model assumes that a male can only mate with one female in a given night given the short 30 min mating period (Tychsen, 1978). Mated females are able to lay eggs the following day. Finally, each surviving fly ages one day and the cycle repeats. The simulation ended if the population went extinct or if the point-source invasion was successful which was defined as a persistent population for 200 days or reaching 1000 individuals (>99.99% of populations of this size persistent for another 200 days).

Design concepts – Successful point-source invasions of Qfly must overcome several obstacles: survival to sexual maturity, finding a sexually mature mate, finding fruit and depositing of eggs in a mature fruit, and the larvae surviving to adulthood. Stochasticity is inserted into the model in regard to landscape structure (e.g. each simulation has unique landscape), sex ratio of initial population and offspring (e.g. binomial distribution), fly movement patterns and survival probabilities (Bernoulli distributions) of both larval flies and adult flies. We explore the parameter space of the model assessing the model's sensitivity to each parameter.

Initialization – Initial founding population of flies were placed in the middle of landscape on a patch with the patch type (soil, fruit tree, non-fruiting tree) randomly. All flies are new adults (age = 0) and the sex is randomly determined (Binomial (0.5,N)). Parameters were initialized as described in Table 1. See 'Parameterization Rationale' in supplemental material.

2.2. Simulations and data analyses

Our main goal was to assess how biological and ecological characteristics affected the relationship between initial population size and probability of establishment. In particular, we were interested in the roles of demographic stochasticity, Allee effects, and the consequence of both processes. Towards this end, we ran three different simulation scenarios. First, we looked at only demographic stochasticity, then only Allee effects, and finally we combined both effects in a single model.

For each simulation scenario, we conducted a sensitivity analysis in which we systematically changed initial population size and one of the other parameters across the possible parameter ranges (Table 1) for 1000 simulations. Sensitivities are ratio of maximum a to minimum a, which were estimated from the dose-response curve fitted to the model results. For Allee and Demographic simulations, not all parameters were relevant to the simulation (see methods). Ranges for each parameter are listed in Table 1. For each simulation, we recorded if the population went extinct. For each parameter, we fitted the following probability of establishment described in (Leung et al., 2004):

$$P = P_{max}(1 - \exp(-a * N^c))$$

where P is the probability a population becomes established. N is the founding population size and a affects how quickly P increases with N.

Table 1
List of parameters used in the model including their initialization value. Initialization values were estimates from the literature, where possible. See 'Parameterization Rationale' in supplemental material. Type is whether the parameter is related to demographics or spatial attributes. Range values were represent extreme values for each parameter.

Category	Parameter	Short Name	Type	Qfly Value	Range	Description
Fly Invasion	Initial Population Size	PopSize			1–100	Number of founding flies.
Fly Mortality	Dispersal Mortality Rates	DisperseMort	Spatial and Demographic	0.009	0–0.032	The probability that a fly dies during a movement from one patch to another
	Non Dispersal Mortality Rates	NoDispMort	Demographic	0.009	0–0.032	The probability that a fly dies just staying in the same tree
	Offspring Mortality	OffspringMort	Demographic	0.4	0.2–0.6	The probability any given larva dies before adulthood.
Fly Dispersal	Probability of Dispersal When No Fruit	DispNoFruitProb	Spatial	0.7	0.1–1.0	The probability of dispersing on tree with no fruit
	Probability of Dispersal When With Fruit	DispFruitProb	Spatial	0.2	0–0.9	The probability of dispersing from a tree with fruit
	Correlatedness Of Movement	DispCorr	Spatial	0.5	0–1	The degree of correlatedness of subsequent movements (only within a dispersal event). 0 is Brownian and 1 is perfectly correlated
Fly Reproduction	Mate Calling Range	MateRange	Spatial	1	0.5–40	Distance (m) in which males can be detected by females during the mating period
	Number of Eggs Laid	EggNumber	Demographic	1	1–7	The number of eggs laid by a mated female during ovipositing event
	Probability Of Laying Eggs	EggProb	Demographic	1.0	0.2–1.0	The probability that a mated female lays eggs if in a fruiting tree
	Length Of Juvenile Period	JuvLength	Demographic	24	14–30	Number of days from egg to adult emergence
	Age Of Sexual Maturity	MateAge	Demographic	9	2–16	Number of days post-enclosion in which a fly sexually matures and will mate
Landscape	Probability of a patch having a tree	TreeProb	Spatial	0.4	0.1–1.0	The probability any given patch has a tree
	Probability that a tree is fruiting	FruitProb	Spatial	0.2	0.1–1.0	Given that a patch has a tree, this is the probability that the tree is fruiting.

P_{max} is the highest establishment probability. Here, we set $P_{max} = 1$. Finally, c affects the effectiveness of N and often represents Allee effects (Leung et al., 2004). We estimated c and a parameters using nonlinear least square means (*nls()* function in R). All curves had a good fit, with $R^2 > 0.96$ for all curves.

2.3. Demographic stochastic simulations

Demographic stochasticity is inherent to all small populations. In our model, this stochasticity is implemented through associating binomial distributions to sex ratio, adult mortality, juvenile mortality, egg laying probability, and offspring sex ratio. To assess the effect of demographic stochasticity without other processes (e.g. Allee effects), we converted the above model into a nonspatial model; in other words, we assume that all flies are in one tree and cannot disperse. Again, a male can only mate with a single female during each night. We ran the sensitivity analysis with only the non-spatial parameters (i.e. we excluded TreeProb, FruitProb, MatingRange, etc.)

2.4. Allee effect simulations

Besides demographic stochasticity, Allee effects can lead to population extinction. Finding mating partners has been one of the most explored mechanisms for Allee effects and has been proposed as a major factor for Qfly invasions (Dominiak, 2012; Meats, 1998). To assess its impact on Qfly invasions, we re-ran the model removing all demographic stochasticity from the model. Thus, we set initial founding population size as even numbers in which sex ratio was 1:1 exactly (Clarke and Dominiak, 2010; Fanson et al., 2014). There was no daily mortality risk as either adult or larva, but adult flies died upon reaching 40 days post eclosion. Females laid eggs in pairs with sex ratio of 1:1. Therefore, the lack of a population establishment is solely due to males and females not finding each other within 40 days. We ran these simulations altering all parameters affecting spatial patterns.

2.5. Full model simulations

The full model included both demographic stochasticity and Allee effects. The sensitivity analysis was run with all parameters.

2.6. Dispersal patterns

Finally, we wanted to know if the dispersal patterns that emerged from the model were similar to empirical finding for released flies. Previous research has shown that trapping patterns for released Qfly can be roughly described by a Cauchy distribution (Meats and Edgerton, 2008). Therefore, we tested whether movement patterns had a similar shape as a Cauchy distribution. We conducted simulations in which flies do not reproduce and recorded the total accumulated number of flies in each patch for 35 days (trapping length in Meats and Edgerton (2008)). Each simulation had 1000 flies and was repeated 100 times. Then, we calculated average number of Qfly visiting each distance after 35 days. Finally, we fitted a Cauchy distribution to these averages by estimating the distribution parameters (location and scale) for the Cauchy using maximum likelihood.

3. Results

3.1. Demographic stochastic simulation

Using a nonspatial model parameterized for Qfly, we estimated the establishment probability in relation to population size for all parameters due solely to demographic stochasticity. For the default Qfly values (Table 1), a population size of 2.0, 3.0, and 5.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). Background mortality rates (NoDispMort) and mating age had the largest effects on

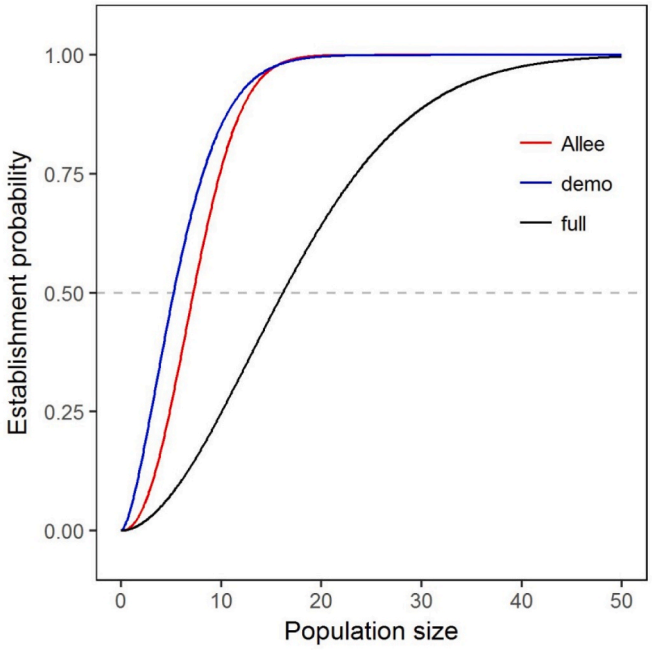


Fig. 3. Plot of the effect of population size on establishment success for each simulation scenario. Plot is the fitted model for the default parameters for Qfly (Table 1). Dashed line is 50% establishment rate.

the relationship between population size and establishment probability (Table 2; Fig. S2).

3.2. Allee effect simulations

Allee effects had slightly smaller effects than demographic stochasticity. For the default Qfly values (Table 1), a population size of 3.0, 4.9, and 7.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). As finding a mate is a key process for establishing a breeding population in this model, mating range had the largest effect (Table 2). Additionally and regarding landscape structure, the density of trees (TreeProb) had a large effect as tree density affects how far flies disperse, with low density of trees leading to further dispersal and hence lower establishment probability.

3.3. Full model simulations

Combining demographic stochasticity and Allee effects resulted in a sharp decrease in establishment probability, and we suggest a very strong interactive effect between the two processes (Fig. 3). For the default Qfly values (Table 1), a population size of 6.0, 10.2, and 16.2 was needed for 10%, 25%, and 50% establishment rate, respectively (Fig. 3). Incursions >50 had greater than a >0.99 probability of becoming established.

The parameters having the greatest effect on establishment probability were non-dispersal mortality risk, mate range, and mate age (Table 2). Mortality reduced the number of flies available for mating and thus made it harder to find mates. Also, increasing the mate range had a large effect on establishment probability, mitigating the Allee effect of mate finding (Table 2). Finally, we found that the time to reproductive maturation (MateAge) strongly affected establishment probability (increasing age decreased establishment probability), as increasing age not only increased number of flies that die before reproduction, but also how far flies disperse into the environment (Table 2).

3.4. Dispersal patterns

Dispersal patterns from the simulations showed that the dispersal pattern in the simulation data were roughly described by a Cauchy distribution (Fig. 4). A main difference between the Cauchy and the simulation data is that the Cauchy distribution has a long tail that reflects long distance dispersal events (e.g. assisted dispersal due to human vehicles, wind storms), which were absent in the simulation. The estimated location factor for the Cauchy distribution was 16.1 m. We estimated the mean daily dispersal was 30 m.

4. Discussion

The main components of biological invasions can be divided into transport/arrival, establishment, and dispersal/range expansion (Kolar and Lodge, 2001). Qfly are one of the better studied Tephritid fruit flies and some information is known about the long distance transport of Qfly (Dominiak and Barchia, 2005; Dominiak et al., 2000; Dominiak and Coombes, 2009) and subsequent dispersal/range expansion of Qfly (Dominiak et al., 2003, 2013; Meats and Edgerton, 2008; Meats et al., 2006; Weldon and Meats, 2010). However, little information is known about what factors affect establishment success. Since Qfly incursions involve small population sizes, there are likely many stochastic events affecting establishment. The model results were well-approximated by dose-response curves and showed that mortality rates, mating range, and landscape structure had the largest effects on the dose-response curve shape.

Table 2
List of ranges in estimated *a* and sensitivities (S) in relation to the probability of obtaining a breeding population for each simulation scenario. Range of *a* is min - max. Sensitivities are ratio of maximum *a* to minimum *a*, which were estimated from the dose-response curve fitted to the model results. For Allee and Demographic simulations, not all parameters were relevant to the simulation (see methods). Ranges for each parameter are listed in Table 1.

Parameter	Allee		Demographic		Full Model	
	a	S	*a*	S	S	S
NoDispMort	–	–	0.0042–5.518	1322	3e-04-5.518	16703
MateRange	0–0.1	295.9	–	–	0–0.02	1293
DispNoFruitProb	0.01–0.03	2.2	–	–	1e-04-0.003	23.5
MateAge	0.01–0.03	3	0.0074–0.089	12.2	7e-04-0.015	19.9
TreeProb	0.01–0.04	3.7	–	–	0.001–0.006	5.6
OffspringMort	–	–	0.0127–0.037	2.9	8e-04-0.004	4.8
EggProb	–	–	0.0152–0.026	1.7	7e-04-0.002	3.2
DispCorr	0.01–0.03	3.9	–	–	0.001–0.003	3.1
DisperseMort	–	–	–	–	0.0017–0.004	2.2
DispFruitProb	0.01–0.05	4.9	–	–	0.0023–0.004	2.0
FruitProb	0.01–0.03	2	–	–	0.0015–0.003	1.8
EggNumber	0.01–0.02	1.3	0.0175–0.032	1.8	0.0022–0.004	1.7
JuvLength	0.01–0.02	1.3	0.0174–0.033	1.9	0.002–0.003	1.6

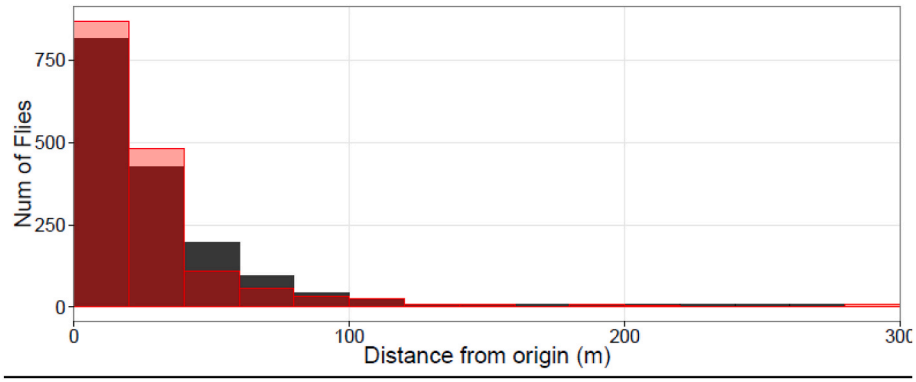


Fig. 4. Histogram of dispersal distances for default scenario. Red bars indicate predicted counts from Cauchy distribution. Black bars are simulation results. Note – The tail of the Cauchy is not shown since some values extend to greater than 100 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.1. Comparison to empirical curves

Our resulting relationship between initial population size and the probability of establishment was consistent with several experimental studies for other species. Our model predicted that ~20 individual Qfly leads to greater than 50% chance that the population will become established. The reverse aspects (of establishment) for eradication of Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) were studied by Manoukis and Collier (2021). However, our model predictions are based on our assumptions. For instance, the mortality rate was based on our assumption that adult flies died upon reaching 40 days post eclosion. This assumption may not reflect reality but there is little published on actual field mortality. Also, mating age in the field will driven by several factors such as nutrition and our model may not reflect reality. However, our model is a good starting point to better understand invasion and successful establishment.

Though rare, a few empirical studies have quantified relationship between population size and establishment probability. For psyllids (Memmott et al., 2005), water fleas (Gertzen et al., 2011) and water-striders (Ahlroth et al., 2003), it takes about 20, 10, and 16 individuals, respectively, to obtain a 50% establishment rate. Using fish (topmouth gudgeon) instead of invertebrates, Britton and Gozlan (2013) found that between 10 and 20 individuals is needed for a 50% establishment probability. However, for chrysomelid beetles, between 200 and 500 individuals are needed for ~50% establishment (Grevstad, 1999). Furthermore, several case studies have found that several pest species were founded by small population, such as 5 individuals for muskrat (*Ondatra zibethicus*) introduction in Europe (Long, 2003) and 8 individuals of a parasite wasp (*Anarhopus sydneyensis*) in California (Clausen, 1978).

4.2. Mating range

Not surprisingly, the distance at which a female Qfly can detect a male had one of the largest effects on establishment probability. The default maximum distance was 5 m × 5 m, which equates to a large tree. Such a mating range is very short, compared to other species like moths, fireflies and mosquitoes (Cardé and Baker, 1984), but the empirical support on Qfly mating distance suggests such a short distance (Meats, 1998; Tychsen, 1978). Furthermore, the mating behaviour of Qfly appears to reflect short effective mating distance. Qfly only mate during a short temporal window at dusk, thus allowing little time for females to successfully find a male, assess the mate, and successfully commence copulation (Tychsen, 1978; Tychsen and Fletcher, 1971). Consequently, it is likely that Qfly use other cues to ensure close proximity to other flies at dusk, such as aggregating in fruiting trees (Dalby-Ball and Meats, 2000). In a previous Qfly dispersal model, Meats (1998) assumed uniform spread of Qfly and assumed only a 10% chance of mating if both a female and male were in a 5 m × 5 m patch. Based on our model results, we suggest that Qfly will clump in suitable fruit trees, increasing their overall density and likelihood of being in close proximity of a mate, which increases establishment probability. Previously, aggregation behaviour was identified as an important mechanism to assuage Allee effects, like finding mates in small populations (Stephens et al., 1999).

4.3. Landscape structure

One of the advantages of utilizing a spatially explicit IBM is that we could explore the effect of landscape. For our model, we found that the density of trees strongly affected fly dispersal patterns, with lower density environments leading to flies being more spread out. Since flies were further apart, the population experiences increased Allee effects due to it being more difficult to find a mate. Our model took a very simplistic approach to modelling tree layout in landscape. Much more realistic tree structures can be modelled to determine what attributes of these tree layouts hinder or promote establishment of fruit fly. Furthermore, detailed GIS data could be used to predict location-specific probability.

4.4. Dispersal

How well the model captured dispersal patterns in Qfly affects greatly the applicability of the model's results. The most directly comparable study is Meats and Edgerton (2008) in which immature flies were released in an orchard and a trapping grid spaced at 0.02 km was constructed. Then, Cauchy distributions were fitted to their trapping data, giving median estimates of 0.018 km and 0.028 km, consistent with our model results (Fig. 4). However, such estimates are much smaller than previous studies that estimate much higher mean dispersal distance (0.2–1.0 km; reviewed in (Dominiak, 2012; Dominiak and Fanson, 2020)). Part of the discrepancy is that other studies used mean distance instead of median, which will be higher than the median given the distribution shape of dispersal patterns. However, the mean dispersal in our study was 0.030 km. Despite their reputation as a major pest, Qfly spent 67.5% of their time walking, 18.0% being inactive, grooming 14% and only 0.6% of their time in flight (Weldon et al., 2010). This small investment in dispersal may explain the relatively short dispersal distances reported by recent authors (Dominiak and Fanson, 2020).

4.5. Factors not considered in model

Our model included several processes known to affect establishment probability, e.g. Allee effects, demographic stochasticity, environmental

stochasticity. Also with small populations, inbreeding avoidance and depression can play significant roles, leading to increased population extinction rates (Simberloff, 2009). Additionally, the model did not include environmental stochasticity, especially extreme climatic conditions like heat waves, cold snaps, drought, and floods were not included in this model. Adding these factors would decrease establishment probability, as our model represented environmentally favourable conditions and assumed no inbreeding depression. Thus, our model may be a conservative model from that perspective.

4.6. Qfly management

A better understanding of Qfly establishment is likely to result in two main areas of improved management; the optimising of exclusion techniques and an understanding of fruit fly populations below a breeding population. If the model delineated factors that affect incursion establishment, the appropriate level of exclusion techniques could be deployed in a cost-efficient manner to obtain a balance between costs of deployment and minimisation of the number of Qfly outbreaks and hence interference to domestic and international trade. Many strategies, such as MAT and surveillance, used by producers are based on the perceptions of the 1990's. Traditionally in surveillance, the larger 1 km array was used in orchards. The smaller grid was a 400 m array and this was used in urban areas. We suggest that these distances are inadequate based on our 0.03 km dispersal distance.

One of the techniques used in a Systems Approach is the use of MAT around the property boundary to trap (and effectively exclude) male flies. Based on our results, we recommend a closer distance between MAT devices to maximise this technique, compared with distances based on the 400 m perception or standard. Also, Systems Approaches use surveillance traps within the production area and many producers have transitioned from a 1 km array to a 400 m array to gain higher confidence that there is no breeding population on their property. Based on our results, another change would be to decrease the array distance between traps to improve the chances of detecting a fly. In a draft protocol for citrus, a 250 m array is being proposed (Kingham, pers. comm.). Both these changes come at an increased cost to producers however they increase the likelihood that Qfly will be excluded from the production site and that incursion flies will be detected early before a breeding population can establish. Additionally, this knowledge may revive the concept of "Areas of Low Pest Prevalence" (Dominiak et al., 2015; Jang, 2016; van Klinken et al., 2020) as both these changes increase the confidence that a breeding population is not present, even though some flies are present. This low level of flies is unlikely to breed because of the low probability that a male and female would be within 16 m of each other for the brief mating time at the end of the day.

Any decrease in distances between traps comes at a cost. More traps result in more time required to inspect and potentially more insects to identify and record. These increased costs may be sustainable if there are improved market access outcomes. Certainly, improved confidence is important but there may be other advantages including reduced shipping costs. These changes may result in no end point treatment being required because of the increased confidence that there is no breeding population and hence no immature fruit fly stages in traded fruit. The currently used end point treatments may contribute to global warming and any movement away from these techniques would be beneficial.

At a regional level, Florec et al. (2013) found it was more cost effective to exclude (e.g. use of roadblocks) Qfly than the costs of surveillance once Qfly entered and established in a zone. Random roadblocks in NSW operated on a maximum of 100 days in higher risk periods (Dominiak and Coombes, 2009). The roadblocks at the South Australian border operate every day and for 24 h in high-risk periods. Both program costs are significant. The travelling public obtain fruit from many sources and unregulated backyard or travelling fruit stalls are a source of particular concern. Surveys at roadside vehicle inspection points revealed that up to 18% of travellers carry fruit (Dominiak and Coombes, 2009). A small proportion is infested but this level is poorly understood and appears to vary with the season (Dominiak et al., 2000). While the proportion of travellers with fruit varies considerably, the number of fruit carried by each fruit carrying vehicle remained fairly constant at 6 to 7 items of fruit (Dominiak and Coombes, 2009). Also, it was reported that fines and community awareness programs result in declines in the proportion of vehicles carrying fruit (Dominiak and Barchia, 2005; Dominiak and Coombes, 2009). The travelling public act as the long distance "jump", often resulting in establishment and local dispersal (Sadler et al., 2011). Our model predicted that circa 16 and 50 flies were required for a 50% and 99% chance of establishment respectively. Hence knowledge about the host reproduction number (HRN) (Dominiak, 2022) and host suitability index (HSI) (Follett et al., 2021) becomes increasingly important to understand which carried fruit pose the highest risk to establishing fruit flies in previously uninfested areas. For instance, two kg of capsicum (*Capsicum annum* L.; HRN = 24) would be required to provide a 99% chance of establishment. Alternatively, only one third of kg of peaches (*Prunus persica* L.; HRN = 179) would provide the same chance of establishment (Follett et al., 2021). Produce inspections, feral tree management and community awareness programs would best focus on these higher HRN and HSI hosts as smaller quantities of these are more likely to result in establishment of a Qfly incursion. Roadside signs could be altered to highlight or target specific (high HRN) fruit and this would decrease the probability of infested fruit entering a fruit fly free area and establishing a breeding population.

With the restricted use of dimethoate and fenthion (Dominiak and Ekman, 2013), there will need to be alternative strategies developed to provide confidence that commercial fruit is not infested with Qfly. It seems increasingly likely that the main response will be a Systems Approach (Dominiak, 2019; Jang, 2016; van Klinken et al., 2020) and one option within this approach is the Area of Low Pest Prevalence (Dominiak et al., 2015). Relatively short dispersal distance and shorter mating distance allows growers to minimise incursions into their productions site. Feral trees in the immediate vicinity should be removed because increased distance between trees or possible hosts will lower likelihood of mating near the property boundary. In particular, fruiting trees should be removed; the host ranking for Qfly of fruit trees was provided in Follett et al. (2021). Our prediction of shorter dispersal distances is relatively consistent with Dominiak (2012) and Dominiak and Fanson (2020). These findings reinforce the concept of property isolation is the best defence for growers to produce fruit fly free fruit using a Systems Approach (Dominiak 2019). This concept can be achieved by altering the landscape structure by removing feral trees and tree corridors which support the movement of fly into the production site. Additionally, increased distance between trees does not favour Qfly matings because of their short mating range. Also, Qfly mortality had a large effect on the dose-response curve. Birds and ants are recognised predators. Therefore, strategies to encourage birds and ants could increase predation. Ants are commonly found in many orchards and frequently are controlled with pesticides. Weldon et al. (2020) reported that Qfly spent most of their time walking, grooming or were inactive and these activities make Qfly highly susceptible to ant predation.

Several areas require further research to better understand the establishment potential of Qfly. Some data on the capability of different host fruit to support different numbers of adult flies was only recently published (Follett et al., 2021) but more needs to be done. The knowledge of hosts and their HRN could be used to further fine tune this model to suit individual production systems or crops. For example, guava (*Psidium guajava* (L.) is widely grown as backyard fruit and has a high HRN and HSI for most tephritids (Dominiak, 2021). Our model could be used to investigate both urban and rural invasion potential, depending on the location and hosts.

5. Conclusion

Propagule pressure is one the best predictors of establishment

probability of a successful introduction of a new species (Lockwood et al., 2009). This effect is partly due to the stochastic processes in small populations such as random fluctuations in key factors as sex ratios, death rates, and birth rates that can lead to population extinction. Additionally, other processes, such as Allee effects, may be important processes in small populations. For Qfly invasions, it has been proposed that dispersal after a point source introduction from infested fruit may greatly reduce the probability of breeding as flies are too far apart to find each other at mating time. Our results are consistent with recent papers which indicate that natural dispersal distances are relatively short and not kilometres as reported in the 1980's (Meats and Edgerton 2008; Dominiak 2012; Dominiak et al., 2013; Dominiak and Fanson, 2020; Caton et al., 2021). Our model predicts that this explanation without demographic stochasticity processes only occurs at very low population sizes (<5 individuals). However, the interactive effect of demographic stochasticity and Allee effects does lead to substantial decrease in establishment probability with starting population size. It is possible to understand why most Qfly incursions appear to fail by combining the model results with information on transport of infested fruit.

This understanding will bring new insights into management concerns such as flight distance and hence incursion pressure. Changes in the deployment of MAT and distance between surveillance traps are likely to decrease the chance of a breeding population developing within the production site. Altering the landscape structure and encouragement of predators are two activities that producers can influence to minimise the likelihood of a Qfly establishment on or near their properties. Additionally, there will be a better understanding of the real threat of fruit infestation in areas of low pest prevalence and similar new phytosanitary strategies following the loss of dimethoate and fenthion. Additionally, a broader knowledge of HRN and HSI for Qfly will assist in making this model more useful for the production of Qfly free fruit and the decreased reliance on end point treatments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Jianhua Mo reviewed an early version and improved of this manuscript. New South Wales Department of Primary Industries partially funded this research. We thank the four journal reviewers for their valuable comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2022.106121.

References

Ahlroth, P., Alatalo, R., Holopainen, A., Kumpulainen, T., Suhonen, J., 2003. Founder population size and number of source populations enhance colonization success in waterstriders. Oecologia 137, 617–620. https://doi.org/10.1007/s00442-003-1344-y.

Bateman, M., 1977. Dispersal and species interaction as factors in the establishment and success of tropical fruit flies in new areas. Proc. Ecol. Soc. Aust. 10, 106–112.

Bateman, M.A., 1991. The Impact of Fruit Flies on Australian Horticulture: Horticultural Policy Council Report, vol. 3.

Bebber, D.P., Holmes, T., Smith, D., Gurr, S.J., 2014. Economic and physical determinants of the global distributions of crop pests and pathogens. New Phytol. 202, 901–910.

Boukal, D.S., Berec, L., 2002. Single-species models of the allee effect: extinction boundaries, sex ratios and mate encounters. J. Theor. Biol. 218, 375–394. https://doi.org/10.1006/jtbi.2002.3084.

Britton, J.R., Gozlan, R.E., 2013. How many founders for a biological invasion? Predicting introduction outcomes from propagule pressure. Ecology 94, 2558–2566.

Brodland, G.W., 2015. How computational models can help unlock biological systems. Semin. Cell Dev. Biol. 47, 62–73.

Cardé RT, Baker, T.C., 1984. Sexual communication with pheromones: chemical ecology of insects. In: WJ Bell & RT Cardé). Springer US, Boston, MA, pp. 355–383.

Caton, B.P., Fang, H., Manoukis, N.C., Pallipparambil, G.R., 2021. Quantifying insect dispersal distances from trapping detections data to predict delimiting survey radii. J. Appl. Entomol. 146, 203–216.

Clarke, A.R., Dominiak, B.C., 2010. Positive correlation of male and female *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae) catches in orange-ammonia traps. Gen. Appl. Entomol. 39, 9–13.

Clarke, A.R., Powell, K.S., Weldon, C.W., Taylor, P.W., 2011. The ecology of *Bactrocera tryoni* (Diptera: Tephritidae): what do we know to assist pest management? Ann. Appl. Biol. 158, 26–54. https://doi.org/10.1111/j.1744-7348.2010.00448.x.

Clausen, C.P., 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. In: Agriculture Handbook. United States Department of Agricultre.

Crespo-Perez, V., Rebaudo, F., Silvan, J.F., Dangles, O., 2011. Modeling invasive species spread in complex landscapes: the case of potato moth in Ecuador. Landsc. Ecol. 26, 1447–1461.

Dalby-Ball, G., Meats, A., 2000. Effects of fruit abundance within a tree canopy on the behaviour of wild and cultured Queensland fruit flies, Bactrocera tryoni (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 39, 201–207.

Dominiak, B.C., 2012. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Ann. Entomol. Soc. Am. 105, 434–446.

Dominiak, B.C., 2019. Components of a systems approach for the management of Queensland fruit fly Bactrocera tryoni (Froggatt) in a post dimethoate fenthion era. Crop Protect. 116, 56–67.

Dominiak, B., 2021. Guava Psidium guajava (L.) may have the potential to be a good host for many tephritids. Gen. Appl. Entomol. 49, 31–34.

Dominiak, BC, 2022. The use of Host Reproduction Number and Host Suitability Index to rank hosts of Fruit Flies in Africa. Int. J. Trop. Insect Sci. 42, 2717–2729.

Dominiak, B., Barchia, I., 2005. A survey of travellers carrying host fruit of Queensland fruit fly, Bactrocera tryoni (Froggatt), into a fruit fly free area in 1998/99 following road signposting of penalties for infringements. Plant Protect. Q. 20, 148–154.

Dominiak, B., Coombes, N., 2009. Fruit carrying characteristics of travellers into a quarantine zone in New South Wales in 1999/2000. Plant Protect. Q. 24.

Dominiak, B.C., Ekman, J.H., 2013. The rise and demise of control options for fruit fly in Australia. Crop Protect. 51, 57–67. https://doi.org/10.1016/j.cropro.2013.04.006.

Dominiak, B.C., Fanson, B.G., 2020. Current quarantine and suspension distances are excessive for incipient populations of Queensland fruit fly (Bactrocera tryoni (Froggatt))(Diptera: Tephritidae) in southern New South Wales, Australia. Crop Protect. 138, 105341.

Dominiak, B.C., Mapson, R., 2017. Revised distribution of Bactrocera tryoni in eastern Australia and effect on possible incursions of mediterranean fruit fly: development of Australia's eastern trading block. J. Econ. Entomol. 110, 2459–2465. https://doi.org/10.1093/jee/tox237.

Dominiak, B., Campbell, M., Cameron, G., Nicol, H., 2000. Review of vehicle inspection historical data as a tool to monitor the entry of hosts of Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera :Tephritidae) into a fruit fly free area. Aust. J. Exp. Agric. 40, 763–771.

Dominiak, B.C., Westcott, A., Barchia, I., 2003. Release of sterile Queensland fruit fly, *Bactrocera tryoni* (Froggatt)(Diptera: Tephritidae), at sydney, Australia. Aust. J. Exp. Agric. 43, 519–528.

Dominiak, B.C., Worsley, P.M., Nicol, H., 2013. Release from a point source and dispersal of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt))(Diptera: Tephritidae) at Wagga Wagga. Plant Protect. Q. 28, 120.

Dominiak, B.C., Wiseman, B., Anderson, C., Walsh, B., McMahon, M., Duthie, R., 2015. Definition of and management strategies for areas of low pest prevalence for Queensland fruit fly *Bactrocera tryoni* Froggatt. Crop Protect. 72, 41–46. https://doi.org/10.1016/j.cropro.2015.02.022.

Fanson, B.G., Taylor, P.W., 2012. Protein:carbohydrate ratios explain lifespan patterns found in Queensland fruit fly on diets varying in yeast:sugar ratios. Age 34, 1361–1368. https://doi.org/10.1007/s11357-011-9308-3.

Fanson, B.G., Sundaralingam, S., Jiang, L., Dominiak, B.C., D'Arcy, G., 2014. A review of 16 years of quality control parameters at a mass-rearing facility producing Queensland fruit fly, *Bactrocera tryoni*. Entomol. Exp. Appl. 151, 152–159.

Fletcher, B.S., 1974. The ecology of a natural population of the Queensland fruit fly, *Dacus tryoni* V. The dispersal of adults. Aust. J. Zool. 22, 189–202.

Florec, V., Sadler, R.J., White, B., Dominiak, B.C., 2013. Choosing the battles: the economics of area wide pest management for Queensland fruit fly. Food Pol. 38, 203–213..

Follett, P.A., Haynes, F.E., Dominiak, B.C., 2021. Host suitability index for polyphagous tephritid fruit flies. J. Econ. Entomol. 114, 1021–1034.

Gertzen, E., Leung, B., Yan, N., 2011. Propagule pressure, Allee effects and the probability of establishment of an invasive species (Bythotrephes longimanus). Ecosphere 2 art30.

Gozlan, R.E., Britton, J., Cowx, I., Copp, G., 2010. Current knowledge on non-native freshwater fish introductions. J. Fish. Biol. 76, 751–786.

Grevstad, F., 1999. Experimental invasions using biological control introductions: the influence of release size on the chance of population establishment. Biol. Invasions 1, 313–323. https://doi.org/10.1023/A:1010037912369.

Grimm, V., Railsback, S.F., Vincenot, C.E., Berger, U., Gallagher, C., DeAngelis, D.L., Edmonds, B., et al., 2020. The ODD protocol for describing agent-based and other simulation models: a second update to improve clarity, replication, and structural realism. J. Artif. Soc. Soc. Simulat. 23 (2), 2020.

Hancock, D.L., Hamacek, E.L., Lloyd, A.C., Elson-Harris, M.M., 2000. The Distribution and Host Plants of Fruit Flies (Diptera: Tephritidae) in Australia. DPI Publications, Brisbane, Australia.

Jang, E.B., 2016. Systems approaches for managing the phytosanitary risk of trading in commodities that are hosts of fruit flies. 737-751. In: Ekesi, S., Mohamed, S., de Meyer, M. (Eds.), Fruit Fly Research and Development in Africa - towards a Sustainable Management Strategy to Improve Horticulture. Springer International, Cham.

Keitt, T.H., Lewis, M.A., Holt, R.D., 2001. Allee effects, invasion pinning, and species' borders. Am. Nat. 157, 203–216.

Kolar, C.S., Lodge, D.M., 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16, 199–204.

Leung, B., Drake, J.M., Lodge, D.M., 2004. Predicting invasions: propagule pressure and the gravity of Allee effects. Ecology 85, 1651–1660.

Lewis, M.A., Petrovskii, S.V., Potts, J.R., 2016. The mathematics behind biological invasions. In: Antman, Greengard & Holmes, vol. 44. Springer International Publishing, Switzerland.

Lockwood, J.L., Cassey, P., Blackburn, T., 2005. The role of propagule pressure in explaining species invasions. Trends Ecol. Evol. 20, 223–228. https://doi.org/10.1016/j.tree.2005.02.004.

Lockwood, J.L., Cassey, P., Blackburn, T.M., 2009. The more you introduce the more you get: the role of colonization pressure and propagule pressure in invasion ecology. Divers. Distrib. 15, 904–910. https://doi.org/10.1111/j.1472-4642.2009.00594.x.

Long, J.L., 2003. Introduced Mammals of the World. Their History, Distribution and Influence. CABI, Wallingford, UK.

Lux, S.A., 2014. PESTonFARM - stochastic model of on-farm insect behaviour and their response to IPM interventions. J. Appl. Entomol. 138, 458–467.

Lux, S.A., 2018. Individual-based modeling approach to assessment of the impacts of landscape complexity and climate on dispersion, detectability and fate of incipient medfly populations. Front. Physiol. 8, 1121.

Manoukis, N.C., Collier, T.C., 2021. Agent-based simulations to determine mediterranean fruit fly declaration of eradication following outbreaks: concepts and practical examples. 869-888. In: Hendrichs, J., Pereira, R., Vreysen, M.J.B. (Eds.), Area-Wide Integrated Pest Management. CRC Press, Boca Raton, FL.

Meats, A., 1998. The power of trapping grids for detecting and estimating the size of invading propagules of the Queensland fruit fly and risks of subsequent infestation. Gen. Appl. Entomol. 28, 47–55.

Meats, A.W., Edgerton, J.E., 2008. Short- and long-distance dispersal of Queensland fruit fly, *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust. J. Exp. Agric. 48, 1237–1245.

Meats, A., Leighton, S.M., 2004. Protein consumption by mated, unmated, sterile and fertile adults of the Queensland fruit fly, *Bactrocera tryoni* and its relation to egg production. Physiol. Entomol. 29, 176–182.

Meats, A., Clift, A., Robson, M., 2003. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Anim. Prod. Sci. 43, 397–406.

Meats, A.W., Smallridge, C.J., Dominiak, B.C., 2006. Dispersion theory and the sterile insect technique: application to two species of fruit fly. Entomol. Exp. Appl. 119, 247–254.

Memmott, J., Craze, P.G., Harman, H.M., Syrett, P., Fowler, S.V., 2005. The effect of propagule size on the invasion of an alien insect. J. Anim. Ecol. 74, 50–62. https://doi.org/10.1111/j.1365-2656.2004.00896.x.

Perez-Staples, D., Prabhu, V., Taylor, P.W., 2007. Post-teneral protein feeding enhances sexual performance of Queensland fruit flies. Physiol. Entomol. 32, 225–232. https://doi.org/10.1111/j.1365-3032.2007.00568.x.

Prabhu, V., Perez-Staples, D., Taylor, P., 2008. Protein: carbohydrate ratios promoting sexual activity and longevity of male Queensland fruit flies. J. Appl. Entomol. 132, 575–582.

Sadler, R.J., Florec, V., White, B., Dominiak, B.C., et al., 2011. Calibrating a jump-diffusion model of an endemic invasive: metamodels, statistics and Qfly. Sustaining our future: Understanding and Living with Uncertainty, MODSIM 2011International Congress on Modelling and Simulation. Modelling and Simulation society of Australia and New Zealand., Perth, Australia.

Schmitz, D.C., Simberloff, D., 1997. Biological invasions: a growing threat. Issues Sci. Technol. 13, 33–40.

Shea, K., Possingham, H.P., 2000. Optimal release strategies for biological control agents: an application of stochastic dynamic programming to population management. J. Appl. Ecol. 37, 77–86. https://doi.org/10.1046/j.1365-2664.2000.00467.x.

Simberloff, D., 2009. The role of propagule pressure in biological invasions. Annu. Rev. Ecol. Evol. Syst. 40, 81–102.

Snyder, R.E., 2003. How demographic stochasticity can slow biological invasions. Ecology 84, 1333–1339. https://doi.org/10.1890/0012-9658(2003)084 [1333:HDSCSB]2.0.

Stephens, P.A., Sutherland, W.J., 1999. Consequences of the Allee effect for behaviour, ecology and conservation. Trends Ecol. Evol. 14, 401–405.

Stephens, P.A., Sutherland, W.J., Freckleton, R.P., 1999. What is the Allee effect? Oikos 185–190.

Taylor, P.W., Pérez-Staples, D., Weldon, C.W., Collins, S.R., Fanson, B.G., Yap, S., Smallridge, C., 2013. Post-teneral nutrition as an influence on reproductive development, sexual performance and longevity of Queensland fruit flies. J. Appl. Entomol. 137, 113–125. https://doi.org/10.1111/j.1439-0418.2011.01644.x.

Tychsen, P.H., 1978. Mating behaviour of the Queensland fruit fly, Dacus tryoni (Diptera: Tephritidae), in field cages. Aust. J. Entomol. 16, 459–465.

Tychsen, P.H., Fletcher, B.S., 1971. Studies on the rhythm of mating in the Queensland fruit fly, Dacus tryoni. J. Insect Physiol. 17, 2139–2156.

van Klinken, R.D., Fiedler, K., Kingham, L., Collins, K., Barbour, D., 2020. A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. Crop Protect. 129, 104994.

Weldon, C.W., 2007. Influence of male aggregation size on female visitation in *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust. J. Entomol. 46, 29–34. https://doi.org/10.1111/j.1440-6055.2007.00587.x.

Weldon, C., Meats, A., 2010. Dispersal of mass-reared sterile, laboratory-domesticated and wild male Queensland fruit flies. J. Appl. Entomol. 134, 16–25. https://doi.org/10.1111/j.1439-0418.2009.01436.x.

Weldon, C.W., Prenter, J., Taylor, P.W., 2010. Activity patterns of Queensland fruit flies (*Bactrocera tryoni*) are affected by both mass-rearing and sterilization. Physiol. Entomol. 35, 148–153.

Wilensky, U., 1999. NetLogo (and NetLogo User Manual), Center for Connected Learning and Computer-Based Modeling, Northwestern University. http://ccl.northwestern.edu/netlogo/.

Williamson, M.H., Brown, K.C., Holdgate, M., Kornberg, H., Southwood, R., Mollison, D., 1986. The analysis and modelling of British invasions [and discussion]. Phil. Trans. Biol. Sci. 314, 505–522.

Yonow, T., Sutherst, R.W., 1998. The geographical distribution of the Queensland fruit fly, Bactrocera (Dacus) tryoni, in relation to climate. Aust. J. Agric. Res. 49, 935–953.

Yonow, T., Zalucki, M.P., Sutherst, R.W., Dominiak, B.C., Maywald, G.F., Maelzer, D.A., Kriticos, D.J., 2004. Modelling the population dynamics of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*: a cohort-based approach incorporating the effects of weather. Ecol. Model. 173, 9–30. https://doi.org/10.1016/S0304-3800(03)00306-5.

International Journal of Tropical Insect Science (2024) 44:647–656
https://doi.org/10.1007/s42690-024-01168-x

ORIGINAL RESEARCH ARTICLE

Host reproduction number as an indicator of reproductive advantage in *Bactrocera dorsalis* over *Bactrocera tryoni* – can the concept elucidate the invasive threat in northern Australia?

Bernard Charles Dominiak[1]

Received: 2 June 2023 / Accepted: 8 January 2024 / Published online: 19 February 2024
© Crown 2024

Abstract
Incursions by exotic tephritids continue to threaten Australia. Host suitability for a specific tephritid is ranked by the number of adults which can emerge from one kg of fruit or the Host Reproduction Number (HRN). *Bactrocera dorsalis* has previously invaded northern Australia but was eradicated. However, *Bactrocera dorsalis* remains the largest exotic threat and is likely to invade through northern Australia but *B. tryoni* and other tephritids are already well established. One question is what hosts would likely provide the best early warning for an exotic incursion. Here, the HRN for 40 hosts for *Bactrocera dorsalis* and *B. tryoni* were established from the scientific literature. The reproductive advantages of one species over the other were calculated by dividing the higher HRN by the lower HRN. The fruits with the highest reproductive advantage (> 30) favouring *B. dorsalis* were soursop, mango and capsicum. The reproductive advantage estimate was compared to surveillance data collected during *B. dorsalis* eradication in north Queensland from 1995 to 1997. Mangoes and capsicum were among the mostly commonly infested hosts. Capsicums provided the second highest number of samples and would seem ideal candidates as sentinel plants for current surveillance programs. Some inconsistencies are identified and discussed. The HRN and reproductive advantage may have the potential to identify hosts and industries for early warning exotic fruit fly surveillance, better-targeted eradication programs and risk assessments for imports/exports.

Keywords Incursion · Threatening species · Tramp ant · Management · Scenario tree

Introduction

International trade in fruit and vegetables continues to increase to feed an increasing world population (Bebber et al. 2014). Additionally, tourism is essential to the world's economy. However, both trade and tourism are implicated in the dispersal of exotic species including fruit flies (Early et al. 2016; Robinson and McNeill 2022). Incursions by exotic fruit flies result in restrictions on trade and loss of productivity (Drew 1997; Ormsby 2021).

More than 300 species of fruit fly occur in Australia although only a few cause any economic impact (Plant Health Australia 2018). For Australia, the main exotic fruit fly threat comes from Asia because New Zealand and Antarctica are fruit fly free (MacLellan et al. 2021). Therefore, Australian surveillance is conducted primarily for exotic Asian tephritids. Fortunately, most endemic and exotic male tephritids are easily monitored by male-lure traps (Suckling et al. 2016).

Frequently, tephritid invasions follow a jump-diffusion model (Sadler et al. 2011) where tourism or trade provide the long-distance jump, followed by diffusion or dispersal into the local environment. *Bactrocera dorsalis* (Hendel) (Oriental fruit fly (OFF)) is a significant concern because it has a long history of successful invasions. In 1935, *B. dorsalis* invaded the Mariana Islands but was deemed eradicated by 1965 (Leblanc et al. 2013a). *Bactrocera dorsalis* invaded Hawaii (1946), Nauru (1992 but eradicated in 1999), and French Polynesia (1996) where it outcompeted *Bactrocera tryoni* (Froggatt) (Queensland fruit fly (Qfly) and became the dominant pest (Leblanc et al. 2013a). Recently, *Bactrocera papayae* (Drew and Hancock) and *B. philippinensis* (Drew and Hancock) were synonymised to *B. dorsalis* (Schutze et al. 2015) and this synonymisation added to the invasion history of *B. dorsalis*.

✉ Bernard Charles Dominiak
bernie.dominiak@dpi.nsw.gov.au

[1] New South Wales Department of Primary Industries, The Ian Armstrong Building, 105 Prince Street, Orange, NSW 2800, Australia

Bactrocera papayae was detected in Papua New Guinea in 1993 and Palau in 1996 (Leblanc et al. 2013a). In October 1995, the exotic *B. papayae* was detected in papaya near Cairns in northern Queensland (Fay et al. 1997; Gillespie 2003). Shortly afterwards in November 1997, *B. philippinensis* was detected in Northern Territory, but both Australian incursions were eradicated (Hancock 2013). Given the invasion history of *B. dorsalis*, another incursion is the primary driver for continued surveillance in all first ports of entry (Gillespie 2003; Wylie et al. 2008; Dominiak 2021a).

The potential for an invasion by *B. dorsalis* into northern Australia is high due to its proximity to Asia. Therefore, many exotic fruit fly traps are on islands in the Torres Strait, some of which are only 4–6 km from Papua New Guinea. These traps act as an early warning system and exotic fruit flies are eradicated annually (Huxham 2002; Murphy 2022). Australia's preparedness of exotic incursion, particularly *B. dorsalis*, was reviewed by Hoskins et al. (2023).

For eastern Australia, another threat is the Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann), from Western Australia. One advantage of *B. tryoni* being endemic is that there is a very low likelihood that Medfly will establish in a *B. tryoni* endemic area (Dominiak and Mapson 2017), as Medfly was previously displaced from eastern Australia in the 1940s (Dominiak and Mapson 2017). There is a perception that Qfly will outcompete Medfly and that Medfly will not establish where there is a resident Qfly population (Dominiak and Mapson 2017). The HRN comparison between Qfly and Medfly will be the subject of another review.

Similar to *C. capitata*, if *B. dorsalis* did enter and attempt to establish again on mainland Australia, it would have to compete with the established fruit flies, primarily *B. tryoni*. In Queensland, other tephritids include *B. aquilonis* (May), *B. frauenfeldi* (Schiner), *B. jarvisi* (Tryon), *B. musae* (Tryon), *B. neohumeralis* (Hardy), and *Zeugodacus cucumis* (French) (Hancock et al. 2000). However, different hosts are known to variously support the full life cycle of different tephritid species (Woods et al. 2005; Lloyd et al. 2013; Dominiak et al. 2020; Follett et al. 2021). These papers report on the number of adults that can emerge from one kg of fruit. Subsequently, this metric was termed the Host Reproduction Number (HRN) (Dominiak 2022). The Host Suitability Index (HSI) (Follett et al. 2021) is a way of placing HRN into six major categories.

Regarding exotic invasions, Ekesi et al. (2009) noted that tephritids with a higher reproductive capacity (or HRN) were likely to eventually displace species with lower reproductive capacity. I wanted to test this HRN theory in northern Australia where *B. dorsalis* may make an incursion into areas where *B. tryoni* is the main tephritid. Theoretically based on HRN alone, *B. dorsalis* is more likely to outcompete *B. tryoni* in hosts that are poor hosts for *B. tryoni.* Conversely, *B. dorsalis* is less likely to establish in hosts that support large numbers of *B. tryoni.* Here, I wanted to use HRN theory to determine whether *B. dorsalis* and *B. tryoni* hosts more or less likely to support an incursion by *B. dorsalis.* The competitive advantage of *B. dorsalis* is compared to host records from its previous establishment in the Cairns region of north Queensland.

Materials and methods

I followed the methodology described by Dominiak (2022). In brief, I used Google Scholar as a search engine because it yields more results than other databases (Pozsgai et al. 2021). In the first search, I used "Bactrocera dorsalis" as the main search term. Additional terms were added, such as "host", "suitability", "susceptibility" or "fruit" and similar terms in successive searches. I examined the results and chose references if they provided useful data for HRN. Usually, useful references were contained in the first four pages of each search. The third search word was changed, based on the results of earlier searches. I repeated these procedures using "Bactrocera tryoni" as the main search term.

To formulate Table 1 containing hosts, HRN and HSI, I examined each reference for data of each host regarding the reproductive capacity to support adult fruit flies. Where possible, all fruit infestation results are standardized on an individual's HRN. Most data were based on field sampling. Unfortunately, not all papers reported the information required. Some papers reported infestations per fruit and provided insufficient information to calculate the adults/kg metric. Data in some papers reported infestation rates in graphs or figures and accurate interpretation was too difficult to obtain exact figures. Other papers reported infestations of larvae or pupae per kg and this information is not reported here. Different papers report a range of HRN figures. In plant biosecurity, the worst-case scenario is always assumed to be the case. Therefore, I did not include any references that reported a HRN lower than the eventual highest HRN in Table 1. Within Table 1, the HRN is followed by the equivalent index (HSI) proposed by Follett et al. (2021).

I reviewed the papers for *B. dorsalis* and *B. tryoni* that contained HRN data. Hosts are listed in alphabetical order in Table 1. The reproductive advantage of *B. dorsalis* over *B. tryoni* is calculated by dividing the higher HRN of fruit for *B. dorsalis* by the lower HRN for *B. tryoni*. The reverse calculation was done where the HRN for *B. tryoni* was larger than the HRN for *B. dorsalis.* In Table 2, these calculated figures are compared to the frequency of fruit samples infested with *B. dorsalis* from November 1995 to December 1997 (Anon 1998). There were 229 detections of *B. dorsalis* across 33 hosts with the frequency ranging from one (ten different hosts) to 68 (mangoes).

In Table 2, HRN and therefore reproductive advantage was not available for all *B. dorsalis* hosts noted by Fay et al.

Table 1 *Bactrocera* hosts with the adults/kg numbers (Host Reproduction Number (HRN)) and Host Suitability Index (HSI) in brackets. The potential reproductive advantage of *Bactrocera dorsalis* over *Bactrocera tryoni* or visa-versa is calculated by dividing the larger HRN by the smaller HRN

Hosts	Fruit fly species		Reproductiveadvantage	
	Bactrocera dorsalis	*Bactrocera tryoni*	*B. dorsalis* over *B. tryoni*	*B. tryoni* over *B. dorsalis*
Anacardium occidentale, cashew	74 (G)[f]	11(G)[i]	6.7	
Annona muricata, soursop	454 (VG)[g]	10 (G)[i]	45.4	
Annona reticulata, custard apple	7.2 (MG)[f]	60 (G)[i]		8.3
Artocarpus altilis, breadfruit	1.7 (MG)[i]	17 (G)[i]		10
Averrhoa carambola, star fruit	8.3 (MG)[i]	21 (G)[i]		2.5
Capsicum annum, capsicum	750 (VG)[i]	24 (G)[a]	31.3	
Carica papaya, papaya	142 (VG)[b]	17 (G)[i]	8.4	
Chrysophyllum cainito, star apple	7.5 (MG)[i]	38 (MG)[i]		5.1
Citrus japonica, kumquat	6.9 (MG)[e]	234 (VG)[a]		33.9
Citrus latifolia, Tahitian lime	13 (G)[i]	6.2 (MG)[i]	2.1	
Citrus limon, lemon	32 (G)[c]	5 (MG)[d]	6.4	
Citrus maxima, pomelo	2.6 (MG)[i]	12 (G)[i]		4.6
Citrus x paradisi, grapefruit	43 (G)[g]	18 (MG)[i]	2.4	
Citrus reticulata, mandarin	5.6 (MG)[i]	89 (G)[i]		15.9
Citrus sinensis, orange Valencia	11 (G)[g]	142 (VG)[a]		12.9
Coffea canephora, robusta coffee	370 (VG)[h]	*		
Cucumis sativus, cucumber	3.9 (MG)[g]	*		
Eriobotrya japonica, loquat	325 (VG)[g]	324 (VG)[a]	1.0	1.0
Hylocereus undatus, dragonfruit	43 (G)[f]	*		
Inocarpus fagifer, Tahitian chestnut	131 (VG)[k]	15 (G)[i]	8.7	
Litchi chinensis, lychee	43 (G)[i]	8.3 (MG)[i]	5.2	
Mangifera indica, mango	505 (VG)[g]	71 (G)[d]	33.7	
Musa sp., banana	247 (VG)[k]	42 (G)[i]	5.9	
Nephelium lappaceum, rambutan	370 (VG)[i]	60 (G)[i]	6.2	
Passiflora edulis, purple passion fruit	66 (G)[i]	6.7 (MG)[i]	9.9	
Passiflora laurifolia, yellow passion fruit	2.5 (MG)[i]	27 (G)[i]		10.8
Passiflora quadrangularis, giant passion fruit	0.4 (MG)[i]	3.8 (MG)[i]		9.5
Persea americana, avocado	7.1 (MG)[i]	129 (VG)[i]		18.2
Pometia pinnata, Pacific lychee	195 (VG)[i]	106 (VG)[i]	1.8	
Pouteria caimito, Abiu	29 (G)[i]	18 (G)[i]	1.6	
Psidium cattleianum, strawberry guava	67 (G)[f]	122 (VG)[i]		1.8
Psidium guajava, guava	145 (VG)[k]	93 (G)[k]	1.6	
Solanum esculentum, tomato	37 (G)[i]	44 (G)[i]		1.2
Spondias dulcis, Jew plum	7 (MG)[f]	4.1 (MG)[i]	1.7	
Syzygium jambos, rose-apple	225 (VG)[i]	119 (VG)[i]	1.9	
Syzygium malaccense, Malay apple	36 (G)[i]	32 (G)[i]	1	1
Syzygium uniflora, Surinam cherry	98 (G)[i]	222 (VG)[i]		2.3
Terminalia catappa, tropical almond	653 (VG)[c]	375 (VG)[j]	1.7	
Zizphus mauritiana, Indian jujube	69 (G)[f]	109 (VG)[i]		1.6

*no data available

[a]Dominiak et al. (2020)

[b]Follett et al. (2019)

[c]Rwomushana et al. (2008)

[d]Lloyd et al. (2013)

[e]Boinahadji et al. (2019)

Table 1 (continued)

[f]Moquet et al. (2021)

[g]Mwatawala et al. (2006)

[h]Mwatawala et al. (2009)

[i]Leblanc et al. (2013b)

[j]Vargas et al. (2007)

[k]Leblanc et al. (2013a)

In HSI, *VG* very good, *G* good, *MG* moderately good, *P* poor, *NH* non host

(1997). Additionally, the HSI (Follett et al. 2021) for both species is provided as a further comparison. These HSI were very poor (< 0.1 adults per kg), poor (0.1–1.0), moderately good (1.0–10.0), good (10–100) and very good (> 100). Table 3 provides QDAF records of fruit collections from 1995 to 1997 in north Queensland and averages the number of fruit fly specimens per collection.

Results

I found data for 39 comparisons between *B. dorsalis* and *B. tryoni*. In the reproductive advantage assessment for "*B. dorsalis* over *B. tryoni*" column (Table 1), 20 hosts scored a reproductive advantage for *B. dorsalis* over *B. tryoni* but 13 hosts with an advantage > 2. There were three hosts with HRN > 30 and no host with a HRN of < 30 and > 10. The advantage scores were quite polarised. There were 14 hosts in the "*B. tryoni* over *B. dorsalis*" column which shows the reproductive advantage for *B. tryoni* with 12 hosts with a score of > 2.

Using the calculated reproductive advantage, *B. dorsalis* is likely to have dominance over *B. tryoni* in soursop (45.4), mango (33.7), capsicum (31.1), purple passion fruit (9.9), Tahitian chestnut (8.7), papaya (8.4), cashew (6.7), lemon (6.4), rambutan (6.2), banana (5.9), lychee (5.2), grapefruit (2.4), Tahitian lime (2.1) with eight other fruits with < 2 advantage. Soursop, mango and capsicum appear superficially to be better candidate fruits for *B. dorsalis* surveillance.

Conversely, *B. tryoni* dominated *B. dorsalis* where the reproductive advantage favoured *B. tryoni*, for example, in kumquat (33.9), avocado (18.2), mandarin (15.9), oranges (12.9), yellow passion fruit (10.8), breadfruit (10), giant passion fruit (9.5), custard apple (8.3), star apple (5.1), pomelo (4.6), star fruit (2.5), Surinam cherry (2.3), with five other fruits with < 2 advantage. I predict that kumquats and avocados would be the poorest candidates for *B. dorsalis* surveillance.

Table 2 contains calculated reproductive advantage from Table 1 and the frequency of fruit infested with *B. dorsalis* detected in the previous Queensland *B. dorsalis* eradication program. Additionally, the HSI comparison is provided for both tephritids. Mangoes and capsicums are in the top four rankings. Table 3 provides the number of collections, the total number of specimens recorded and the average number of specimens per collection. Capsicums were ranked higher than mangoes in Table 3.

Table 2 Comparison between the frequency of infested fruit (*B. dorsalis*) samples in 1995–1997 incursion and reproductive advantage

Host	Frequency of fruit samples infested with B. dorsalis between 1995–1997	Calculated reproductive advantage (from Table 1)	Host suitability Index of B. dorsalis and B. tryoni (Follett et al. 2021)
Mangifera indica, mango	68	33.7 (*B. dorsalis*)	VG - G
Terminalia catappa, tropical almond	28	1.7 (*B. dorsalis*)	VG - VG
Psidium guajava, guava	20	1.6 (*B. dorsalis*)	VG - VG
Capsicum annum, capsicum	13	31.3 (*B. dorsalis*)	VG - G
Carica papaya, papaya	11	8.4 (*B. dorsalis*)	VG - G
Fortunella japonica, kumquat	7	33.9 (*B. tryoni*)	MG – G
Citrus limon, lemon	6	6.4 (*B. dorsalis*)	G – MG
Solanum esculentum, tomato	6	1.2 (*B. tryoni*)	G – G
Citrus x paradisi, grapefruit	5	2.4 (*B. dorsalis*)	G – G
Averrhoa carambola, star fruit	4	5.1 (*B. tryoni*)	VG - G

In the Host Suitability Index, *VG* very good, *G* good, *MG* moderately good, *P* poor, *NH* non host

Table 3 Records from QDAF Insect Collection for specimens of *B. dorsalis (papayae)* and *B. tryoni* collected in far north Queensland during the OFF campaign 1995–1997

Host	*B. dorsalis*			*B. tryoni*		
	No. +ve collections	Total No. specimens	Specimens per collection	No. +ve collections	Total No. specimens	Specimens per collection
Psidium guava, guava	9	161	17.9	9	57	6.3
Capsicum annum, capsicum	8	18	2.3	0	0	0
Terminalia catappa, tropical almond	6	57	9.5	7	46	6.6
Mangifera indica, mango	5	60	12	5	33	6.6
Anacardium occidentale, cashew	4	17	4.3	4	33	8.3
Malpighia glabra, Barbados cherry	3	20	6.7	3	7	2.3
Musa sp., banana	2	82	41	2	7	3.5
Carica papaya, papaya	2	33	16.5	0	0	0
Fortunella japonica, kumquat	2	23	11.5	1	1	1
Passiflora spp., passion fruit	2	13	6.5	2	12	6
Chrysophyllum cainto, star apple	2	10	5	2	7	3.5
Citrus aurantiifolia, lime	1	8	8	0	0	0
Averrhoa carambola, carambola	0	0	0	4	21	5.3
Citrus x paradisi, grapefruit	0	0	0	3	8	2.7
Citrus reticulata, mandarin	0	0	0	1	3	3
Citrus limon, lemon	0	0	0	2	3	1.5
Total	**46**	**502**		**45**	**238**	

Discussion

In Tahiti, *Bactrocera kirki* (Froggatt) invaded in 1928 and became established (Leblanc et al. 2013a). Subsequently, *B. tryoni* was introduced in 1970 and displaced *B. kirki* in many areas. In 1996, *B. dorsalis* was detected and established, becoming the dominant fruit fly, displacing both *B. kirki* and *B. tryoni* (Leblanc et al. 2013a). The competitive displacement was attributed to several factors including a high reproductive rate (HRN) and increased longevity under mild tropical temperatures (Vargas et al. 1997; Leblanc et al. 2013a). Adult *B. dorsalis* has aggressive behaviour and aggressive larval competition (Ekesi et al. 2009; Leblanc et al. 2013a) and very broad host range (Follett et al. 2021; Dominiak 2022). Additionally, *B. dorsalis* had a developmental advantage in preferred hosts such as *P. guajava* (Vargas et al. 2012; Leblanc et al. 2013b). Another competitive advantage is that *B. dorsalis* attacks fruit at an earlier stage than many other tephritids.

For biosecurity, the understanding of host suitability and reproductive capacity is fundamental information to underpin emergency response plans and effective eradication programs for exotic tephritids. This information facilitates the targeting of the most reproductive hosts, as was achieved in Nauru (Allwood et al. 2002) and the Cook Islands (Allwood 2002). Similarly, these data will assist importing countries in the risk assessment associated with the potential importation of infested produce (Leblanc et al. 2013a).

In my review, some HRNs were not available for all fruits in this assessment. However, there are some consistencies between this HRN assessment and the frequency of fruit samples infested with *B. dorsalis* in the 1995–1997 data (Table 2). Firstly, there are ten hosts listed in Table 2. Of the five fruit most infested by *B. dorsalis* (mango, tropical almond, guava, capsicum, papaya in that order in Table 2), all five hosts had a calculated reproductive advantage for *B. dorsalis*. Of the five hosts less frequently infested by *B. dorsalis*, three hosts (tomato, grapefruit, star fruit in Table 2) had a calculated competitive advantage favouring *B. tryoni.*

Mangoes were the highest competitive ranking (33.7) and were most frequently infested (68). Tropical almond was the second most frequently infested host (28). Jose et al. (2013) considered that tropical almond was an important reservoir for *B. dorsalis* in Africa. Guava was the third most frequently infested host (20) and is a highly suitable fruit for many tephritids (Dominiak 2021b). Guava and tropical almond were both "very good" hosts (Follett et al. 2019) and the competitive advantage was <2.5 for both hosts. Perhaps, both tephritid species could coexist in these hosts given the low reproductive advantage. Capsicums were the fourth most frequently infested host (13) and had a competitive advantage of 31.1 favouring *B. dorsalis.* These data need to

be balanced with host availability in Cairns. Mangoes, guava and tropical almonds were widely available and provided a huge resource for both species. This availability may have negated any advantage for both tephritids. Overall, capsicums were well ranked in all three tables and offer a good candidate for *B. dorsalis* surveillance, followed by mangoes. Because of their size, fruiting capsicum plants could be used as sentinel plants in high risk areas (such as first ports of entry) to optimise early detection of any incursion in most parts of Australia. This is because fresh fruiting capsicum plants could be provided on a regular schedule unlike fruiting mango plants which cannot be put in pots due to their size and weight. Additionally, moving fruiting mango plants in pots offer larger challenges due to their size and weight.

Based on initial data easily available, I infer that reproductive advantage scores of 5 or less indicate a minimal competitive advantage for both tephritid species. If this was the case, I propose that pomelo (4.6), star fruit (2.5), grapefruit (2.4), Surinam cherry (2.3), Tahitian lime (2.1), rose-apple (1.9), Pacific lychee (1.8), strawberry guava (1.8), tropical almond (1.7), Jew plum (1.7), guava (1.6), abiu (1.6), Indian jujube (1.6), tomato (1.2), loquat (1), and Malay apple (1) were about equal for both *B. dorsalis* and *B. tryoni* and these tephritids may co-exist in these hosts. Additionally, any host with a MG ranking (kumquat), P ranking (pomegranate) or NH (finger lime) is unlikely to support an incursion by *B. dorsalis*. Some of these hosts are unlikely to be grown in northern Queensland.

There may be some support for the role of endemic tephritids in minimizing the chances of successful establishment by *B. dorsalis*. Fay (2008) reported that OFF may have arrived 12 months before detection. Furthermore, Cantrell et al. (2002) suggested introduction occurred 2.5 years before detection. It might be inferred that the endemic tephritids caused challenges for the establishment of OFF. Kay (2023) found that *B. tryoni* and *B. neohumeralis* exhibited similar aggressive behaviour of *B. dorsalis* on fruit. These behaviours (including crabbing, wing supination, and pushing (Kay 2023)) may partially explain the delay between incursion and detection at Cairns.

In the 1995 incursion, *B. dorsalis* was originally detected in papaya and the local grower, John Crawford, observed OFF attacking papaya earlier than local tephritids (Fay et al. 1997). Follett et al. (2019) reported a field HRN (142) of papaya for *B. dorsalis*, while a HRN of 500 can be reached in screen cage tests (Follett et al. 2019). The HRN for *B. tryoni* in papaya was 17 so perhaps the establishment of *B. dorsalis* in papaya was to be expected. The reproductive advantage for papaya was comparatively low at 8.4 favouring *B. dorsalis.*

Reitz and Trumble (2002) noted that *B. dorsalis* has a higher net reproductive capacity on certain hosts. However, this competition is host-mediated and the less competitive tephritids persisted in hosts where they were better adapted. In my assessment, there are eight examples where the competitive advantage was > 10 for either species. It is possible that the two tephritids may coexist, but one may evolve superior competitive abilities and eventually displace the less competitive tephritid species over time (Reitz and Trumble 2002).

Another reason for inconsistencies may be the altitude where data was collected. *Bactrocera dorsalis* is reputed to be a lowland fly (Ekesi et al. 2009; Reitz and Trumble 2002). My HRN comparison ignores aspects such as earlier utilisation associated with *B. dorsalis*. In my literature review, papers provided HRN data but rarely gave altitude data and, therefore, HRN figures used here may not all be on the same basis (altitude). Also, pesticide use could skew the eradication data. For example, the use of pesticides and sampling of some hosts such as *Terminalia* spp. and feral guavas as reported by Fay et al. (1997) could have skewed Australian invasion and eradication data. During the *B. dorsalis* eradication, bait spraying was targeted at specific hosts such as mangoes and guavas, and then coffee where later *B. dorsalis* was found breeding. Additionally, usual pesticide applications in commercial crops influence infestation success by the endemic and invader tephritid. Some crops are known to be very suitable to *B. tryoni* and be subject to pesticide programs which might equally disadvantage *B. dorsalis*. Conversely, coffee has few insect problems and receives few pre-harvest insecticides (Fay et al. 1997). There were seven examples of infested *Coffea arabica* but no HRN recorded. In Africa, *Coffea canephora* has a HRN of 370 for *B. dorsalis* (Mwatawala et al. 2009).

Ekesi et al. (2009) noted several mechanisms for competitive displacement between tephritids. Rapid population growth (based on HRN) resulted in pre-emptive use of resources, particularly during egg laying and larval feeding. *Bactrocera dorsalis* is very mobile and has a high dispersive power compared to *Ceratitis*, however, this advantage may not be the case when compared to another *Bactrocer*a such as *B. tryoni*. Therefore, rapid displacement of other species, as occurred in Africa, may not occur in Australia where many *Bactrocera* spp. are resident (Hancock et al. 2000). *Bactrocera tryoni* and *B. neohumeralis* exhibit similar aggressive behaviour on fruit compared to *B. dorsalis* (Kay 2023) with seven identified behaviours in competitive contests. The range of *B. tryoni* extends along the entire eastern seaboard of Australia, including three capital cities and likely first ports of entry (Wylie et al. 2008; Dominiak and Mapson 2017). The sister species, *B. aquilonis* (May) is distributed across northern parts of Western Australia, Northern Territory and Queensland (Cameron et al. 2010). The range of *B. neohumeralis* and *B. bryoniae* extends from northern Queensland down to Sydney, the largest city in Australia (Dominiak and Worsley 2016; Dominiak and Millynn 2022). From the results presented here, *Capsicum*

annum, which is a preferred host of *B. bryoniae* (Dominiak and Millynn 2022) and also is a preferred host of *B. dorsalis* (this paper).

Dominiak and Worsley (2017) reported the presence of *B. jarvisi* in northern NSW while *Z. cucumis* was found just in the south of the Queensland border (Fay et al. 2022). Some, if not all, of these species may exhibit the aggressive behaviour to each other (Kay 2023), and to *B. dorsalis.* Therefore, it is likely that these behaviours, and HRN, are part of the competition that will contribute to any possible establishment success of *B. dorsalis* in Australia (Clarke and Measham 2022).

This comparison has some limitations. It is a comparison between two species based only on HRN. There are other factors including host availability, ripeness or other physical factors which may influence competition between the fruit flies. In biosecurity, the worst-case scenario is always assumed to be the case, irrespective of where the HRN originated. I used the highest HRN figures from all papers. However, some values originate from different continents and the comparison may not be fair. The issues of altitude and climate may influence a fair comparison. Latitudes may be important as a component of climate, or proximity to the equator and this could be an indicator of tolerance to heat or cold. Hassani et al. (2022) found *B. dorsalis* had a distinct preference for lowland (0-300 m ASL) and gradually decreased up to 800 m ASL. Therefore, it is likely that reproductive advantage might be higher at lower altitudes and disfavour *B. tryoni*. Additionally, soils may influence survival. *Bactrocera tryoni* are known to survive relatively well in wet or saturated soils (Hulthen and Clarke 2006; Dominiak et al. 2011) whereas *B. dorsalis* has poor survival in wet soils (Hou et al. 2006). It is likely that *B. tryoni* may dominate *B. dorsalis* at the bottom of slopes in higher rainfall areas, irrespective of HRN.

Therefore, the direct HRN comparison and the calculated competitive advantage may be the worst-case scenario and not warranted in all cases. For instance, for *B. tryoni* in Valencia oranges, Lloyd et al. (2013) found a HRN of 10 in central Queensland whereas Dominiak et al. (2020) reported a HRN of 142 in southern New South Wales, 1120 km further south. This difference may reflect different climate or Qfly population pressure and this difference demonstrates that one HRN does not fit all scenarios. However, for a *B. dorsalis* incursion into Queensland, Lloyd et al. (2013) might be more locally appropriate; if so, the reproductive advantage would change from 12.9 to *B. tryoni* to about one or neutral for both species. Follett et al. (2021) discussed some of the issues influencing host suitability. The use of a wide range of data from different studies and localities is recognised and problematic. However, there is no option when attempting to quantify the invasion threat of an exotic species, given the currently availability of data.

Notwithstanding, this was an assessment to demonstrate how HRN and reproductive advantage could be used to better target vulnerable industries and to identify where surveillance might be best placed. The threat of incursion exists for all countries due to increased trade in fruit and vegetables (Bebber et al. 2014) which are further compounded by international movements of tourists (Robinson and McNeill 2022). For instance, there were 15 documented incursions of fruit flies in New Zealand since the early 20th century (Kean 2017), two of which were of *B. dorsalis* (Hancock 2013). Although they were eradicated, these incursions may occur in future. Therefore, trap surveillance for exotic fruit flies such as *B. dorsalis* is key for their early detection in fruit fly-free countries. Hosts with higher competitive advantage may be better options for surveillance sites.

The first ports of entry of fruit fly host materials may signal an obvious early warning of fruit fly incursions (Gillespie 2003; Wylie et al. 2008; Augustin et al. 2012). There was no trapping surveillance at Cairns at the time of the *B. dorsalis* incursion in 1997 (Fay et al. 1997; Gillespie 2003), however the detection in fruit prompted an increased fruit fly trapping program in Australia. In Australia, *B. dorsalis* was not detected in these ports and therefore, a second tier of surveillance in vulnerable crops may be a valuable support to the first ports of entry. HRN could be used in ports, market access, and urban areas, which mostly offer favourable sites for many tephritids because of the increased temperature and moisture regimes (Dominiak et al. 2006; Raghu et al. 2000) and a continuum of hosts. In these areas, hosts are grown opportunistically and are usually poorly managed, which may result in secondary spread of tephritids into nearby commercial orchards (Dominiak et al. 1998).

Furthermore, HRN should be integrated in the System Approach of pest management (Dominiak 2019; van Klinken et al. 2020) and advising the appropriate disinfestation treatment required (Balagawi et al. 2021).

Regarding the possible introduction of infested fruits by air passengers, HRN could be used to inform targeted surveillance and education at airports. Fruit fly host materials are commonly carried by international tourists. Of the domestic flights in Papua New Guinea during February and March 2000, 38.9% of passengers carried fresh commodities, including 34 commodities that were known fruit fly hosts. About 20% of crops are infested in Papua New Guinea (Putulan et al. 2004). Hosts were mainly bananas, oranges, cucumbers, mangoes, passion fruits and guavas (Putulan et al. 2004). Similarly, in Japan from 1979 to 1998, authorities confiscated 1,093 items of OFF hosts, mainly mangoes, *Syzygium* sp., longans, guavas, star apples and capsicums (Iwaizumi 2004).

What are the future steps for HRN and its use in Australia? Unfortunately and regarding potential incursions,

there is HRN data only for *B. tryoni* and not the other endemic tephritids. Therefore, the possible influence of these other tephritids is unknown but may impact any calculated reproductive advantage between *B. dorsalis* and *B. tryoni*. Thus, more data is required for HRN for hosts, and particularly for other Australian fruit fly species. Additional data on issues such as climate, altitude, latitude and host ripeness would facilitate a more meaningful analysis of invasive potential. Additionally, more research is required to evaluate the role of HRN in fruit fly management and trade. This additional data would provide the basis for a more informed view of incursion risk, and the establishment of any fruit fly in any circumstance or country.

However, based on my assessment, capsicums may be well-suited as sentinel plants for the early detection of *B. dorsalis* in many parts of Australia. Capsicums are grown throughout the year (particularly in protected cropping) in most parts of Australia. These capsicums are sold mainly for domestic consumption although some capsicums are imported. Capsicums are ranked third in the *B. dorsalis* reproductive advantage in Table 1. This review should not be seen as definitive because of much missing data. However, it does demonstrate how HRN can be used to better inform surveillance, management and trade.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42690-024-01168-x.

Acknowledgements Harry Fay provided many insights which greatly improved the manuscript. Fay Haynes, Megan Power and Asad Shabbir reviewed a pre-submission version of the manuscript and provided useful suggestions. One anonymous journal reviewer provided useful comments.

Author contributions The author conceived the concept, conducted the literature review and created the manuscript.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions NSW Department of Primary Industries funded this review. There were no specific grants or funded projects. Open access publishing was facilitated by New South Wales Department of Planning and Environment, as part of the Springer-New South Wales Department of Planning and Environment agreement via the Council of Australian University Librarians.

Declarations

Conflict of interest The author declared that there are no conflicts of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Allwood AJ (2002) Eradication of Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) in Rarotonga, Cook Islands. Secretariat of the Pacific Community Report. Suva, Fiji

Allwood AJ, Vueti ET, Leblance L, Bull R (2002) Eradication of introduced Bactrocera species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques. In: Veitch CR, Clout MN (eds) Turning the tide: The eradication of invasive species. IUCN Publications Services Unit Cambridge, UK, In, pp 19–25

Anon (1998) Report of the papaya fruit fly scientific advisory panel meeting no. 5, Cairns. 14 January 1998. pp 194

Augustin S, Boonham N, De Kogel WJ, Donner P, Faccoli M, Lees DC, Marini L, Mori N, Toffolo EP, Quilici S, Roques A, Yart A, Battisti A (2012) A review of pest surveillance techniques for detecting quarantine pests in Europe. Bull OEPP/EPPO 42:515–551

Balagawi S, Archer J, Cruickshank D, Cruickshank C, Barchia I (2021) Cold treatment: an effective post harvest disinfestation treatment for *Bactrocera tryoni* (Diptera: Tephritidae) in gold3 kiwifruit. Aust Entomol 60:621–627

Bebber PD, Holmes T, Smith D, Gurr SJ (2014) Economic and physical determinants of the global distributions of crop pests and pathogens. New Phytol 202:901–910

Boinahadji AK, Coly EV, Dieng EO, Diome T, Sembene PM (2019) Interactions between the oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) and its host plant range in the Niayes area in Senegal. J Entomol Zool Stud 7:855–864

Cameron EC, Sved JA, Gilchrist AS (2010) Pest fruit fly (Diptera: Tephritidae) in northwestern Australia: One species or two? Bull Entomol Res 100:197–206

Cantrell B, Chadwick B, Cahill A (2002) Fruit fly fighters: eradication of the Papaya Fruit fly. CSIRO Publishing

Clarke AR, Measham PF (2022) Competition: A missing component of fruit fly (Diptera: Tephritidae) risk assessment and planning. Insects 13:1065

Dominiak BC (2019) Components of a systems approach for the management of Queensland fruit fly *Bactrocera tryoni* (Froggatt) in a post dimethoate fenthion era. Crop Prot 116:56–67

Dominiak BC (2021a) Surveillance for exotic fruit fly of the subfamily Dacinae (Insecta, Diptera, Tephrididae) and a review of the Dacinae established in Sydney, Australia, between 2010 and 2019. N Z Entomol 43:114–121

Dominiak BC (2021b) Guava (*Psidium guajava* (L.) may be a very good host for many tephritids. Gen Appl Entomol 49:31–34

Dominiak BC (2022) The use of host reproduction number and host suitability index to rank hosts of fruit flies in Africa. Int J Trop Insect Sci 42:2717–2729

Dominiak B, Millynn B (2022) A review of *Bactrocera bryoniae* (Tryon) and revised distribution in Asia and Australia, with a focus on New South Wales. Gen Appl Entomol 50:1–9

Dominiak BC, Mapson R (2017) Revised distribution of *Bactrocera tryoni* in Eastern Australia and effect on possible incursions of Mediterranean fruit fly: Development of Australia's eastern trading block. J Econ Entomol 110:2459–2465

Dominiak BC, Worsley P (2016) Lesser Queensland fruit fly *Bactrocera neohumeralis* (hardy) (Diptera: Tephritidae: Dacinae) not detected in inland New South Wales or south of Sydney. Gen Appl Entomol 44:9–15

Dominiak BC, Worsley P (2017) Review of the southern boundary of Jarvis fruit fly *Bactrocera jarvisi* (Tryon) (Diptera: Tephritidae:

Dacinae) and its likely southern distribution in Australia. Gen Appl Entomol 45:1–7
Dominiak BC, Kerruish B, Cooper D (2020) Reproductive capacity of Queensland fruit fly *Bactrocera* tryoni Froggatt in different host fruit – a field assessment in southern New South Wales. Gen Appl Entomol 48:39–42
Dominiak BC, Mavi HS, Nicol HI (2006) Effect of town microclimate on the Queensland fruit fly Bactrocera tryoni. Aust J Exper Agri 46:1239–1249
Dominiak BC, Rafferty TD, Barchia I (1998) An analysis of travellers carrying fruit near Griffith, NSW, during Easter 1996 to assess the risk of Queensland fruit fly (*Bactrocera tryoni* Froggatt). Gen Appl Entomol 28:13–19
Dominiak BC, Sundaralingham S, Jiang L, Nicol HI (2011) Effects of conditions in sealed plastic bags on eclosion of mass-reared Queensland fruit fly *Bactrocera tryoni*. Entomol Exper Applic 141:123–128
Drew RAI (1997) The economic and social impact of the *Bactrocera papaya* Drew and Hancock (Asian Papaya fruit fly) outbreak in Australia. In: Allwood AJ, Drew RAI (eds) Management of fruit flies in the Pacific. ACIAR Proceed 205–207
Early R, Bradley B, Dukes J, Lawler JJ, Olden JD, Blumenthal DM, Gonzalez P, Groholz ED, Ibanez I, Miller LP, Sorte CJB, Tatem AJ (2016) Global threats from invasive alien species in the twenty-first century and national response capacities. Nat Commun 7:e12485
Ekesi S, Billah MK, Nderitu PW, Lux SA, Rwomushana I (2009) Evidence for competitive displacement of *Ceratitis cosyra* by the invasive fruit fly *Bactrocera invadens* (Diptera: Tephritidae) on mango and mechanisms contributing to the displacement. J Econ Entomol 102:981–991
Fay HAC (2008) Papaya fruit fly eradication program in Australia: Key factors in its success. Int Symp Recent Progress Tephritid Fruit Flies Manag 47–53
Fay HAC, DeFaveri S, Dominiak BC (2022) A new southern detection of *Zeugodacus Cucumis* (French 1907) in northern New South Wales. Gen Appl Entomol 50:31–37
Fay HAC, Drew RAI, Lloyd AC (1997) The eradication program for papaya fruit fly (*Bactrocera papayae* Drew and Hancock) in north Queensland. Pp. 259–261. *In* Management of fruit flies in the Pacific. A.J. Allwood and R.A.I. Drew (eds). ACIAR Proc
Follett PA, Haynes FEM, Dominiak BC (2021) Host suitability index for polyphagous tephritid fruit flies. J Econ Entomol 114:1021–1034
Follett PA, Jamieson L, Hamilton L, Wall M (2019) New associations and host status: infestability of kiwifruit by the fruit fly species Bactrocera dorsalis, Zeugodacus cucurbitae and Ceratitis capitata (Diptera: Tephritidae). Crop Prot 115:113–121
Gillespie P (2003) Observations on fruit flies (Diptera: Tephritidae) in New South Wales. Gen Appl Entomol 32:41–47
Hancock DL (2013) A revised checklist of Australian fruit flies (Diptera: Tephritidae). Aust Entomol (Brisb) 40:219–236
Hancock DL, Osborne R, Broughton S, Gleeson P (2000) Eradication of *Bactrocera papayae* (Diptera: Tephritidae) by male annihilation and protein baiting in Queensland, Australia. *In* Area-wide control of fruit flies and other insect pests. pp.381–388. Eds K.H.Tan. Penerbit Universiti Sains Malaysia, Penang, 2000
Hassani IM, Delatte H, Ravaomanarivo LHR, Nouhou S, Duyck P-F (2022) Niche partitioning via host plants and altitude among fruit flies following the invasion of *Bactrocera dorsalis*. Agr for Entomol 24:575–585
Hoskins JL, Rempoulakis P, Stevens MM, Dominiak BC (2023) Biosecurity and management strategies for economically important exotic tephritid fruit fly species in Australia. Insects 14:801
Hou B, Xie Q, Zhang R (2006) Depth of pupation and survival of the oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae) pupae at selected soil moistures. Appl Entomol Zoll 41:515–520
Hulthen AD, Clarke AR (2006) The influence of soil type and moisture on pupal survival of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae). Aust J Entomol 45:16–19
Huxham KA (2002) A unique fruit fly monitoring and control system – Australia's frontline of northern defense. Proc 6th Int Fruit Fly Symp 6–10 May, 2002 Stellenbosch S Afr 331–334
Iwaizumi R (2004) Species and host record of the *Bactrocera dorsalis* complex (Diptera: Tephritidae) detected by the plant quarantine of Japan. Appl Entomol Zool 39:327–333
Jose L, Cugala D, Santos L (2013) Assessment of invasive fruit fly fruit infestation and damage in Cabo Delgado Province, Northern Mozambique. Afr Crop Sci J 21:21–28
Kay BJ (2023) The complexity of competition between three native Australian fruit fly species, *Bactrocera tryoni*, *B. neohumeralis* and *B. jarvisi* in a challenging environment. Doctor of Philosophy thesis. Queensland University of Technology. 202
Kean JM (2017) Summary of research underpinning New Zealand's National Fruit fly Surveillance programme (No. 6451). Ministry for Primary Industries
Leblanc L, Vargas RI, Putoa R (2013a) From eradication to containment: invasion of French polynesia by *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) and releases of two natural enemies: A 17-year case study. Proc Hawaii Entomol Soc 45:31–43
Leblanc L, Vueti ET, Allwood AJ (2013b) Host records for fruit flies (Diptera: Tephritidae: Dacini) in the Pacific Islands: 2. Infestation statistics on economic hosts. Proc Hawaii Entomol Soc 45:83–117
Lloyd AC, Hamacek EL, Smith D, Kopittke RA, Gu H (2013) Host susceptibility of citrus cultivars to Queensland fruit fly (Diptera: Tephritidae). J Econ Entomol 106:883–890
MacLellan R, King K, McCarthy B, France S (2021) National fruit fly surveillance programme annual report. Surve 48:131–134
Moquet L, Payet J, Glenac S, Delatte H (2021) Niche shift of tephritid species after the oriental fruit fly (*Bactrocera dorsalis*) invasion in La Reunion. Divers Distrib 27:109–129
Murphy J (2022) Funding to stop exotic fruit fly island hopping to mainland. Insect Pest Control Newsletter. Int At Energy Agency 37
Mwatawala MW, De Meyer M, Makundi RH, Maerere AP (2006) Seasonality and host utilization of the invasive fruit fly, *Bactrocera invadens* (Dipt., Tephritidae) in central Tanzania. J Appl Entomol 130:530–537
Mwatawala MW, De Meyer M, Makundi RH, Maerere AP (2009) Host range and distribution of fruit-infesting pestiferous fruit flies (Diptera: Tephritidae) in selected areas of Central Tanzania. Bull Entomol Res 99:629–641
Ormsby MD (2021) Establishing criteria for the management of tephritid fruit fly outbreaks. CABI Agric Biosci 2:23
Plant Health Australia (2018) The Australian handbook for the identification of fruit flies. Version 3.0. Plant Health Australia, Deakin, ACT Australia 2600, pp 157
Pozsgai G, Lovei GL, Vasseur L, Gurr G, Batary P, Korponal J, Littlewood NA, Liu J, Mora A, Obrycki J, Reynolds O, Stockan JA, VanVolkenburg H, Zhang J, Zhou W, You M (2021) Irreproducibility in searches of scientific literature: A comparative analysis. Ecol Evol 11:14658–14668
Putulan D, Sar S, Drew RAI, Raghu S, Clarke AR (2004) Fruit and vegetable movement on domestic flights in Papua New Guinea and the risk of spreading pest fruit-flies (Diptera: Tephritidae). Int J Pest Manag 50:17–22
Raghu S, Clarke AR, Drew RAI, Hulsman K (2000) Impact of habitat modification on the distribution and abundance of fruit flies (Diptera: Tephritidae) in southeast Queensland. Pop Ecol 42:153–160

Reitz SR, Trumble JT (2002) Competitive displacement among insects and arachnids. Annu Rev Entomol 47:435–465

Robinson AP, McNeill MR (2022) Biosecurity and post-arrival pathways in New Zealand: Relating alien organism detections to tourism indicators. NeoBiota 71:51–69

Rwomushana I, Ekesi S, Gordon I, Ogol CKPO (2008) Host plants and host plant preference studies for *Bactrocera invadens* (Diptera: Tephritidae) in Kenya, a new invasive fruit fly species in Africa. Ann Entomol Soc Am 101:331–340

Sadler RJ, Florec V, White B, Dominiak BC (2011) Calibrating a jump-diffusion model of an endemic invasive: Metamodels, statistics and Qfly. In Sustaining our Future: Understanding and Living with Uncertainty, MODSIM 2011 International Congress on Modelling and simulation 7–11 December. 2011. Eds Chan F & Marinova D). Model Simul Soc Aust N Z Perth Aust

Schutze MK, Akertarawong N et al (2015) Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): Taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. Syst Entomol 40:456–471

Suckling DM, Kean JM, Stringer LD, Caceres-Barrios C, Hendrichs J, Reyes-Flores J, Dominiak BC (2016) Eradication of tephritid fruit fly populations: Outcomes and prospects. Pest Manag Sci 72:456–465

van Klinken RD, Fiedler K, Kingham L, Collins K, Barbour D (2020) A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. Crop Prot 129:104994

Vargas RI, Leblanc L, Putoa R, Eitam A (2007) Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius Arisanus* (Hymenoptera: Braconidae) on economically important fruit flies in French polynesia. J Econ Entomol 100:670–679

Vargas RI, Leblanc L, Putoa R, Pinero JC (2012) Population dynamics of three *Bactrocera* spp. fruit flies (Diptera: Tephritidae) and two introduced natural enemies, *Fopius arisanus* (Sonan) and *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), after an invasion by *Bactrocera dorsalis* (Hendel in Tahiti. Biol Control 60:199–206

Vargas RI, Walsh WA, Kanehisa D, Jang EB, Armstrong JW (1997) Demography of four hawaiian fruit flies (Diptera: Tephritidae) reared at five constant temperatures. Ann Entomol Soc Am 90:162–168

Woods B, Lacey IB, Brockway CA, Johnstone CP (2005) Hosts of Mediterranean fruit fly Ceratitis capitata (Wiedemann) (Diptera: Tephritidae) from Broome and the Broome Peninsula, Western Australia. Aust J Entomol 44:437–441

Wylie FR, Griffiths M, King J (2008) Development of hazard site surveillance programs for forest invasive species: a case study from Brisbane, Australia. Aust for 71:229–235

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Check for updates

Received: 14 December 2021 | Revised: 28 March 2022 | Accepted: 14 April 2022

DOI: 10.1002/ece3.8880

Ecology and Evolution Open Access WILEY

REVIEW ARTICLE

Sequential invasions by fruit flies (Diptera: Tephritidae) in Pacific and Indian Ocean islands: A systematic review

Pierre-François Duyck[1,2] | Hervé Jourdan[3] | Christian Mille[2]

[1]CIRAD, UMR PVBMT, Noumea, New Caledonia

[2]IAC, Equipe ARBOREAL, La Foa, New Caledonia

[3]Aix Marseille Univ, Avignon Univ, CNRS, IRD, IMBE, Noumea, New Caledonia

Correspondence
Pierre-François Duyck, CIRAD UMR PVBMT, Peuplements Végétaux et Bioagresseurs en Milieu Tropical, Institut Agronomique néo-Calédonien (IAC), Centre IRD, BP A5 – 98848 Nouméa, New Caledonia.
Email: duyck@cirad.fr

Funding information
Centre de Coopération Internationale en Recherche Agronomique pour le Développement; Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt

Abstract

The aim of our review was to examine the cases of Tephritidae invasions across island systems in order to determine whether they follow a hierarchical mode of invasion. We reviewed the literature on factors and mechanisms driving invasion sequences in Pacific and Southwest Indian Ocean islands and gathered every record of invasion by a polyphagous tephritid in island groups. From invasion date or period, we defined an invasion link when a new fruit fly established on an island where another polyphagous tephritid is already resident (that was indigenous or a previous invader). Across surveyed islands, we documented 67 invasion links, involving 24 tephritid species. All invasion links were directional, i.e., they involved a series of invasions by invaders that were closely related to a resident species but were increasingly more competitive. These sequential establishments of species are driven by interspecific competition between resident and exotic species but are also influenced by history, routes, and flows of commercial exchanges and the bridgehead effect. This information should be used to improve biosecurity measures. Interactions between trade flow, invasive routes, and the presence of invasive and resident species should be integrated into large-scale studies.

KEYWORDS
biosecurity, exotic species, human-mediated dispersal, interspecific competition, patterns of invasion

TAXONOMY CLASSIFICATION
Community ecology; Entomology; Invasion ecology

1 | INTRODUCTION

Globally, the increase in the number of invasive alien species shows no sign of saturation, with an increasing number of species threatening to invade new territories (Seebens et al., 2017). The threat of invasion is especially high in remote places such as isolated islands because they often offer vacant niches that alien species can reach via new human-created pathways (Moser et al., 2018; Seebens et al., 2018). Communities that are vulnerable to invasion have unsaturated niche space mainly because of evolutionary history in isolation (islands), dispersal limitation, and/or anthropogenic disturbance (David et al., 2017).

Understanding general rules governing invasions is required to improve biosecurity measures and therefore to develop sustainable

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2022 The Authors. *Ecology and Evolution* published by John Wiley & Sons Ltd.

agriculture and to conserve biodiversity (Hulme, 2010; Sikes et al., 2018). Indeed, if many pests are already causing significant damage to crops in various territories, the most serious in terms of crop damage and effects on human populations are often those which are not yet present but which threaten to invade (Fournier et al., 2019; Hulme, 2021; Paini et al., 2016). Once an exotic species has been established in a territory, its eradication is often impossible, and the implementation of control measures is difficult, expensive, and often polluting (Simberloff et al., 2013).

Many species in the family Tephritidae (true fruit flies) are major pests of fruit and vegetable crops in most tropical and subtropical countries (Qin et al., 2015; Schutze et al., 2015; Vargas et al., 2015; White & Elson-Harris, 1992). Numerous cases of biological invasions have been observed in this family around the world despite serious and strong quarantine procedures (Clarke et al., 2005; Duyck et al., 2004; Ekesi et al., 2009; Moquet et al., 2021). Most of these invasions have catastrophic consequences, including the destruction of fruits and vegetables and even the destruction of entire crops, dependence on imports, change of the phytosanitary status in the context of the International Standards for Phytosanitary Measures and the International Plant Protection Convention (IPPC) (https://www.ippc.int/) resulting in the inability to export when a quarantine regulated species arrives, and the use of chemicals for control (N'depo et al., 2015). It is therefore essential to avoid and prevent these introductions by strengthening biosecurity procedures (Phillips, 2013).

When introduced, a species may persist only if it is able to pass through environmental and biotic filters (David et al., 2017). Biotic filters include the level and availability of resources, competition, and natural enemies, which define the realized niche (Broennimann et al., 2007). Because invasive species must exploit available resources in the recipient ecosystem, they establish trophic interactions with the resident species (David et al., 2017). But, indirect biotic factors such as exploitative competition, while they often occur in invasion processes (White et al., 2006), are rarely studied in detail because assessing resource density and dynamics is difficult (Hart et al., 2018).

In the Tephritidae family, abundance and distribution are mainly structured by both abiotic factors, such as temperature and humidity, and biotic ones, mostly host plant distribution and abundance (Duyck et al., 2004; Facon et al., 2021). Although interspecific competition among Tephritidae may not be very important in native communities (Clarke, 2017), in an unstable situation, such as occurs when resident species interact with closely related invasive species, this interspecific exploitative competition may be very strong and asymmetrical, leading to the competitive exclusion or displacement of resident species (Duyck et al., 2004, 2006; Ekesi et al., 2009; Moquet et al., 2021). In contrast, substantial interspecific competition at the inception of invasion may prevent the establishment of less competitive species. This should subsequently result in invasion sequences that involve increasingly competitive invasive species. In their review, Duyck et al. (2004) listed cases of invasions by polyphagous Tephritidae species and showed that these invasions were "sequential", i.e., they involved a hierarchical mode of invasion with invaders being increasingly competitive over time. Trade history and networks also affect the distribution and occurrence of invasive species (Chapman et al., 2017; MacLachlan et al., 2021) and may also lead to a hierarchical mode of invasion (Duyck et al., 2004).

Eighteen years after the synthesis by Duyck et al. (2004), many new cases of invasions by Tephritidae have been documented worldwide. Numerous recent studies on invasive tephritids, whether focused on field data, population genetics, or laboratory experiments (Charlery de la Masselière, Facon, et al., 2017; Clarke et al., 2005; Hafsi, Facon, et al., 2016), have increased our understanding of the invasion process. In particular, *Bactrocera dorsalis* has continued its range of expansion across Africa and in Indian Ocean islands (Ekesi et al., 2016; Hassani et al., 2016; Moquet et al., 2021; Rasolofoarivao et al., 2021).

The aim of our paper is to document invasions of Tephritidae across both Pacific and Southwest Indian ocean islands. We focused on these regions because such island systems offer an ideal opportunity to track and monitor community processes in the context where numerous invasions by tephritids have occurred and have been deeply studied both recently and in the last century with fruit flies. We chose to study invasions on islands because they can be considered to be independent of invasions of continental areas, for which it would be necessary to think of invasions in terms of continuous expansion in space (Moser et al., 2018; Russell et al., 2017). We used previously published data to answer the following questions: (i) Do Tephritidae invasions always follow a hierarchical mode of invasion? and (ii) What are the factors and mechanisms driving invasion sequences?

2 | METHODS

We conducted a systematic review of literature on polyphagous tephritid invasions in island groups from the Indian Ocean and Pacific region. We first explored published work from Web of Science using the query "Tephritidae AND (invasion OR introduction)" as keywords for islands from Pacific Islands or Southwest Indian Ocean Islands. However, as a lot of information on occurrence and invasion by Tephritidae are present in gray literature, we therefore tracked information from unformal and gray literature such as various proceedings of conferences that took places in the Indian Ocean and Pacific islands and information from leaflets from the Pacific Fruit Fly Project (Land and resource Division, Pacific Community). We also extracted information from PhD theses conducted on Tephritidae in the different islands and older technical reports being in French or English that have been produced by local organizations and services or regional organizations.

The cases selected in the present study need to match different eligibility criteria: (i) the invasive species need to have invaded an island in the Pacific or Indian Ocean, (ii) the invasive species must be a polyphagous tephritid, and (iii) another polyphagous tephritid was already present in the invaded area during the invasion process. These criteria were selected in order to ensure that the ecological niches of the two species largely overlapped. We screened full-text

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

for the mention of invasion of a polyphagous tephritid and/or for the presence of polyphagous tephritid, being indigenous or previously established, in each reference. Then, we kept all observations of a polyphagous tephritid become established on islands where important polyphagous species were already dwelling because they were indigenous or had previously invaded.

Regarding the coverage of our data set, we need to precise various points regarding both taxonomy and post-invasion event (such as successful eradication program). Some invasive species, such as *B. dorsalis* in Australia or Nauru (Allwood et al., 2002; Suckling et al., 2016), were eradicated after their introduction but have been considered in this review as successful invasions in the presence of one or several already present species. *Bactrocera philippinensis* has been described as invasive in Palau but has been further synonymised with *B. carambolae*, which has been synonymised with *B. dorsalis* (Clarke et al., 2005; Schutze et al., 2015). Although *B. occipitalis* belongs to the *B. dorsalis* complex, it is considered a distinct species. *Bactrocera dorsalis* was first identified as *B. papayae* in PNG and *B. papayae* was later synonymised with *B. dorsalis* (Schutze et al., 2015).

Even if it is still dwelling in La Réunion Island, the Mascarene fruit fly *Ceratitis catoirii* is considered to be extinct in Mauritius because it has not been observed since 1957 (White et al., 2006). We therefore have not identified links between this species and species that invaded Mauritius after this date. *Ceratitis malgassa* is considered an endemic species in Mauritius and Comoros (De Meyer et al., 2012), but only a few specimens were observed in the latter study, and the species is rarely mentioned in the literature. We are not sure whether this species was present in Mauritius before the first species invaded. We therefore did not include this species in defining invasion links for these territories. Regardless, these cases would not modify invasion sequences as these species are not invasive in other territories.

For most of the studied islands, dates or periods of invasion by polyphagous Tephritidae have been documented (Appendix S1), but one limitation on this aspect of our study could be the accuracy about the date of invasion. A lag of detection may exist according to the presence and extent of a monitoring network. However, we considered that invasion by polyphagous Tephritidae is usually so dramatic for fruit producers that invasion and spread of new species are quickly detected even in the context of lack of regular monitoring. When no date was available or in case of uncertainty, we used a range of the date of invasion.

We defined an "invasion link" as occurring when a species established on an island in the presence of another polyphagous tephritid (indigenous or previously established). Several invasion links are established for islands where several polyphagous tephritid were present when the invasion occurred. When several species subsequently invaded the same island, we defined this situation as an "invasive series".

In order to visualize invasion links, we performed a diagram using the Sankey Network function from package *networkD3* (Allaire et al., 2017) in R statistical software v4.0.2 (R Core Team, 2021) with the different Tephritidae species set as nodes and the invasions links between two species as links using the number of invasions links recorded between two species as value.

3 | RESULTS AND DISCUSSION

3.1 | Invasions links are directional

Based on our extensive literature review, we documented 67 invasion links of an invasive polyphagous tephritid species occurring with a resident polyphagous tephritid species, i.e., an indigenous species or a previous invader that achieved establishment in Pacific and Southwest Indian Ocean islands (Appendix S1, Figures 1 and 2). Our study focuses on 24 fruit species, which are involved in at least one invasion situation (Figures 1 and 2). All invasion links documented in our review were directional: reciprocal invasions were never documented, i.e., if species A invaded an island occupied by species B, then B never invaded an island previously occupied by A. These invasion links were also "transitive" (i.e., when A invaded in the presence of B, and B in the presence of C, there are some instances of A invading in the presence of C but not the reverse). Thirty links of invasions have been documented in the Pacific islands, and thirty-seven links of invasions have been documented in the Southwest Indian Ocean islands.

These observations confirm previous hypotheses of directional invasions (Duyck et al., 2004). For some islands, we observed a series of invasions, i.e., the sequential invasion of the same island by several species. This is particularly relevant in La Réunion, Mauritius, and French Polynesia where four invaders have established in a sequential manner. From the invasion series reported, *B. dorsalis* was always the last species to spread when it is present. *Bactrocera dorsalis* invaded 13 islands where other polyphagous tephritid species were already present; the first case was in Hawaii in 1945, and the last one was in La Réunion in 2017. For *B. dorsalis*, this represents 17 and 15 invasion links, respectively, in Southwest Indian Ocean islands and Pacific islands (Figure 3, Appendix S1).

3.2 | Causes of observed pattern: Interspecific competition hypothesis

The observed patterns could have several causes. First, the limitation of resident species by interspecific competition along with an increasing competitive ability of the next invaders can lead to directional links of invasions (Duyck et al., 2004, 2006). Although abundance data for the different tephritid species are not always available before and after invasions, some competitive displacements have been clearly documented. In La Réunion and in French Polynesia, *B. dorsalis* reduced the abundance and displaced dominant tephritids that were already present (Moquet et al., 2021; Vargas et al., 2012). Competitive displacements have also been well described on the African mainland where *B. dorsalis* has displaced four species *C. rosa*, *C. cosyra*, *C. quilicii*, and *C. capitata* in different countries

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

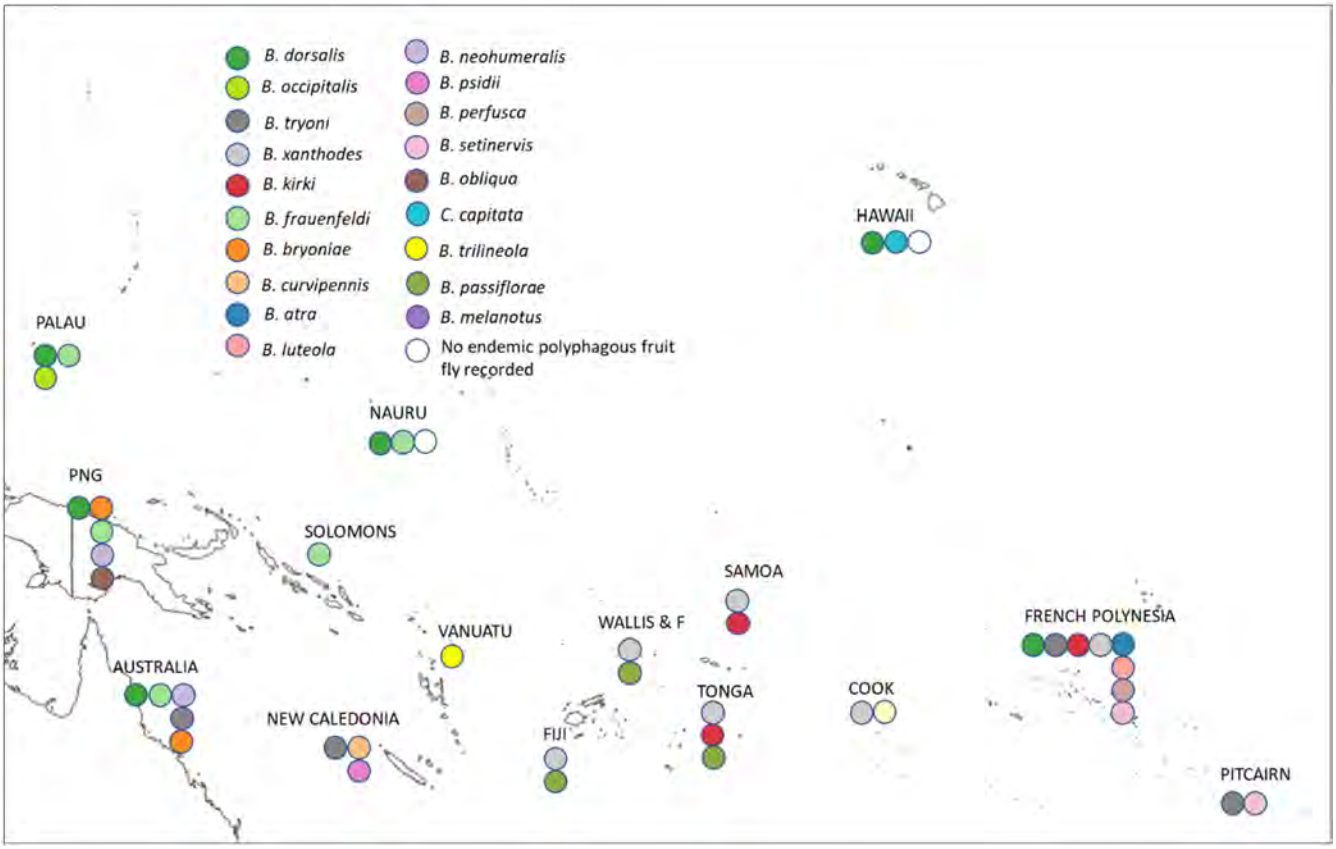


FIGURE 1 Invasion among 15 Pacific territories by polyphagous fruit flies. For each territory, the sequence of circles extends from indigenous species (when present) on the right to invasive species to the left, with 1st-, 2nd-, 3rd-, and 4th-order invaders in temporal sequence from right to left using invasion date or period from Appendix S1. Some species were eradicated after introduction (such as *B. dorsalis* in Nauru and in Australia) but represent successful cases of invasion of one polyphagous species in the presence of another polyphagous species

(Ekesi et al., 2009; Mwatawala et al., 2009; Rwomushana et al., 2008). The importance of interspecific competition among polyphagous tephritids has been studied in detail in the laboratory with reared populations (Duyck et al., 2006); the results showed that each successive invader was a better competitor than the previous invaders or native species in terms of exploitative competition between larvae or of female interference. These hierarchies in competitive ability also follow an *r*/*K* continuum with the last species established being competitively dominant and more *K*-selected than the already resident species (Duyck et al., 2007). Recent invaders, such as *B. dorsalis* or *B. zonata* tend to produce fewer, but larger, juveniles, delay the onset but increase the duration of reproduction, and survive longer than earlier ones (Duyck et al., 2007; Vargas et al., 2000).

Should *B. dorsalis* be considered a super invader? In most invasion series involving polyphagous tephritids documented to date, *B. dorsalis* appears as the last species to establish and to be dominant in terms of abundance (Hassani et al., 2016; Moquet et al., 2021; Vargas et al., 2012). This seems not to be the case, however, in Papua New Guinea (PNG) or in Madagascar; although *B. dorsalis* has invaded both places, the indigenous *B. frauenfeldi* remains very abundant on many hosts in PNG (Leblanc et al., 2013; Putulan et al., 2004), and the same is true for *C. malgassa* in Madagascar (Rasolofoarivao et al., 2021). These situations could be explained by ecological effects, such as a high diversity of fruit fly species in both places, or by evolutionary effects, such as the presence of different *B. dorsalis* strains (Schutze et al., 2015).

On the other hand, not all researchers agree that interspecific competition dominates relationships among Tephritidae. Tephritid abundance may not be generally limited by interspecific competition for fruit resources (Clarke, 2017), although abundances may be sufficiently high to result in interspecific competition during biological invasions. Also, in a recent study using joint species distribution modeling and network inference, Facon et al. (2021) suggest that interspecific competition among the tephritids of La Réunion was less important than expected. Interspecific competition may not be currently important, however, if niche partitioning caused by intense interspecific competition previously occurred; this paradox has been termed "the ghost of competition past" (Connell, 1980). Competition experiments involving the modification of species densities in the field are difficult (Hart et al., 2018) to perform but would help clarify the importance of interspecific competition when invasion occurs.

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

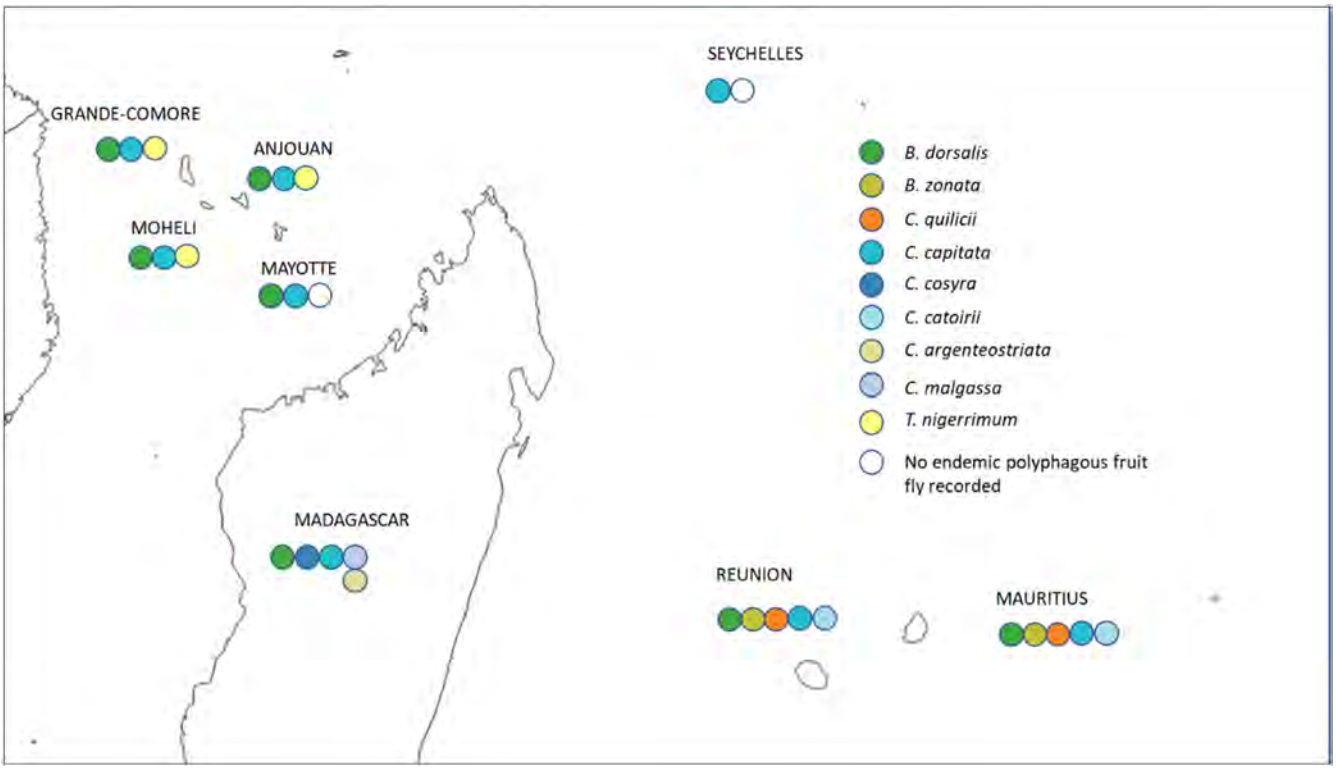


FIGURE 2 Invasion of eight islands in the Southwest Indian Ocean by polyphagous fruit flies. For each territory, the sequence of circles extends from indigenous species (when present) on the right to invasive species to the left, with 1st-, 2nd-, 3rd-, and 4th-order invaders in temporal sequence from right to left using invasion date or period from Appendix S1

3.3 | Causes of observed pattern: History, routes, and flows of commercial exchanges

Patterns of invasion are largely governed by global trade networks (Chapman et al., 2017). The observed patterns of sequential invasions by polyphagous Tephritidae may also have been caused by the history, routes, and flow of commercial exchanges. Overall, the invasion of Indian Ocean islands by polyphagous *Ceratitis* spp. from Africa preceded invasion by polyphagous *Bactrocera* spp. from Asia (Appendix S1). The increasing trade between Asia and the rest of the world has certainly promoted invasions by *Bactrocera* spp. Worldwide, several waves of invasions may have therefore led to this hierarchical mode of invasion, i.e., to directional invasions (Bertelsmeier & Ollier, 2021; Bonnamour et al., 2021). In the case of Tephritidae, the first wave with several *Ceratitis* spp. native to Africa may have spread across Indian Ocean islands, establishing "bridgeheads" from island to island according to the trade routes during the first part of the 20th century. Distance to the native area seems also to influence the probability of introduction: except for the invasion of Hawaii by *C. capitata*, *Ceratitis* spp. has not invaded the Pacific islands. In the late part of the 20th century, the second wave of *Bactrocera* spp. mostly native to Asia colonized most of the studied islands; this second wave was associated with new trade routes. Most recently, these islands have been invaded by *B. dorsalis* (Appendix S1).

3.4 | Causes of the observed pattern: The bridgehead effect

As an increasing number of species are invasive worldwide, introduced populations often become a source of new invasions *via* secondary introductions, a pattern that has been termed the "bridgehead effect" (Bertelsmeier & Keller, 2018; Bertelsmeier & Ollier, 2021). The bridgehead effect may explain at least some cases of the observed pattern of sequential invasions by Tephritidae. As indicated by population genetics data, for instance, invasions of French Polynesia by *B. tryoni* involved invasive populations from New Caledonia (Popa-Báez et al., 2020). In invading most of the Indian Ocean islands, *B. dorsalis* has probably moved from one island (one bridgehead) to another. The bridgehead effect may also be involved in the introduction of *B. dorsalis* in French Polynesia from an invasive population in Hawaii. Partial invasion routes are known for some species, but additional population genetics data will increase our understanding of the relevance of the bridgehead effect to the observed pattern of sequential invasions. Population genetics studies may also reveal that invasiveness may differ among populations or strains of tephritids (Clarke et al., 2005; Godefroid et al., 2015). Evolutionary adaptation *via* genetic admixture among several invasion events may also complete the bridgehead effect and lead to invasion success, which has been shown in the worldwide invasion of *Drosophila suzukii* (Fraimout et al., 2017).

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

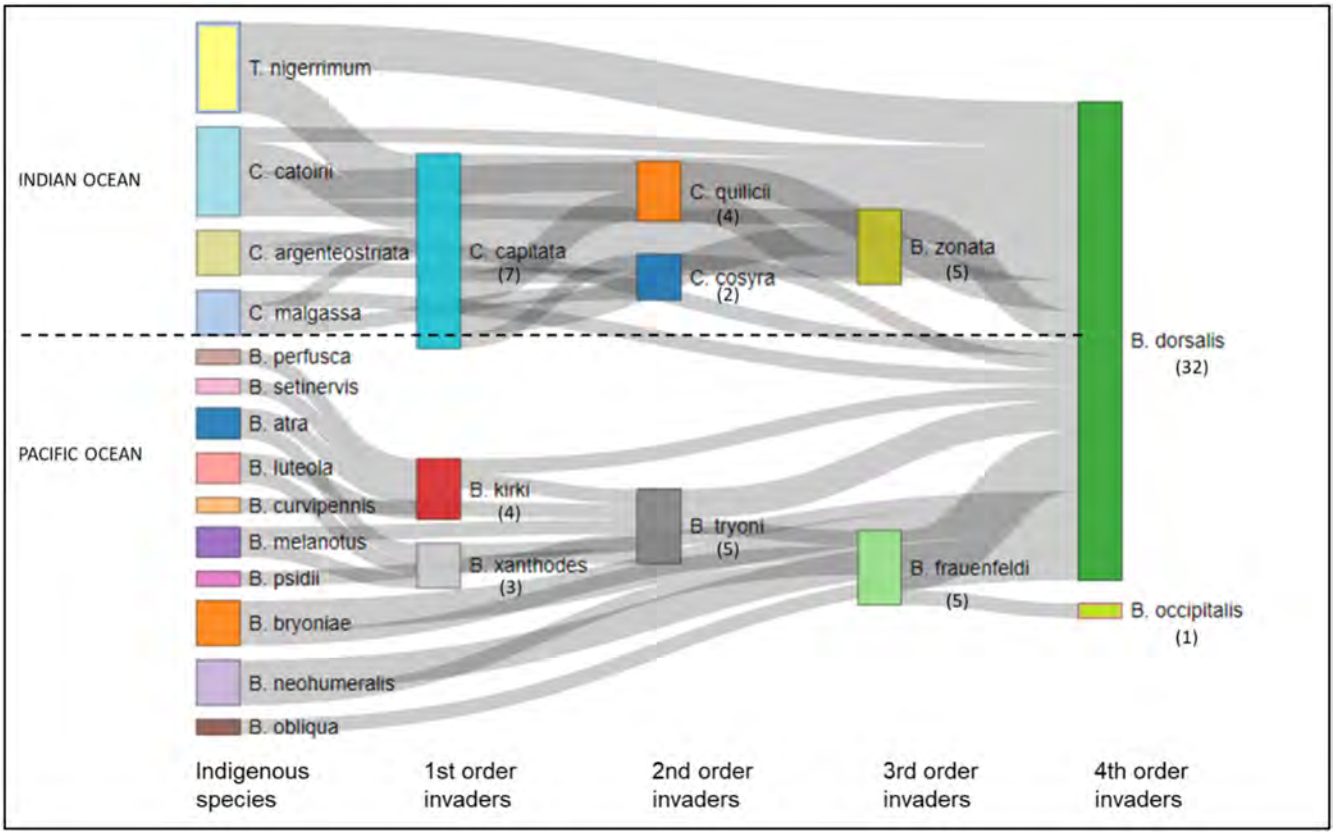


FIGURE 3 Diagram of the invasion links among polyphagous tephritids from Appendix S1. Each link represents a successful invasion by one species in the presence of another species. The number in brackets for each invasive species represents the number of invasions observed in the presence of another polyphagous species

3.5 | Conclusion: Interactions among the different factors

We have shown that all cases of invasions by polyphagous Tephritidae in islands of the Pacific and the Southwest Indian Oceans are directional with the last species established being dominant. These sequential species establishments are driven by the interspecific competition ability among resident and exotic species but are also influenced by the history, routes, and flow of commercial exchanges and by the bridgehead effect. We have argued that the observed pattern is probably due to interaction among these different factors. The invasion of French Polynesia by *B. dorsalis*, for example, might be explained by *B. dorsalis* being more competitive than the resident species, but also because of the availability of a probable pathway for invasion (i.e., direct airplane transport of infested fruit between Hawaii and French Polynesia) and the presence of an invasive *B. dorsalis* population in Hawaii that was already adapted to the environment and resources in French Polynesia. Because many fruits and fruit plants have been spread by humans for many years, mango, guava, Indian almond, and other tephritid host plants are present throughout the tropics. That *Ceratitis* spp. has not invaded Pacific Ocean islands (except Hawaii) can be explained by the distance to the native area but also by the presence of more competitive *Bactrocera* spp. in most of the Pacific islands. Interestingly, Hawaii is one of the only Pacific islands where no endemic polyphagous *Bactrocera* species is present and is the only Pacific island where *C. capitata* has been able to establish a bridgehead and thrive (Vargas et al., 1995).

Our results indicate that islands that have not had an invasion series (or that have only 1st-order invaders; see Figure 1 for an explanation of 1st-order invaders) and that are well connected to areas hosting higher order invaders are especially susceptible to invasion by new species. This is the case in New Caledonia and Vanuatu, where *B. dorsalis* has not yet been established even though New Caledonia and Vanuatu are near areas where *B. dorsalis* is well established. We also argue that weakly competitive species, such as *C. capitata* (Duyck et al., 2006), have very little chance of invading islands where competitive species (such as *B. dorsalis*) already occupy most of the niches. Where the two species are present, however, the coexistence of *C. capitata* is possible only on refuge niches consisting of a few hosts like chili and coffee on which *B. dorsalis* does not develop.

The relationship between interspecific competition and overlap in the resource is complex but has important consequences for population dynamics and thus for the management of these species. Most important resources (in terms of quality and quantity) are generally shared by the polyphagous species (Charlery de la Masselière, Ravigné, et al., 2017). These species such as guava, Indian almond, or mango are present on most islands. While competition strength at the island scale is mediated by these plant species, other host plants

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

not shared or preferred by all Tephritidae species may act as refuge niche and avoid generally complete extinction (Charlery de la Masselière, Ravigné, et al., 2017).

The question arises "Why are there no reciprocal invasions?" The opportunity to invade depends on the availability of a particular habitat with associated resources (a *filter niche*, David et al., 2017) where the introduced species can establish a viable population and resist competition before spreading to other habitats and resources. For polyphagous tephritids, this corresponds to warm and largely human-modified lowlands where abundant and rich resources such as mango, guava, and Indian almond are present. It follows that, although *C. capitata* may be present in refuge niches in highland areas on particular hosts, there is very little chance that an invasion in these ecological niches could succeed.

3.6 | Biosecurity applications

The information provided in this report could be used to increase biosecurity by encouraging those responsible for such security to do the following: define priorities in invasion risk; determine the presence of the host plant species in the area susceptible to invasion; determine the presence of competitive species in the connected areas; and identify the important pathways and routes (trade, flights) between the different areas. This information could also help biosecurity officers improve the network of traps used to monitor tephritid movement (Suckling et al., 2016). Regardless of the mechanisms involved in the invasion processes, the information presented here regarding invasion direction can be used for biosecurity. To ensure a better assessment of future threats, those who perform risk analysis should also pay attention to the resident fruit fly communities in countries that commercially produce the fruit in question in order to determine which commodities are threatened by tephritid invasion. For the sustainability of small islands, local fruit production must be promoted so as to avoid fruit imports according to the risk of introducing an invasive tephritid, especially when quarantine means are limited.

3.7 | Perspectives

The observed pattern of sequential invasions therefore involves an interaction between species traits and human-mediated dispersal, with the importance of these factors varying among cases. The different components of these factors and their interactions warrant additional study. For example, comparative analyses of interspecific interactions before and after invasion events are necessary to determine how invasive species affect the ecological network (Frost et al., 2019). Although researchers have recently followed changes in relationships between species and host range associated with changes in tephritid food webs (Moquet et al., 2021), these analyses should be expanded to additional cases so as to determine which patterns are general for different species and areas. Also needed are studies of life-history traits of tephritids on numerous resources in the laboratory; the results of such studies can be used to determine fundamental niches, to predict distributions and abundance of tephritid populations in the field, and to better understand and estimate interspecific interactions (Facon et al., 2021). This work has been done for some of the studied species (Charlery de la Masselière, Facon, et al., 2017; Facon et al., 2021; Hafsi, Facon, et al., 2016), but it should be very informative to compare realized and fundamental niches at a larger scale including numerous islands and fruit fly species.

Additional analyses of human-mediated dispersal (Chapman et al., 2017), known invasive routes, and the presence of invasive and resident species in many locations would improve our ability to identify important interactions among these factors. Tephritids of Pacific and Indian Ocean islands would be a good model system for such studies, which would complement and help provide a synthesis of existing data. Such studies should also consider climate change, because species may differ in their responses to changes in climate (Zhang et al., 2022), which may affect the observed hierarchy among species.

Finally, fruit fly management relies on strong international phytosanitary measures to manage established species and to avoid new species invasions (Phillips, 2013; Stephenson et al., 2003). If despite all biosecurity and phytosanitary measures fail to avoid an invasion, it is essential to improve all the panels of fruit fly management system, i.e., sterile insect technique (SIT), attract and kill systems, postharvest treatments, and the biological control (Bhoyroo et al., 2021; Follett & Neven, 2006; Garcia et al., 2020; Hafsi, Abbes, et al., 2016a; Suckling, 2003). Most of these management techniques are specific at the species level and therefore should consider, not only the competitively dominant species, but also other species that could have their population increased by lower populations of previously dominant species. More than ever, the fruit fly management system needs to be global focusing on all the fruit fly community present and regarding interactions among the biosecurity services of the different countries. Also, awareness of citizens should be enforced to prevent introduction with unconsidered behavior of bringing back fruit from travels, but also the involvement and the support of the community should be promoted in the context of incursion in a new area to complement fly management technical strategies (Ram, 2021).

ACKNOWLEDGMENTS

This work is dedicated to Serge Quilici who has been leading research on the Tephritids, his whole career, and initiated partnerships between the Indian Ocean and Pacific researchers; he also initiated, trained, and encouraged two of us PFD and CM, to the study of Tephritid fruit flies. PFD received the financial support of the French Ministry of Agriculture (Ecophyto II) through GEMDOTIS project (Evaluation de la faisabilité d'une GEstion Multi-échelles du ravageur invasif *Bactrocera DOrsalis* sur manguier à La Réunion, incluant la Technique de l'Insecte Stérile). This research was conducted within the framework of the UMT BAT: 'Biocontrole en Agriculture Tropicale' and was funded by CIRAD.

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

CONFLICT OF INTEREST

All the authors declare there is no competing interest related to the material of this manuscript.

AUTHOR CONTRIBUTIONS

Pierre-François Duyck: Conceptualization (lead); Formal analysis (lead); Investigation (lead); Methodology (lead); Visualization (lead); Writing – original draft (lead). **Christian Mille:** Conceptualization (supporting); Validation (supporting); Writing – review & editing (equal). **Hervé Jourdan:** Conceptualization (supporting); Validation (supporting); Writing – review & editing (equal).

DATA AVAILABILITY STATEMENT

This work is a review of the findings published in the field of fruit fly invasions and not based on collecting experimental data. Data generated and analyzed in this study are provided in Appendix S1.

ORCID

Pierre-François Duyck https://orcid.org/0000-0001-5484-1970

REFERENCES

Allaire, J., Gandrud, C., Kenton, R., & Yetman, C. (2017). *networkD3: D3 JavaScript Network Graphs from R*. https://CRAN.R-project.org/package=networkD3

Allwood, A. J., Vueti, E. T., Leblanc, L., & Bull, R. (2002). Eradication of introduced Bactrocera species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques. In *Turning the tide: The eradication of invasive species. Proceedings of the International Conference on Eradication of Island Invasives* (p. 19). IUCN Publications Services Unit.

Bertelsmeier, C., & Keller, L. (2018). Bridgehead effects and role of adaptive evolution in invasive populations. *Trends in Ecology & Evolution*, *33*(7), 527–534. https://doi.org/10.1016/j.tree.2018.04.014

Bertelsmeier, C., & Ollier, S. (2021). Bridgehead effects distort global flows of alien species. *Diversity and Distributions*, *27*(11), 2180–2189. https://doi.org/10.1111/ddi.13388

Bhoyroo, R. D., Facknath, S., & Sookar, P. (2021). Life table of Bactrocera zonata (Saunders) (Diptera: Tephritidae) for Sterile Insect Technique (SIT) in Mauritius. *African Entomology*, *29*(2), 361–369. https://doi.org/10.4001/003.029.0361

Bonnamour, A., Gippet, J. M. W., & Bertelsmeier, C. (2021). Insect and plant invasions follow two waves of globalisation. *Ecology Letters*, *24*(11), 2418–2426. https://doi.org/10.1111/ele.13863

Broennimann, O., Treier, U. A., Müller-Schärer, H., Thuiller, W., Peterson, A. T., & Guisan, A. (2007). Evidence of climatic niche shift during biological invasion. *Ecology Letters*, *10*(8), 701–709. https://doi.org/10.1111/j.1461-0248.2007.01060.x

Chapman, D., Purse, B. V., Roy, H. E., Bullock, J. (2017). Global trade networks determine the distribution of invasive non-native species. *Global Ecology and Biogeography*, *26*(8), 907–917. https://doi.org/10.1111/geb.12599

Charlery de la Masselière, M., Facon, B., Hafsi, A., & Duyck, P.-F. (2017). Diet breadth modulates preference—Performance relationships in a phytophagous insect community. *Scientific Reports*, *7*(1), 16934. https://doi.org/10.1038/s41598-017-17231-2

Charlery de la Masselière, M., Ravigné, V., Facon, B., Lefeuvre, P., Massol, F., Quilici, S., & Duyck, P.-F. (2017). Changes in phytophagous insect host ranges following the invasion of their community: Long-term data for fruit flies. *Ecology and Evolution*, *7*(14), 5181–5190. https://doi.org/10.1002/ece3.2968

Clarke, A. R. (2017). Why so many polyphagous fruit flies (Diptera: Tephritidae)? A further contribution to the 'generalism' debate. *Biological Journal of the Linnean Society*, *120*(2), 245–257. https://doi.org/10.1111/bij.12880

Clarke, A. R., Armstrong, K. F., Carmichael, A. E., Milne, J. R., Raghu, S., Roderick, G. K., & Yeates, D. K. (2005). Invasive phytophagous pests arising through a recent tropical evolutionary radiation: The *Bactrocera dorsalis* complex of fruit flies. *Annual Review of Entomology*, *50*, 293–319.

Connell, J. H. (1980). Diversity and the coevolution of competitors, or the ghost of competition past. *Oikos*, *35*(2), 131. https://doi.org/10.2307/3544421

David, P., Thébault, E., Anneville, O., Duyck, P.-F., Chapuis, E., & Loeuille, N. (2017). Impacts of invasive species on food webs. *Advances in Ecological Research*, *56*, 1–60. https://doi.org/10.1016/bs.aecr.2016.10.001

De Meyer, M., Quilici, S., Franck, A., Chadhouliati, A. C., Issimaila, M. A., Youssoufa, M. A., Abdoul-Karime, A.-L., Barbet, A., Attié, M., & White, I. M. (2012). Records of frugivorous fruit flies (Diptera: Tephritidae: Dacini) from the Comoro archipelago. *African Invertebrates*, *53*(1), 69–67. https://doi.org/10.5733/afin.053.0104

Duyck, P.-F., David, P., Junod, G., Brunel, C., Dupont, R., & Quilici, S. (2006). Importance of competition mechanisms in successive invasions by polyphagous tephritids in La Réunion Island. *Ecology*, *87*(7), 1770–1780. https://doi.org/10.1890/0012-9658(2006)87[1770:IOCMIS]2.0.CO;2

Duyck, P.-F., David, P., & Quilici, S. (2004). A review of relationships between interspecific competition and invasions in fruit flies (Diptera: Tephritidae). *Ecological Entomology*, *29*(5), 511–520. https://doi.org/10.1111/j.0307-6946.2004.00638.x

Duyck, P.-F., David, P., & Quilici, S. (2007). Can more K-selected species be better invaders? A case study of fruit flies in La Réunion: r-K trade-off in biological invasions. *Diversity and Distributions*, *13*(5), 535–543. https://doi.org/10.1111/j.1472-4642.2007.00360.x

Ekesi, S., Billah, M. K., Nderitu, P. W., Lux, S. A., & Rwomushana, I. (2009). Evidence for competitive displacement of *Ceratitis cosyra* by the invasive fruit fly *Bactrocera invadens* (Diptera: Tephritidae) on mango and mechanisms contributing to the displacement. *Journal of Economic Entomology*, *102*(3), 981–991.

Ekesi, S., De Meyer, M., Mohamed, S. A., Virgilio, M., & Borgemeister, C. (2016). Taxonomy, ecology and management of native and exotic fruit fly species in Africa. *Annual Review of Entomology*, *61*, 219–238. https://doi.org/10.1146/annurev-ento-010715-023603

Facon, B., Hafsi, A., Charlery de la Masselière, M., Robin, S., Massol, F., Dubart, M., Chiquet, J., Frago, E., Chiroleu, F., Duyck, P.-F., & Ravigné, V. (2021). Joint species distributions reveal the combined effects of host plants, abiotic factors and species competition as drivers of species abundances in fruit flies. *Ecology Letters*, *24*(9), 1905–1916. https://doi.org/10.1111/ele.13825

Follett, P. A., & Neven, L. G. (2006). Current trends in quarantine entomology. *Annual Review of Entomology*, *51*(1), 359–385. https://doi.org/10.1146/annurev.ento.49.061802.123314

Fournier, A., Penone, C., Pennino, M. G., & Courchamp, F. (2019). Predicting future invaders and future invasions. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(16), 7905–7910. https://doi.org/10.1073/pnas.1803456116

Fraimout, A., Debat, V., Fellous, S., Hufbauer, R. A., Foucaud, J., Pudlo, P., Marin, J.-M., Price, D. K., Cattel, J., Chen, X., Deprá, M., François Duyck, P., Guedot, C., Kenis, M., Kimura, M. T., Loeb, G., Loiseau, A., Martinez-Sañudo, I., Pascual, M., … Estoup, A. (2017). Deciphering the routes of invasion of *Drosophila suzukii* by means of ABC random forest. *Molecular Biology and Evolution*, *34*, 980–996. https://doi.org/10.1093/molbev/msx050

Frost, C. M., Allen, W. J., Courchamp, F., Jeschke, J. M., Saul, W.-C., & Wardle, D. A. (2019). Using network theory to understand and

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

predict biological invasions. *Trends in Ecology & Evolution*, *34*(9), 831–843. https://doi.org/10.1016/j.tree.2019.04.012

Garcia, F. R. M., Ovruski, S. M., Suárez, L., Cancino, J., & Liburd, O. E. (2020). Biological control of tephritid fruit flies in the Americas and Hawaii: A review of the use of parasitoids and predators. *Insects*, *11*(10), 662. https://doi.org/10.3390/insects11100662

Godefroid, M., Cruaud, A., Rossi, J.-P., & Rasplus, J.-Y. (2015). Assessing the risk of invasion by tephritid fruit flies: Intraspecific divergence matters. *PLoS One*, *10*(8), e0135209. https://doi.org/10.1371/journal.pone.0135209

Hafsi, A., Abbes, K., Harbi, A., Duyck, P.-F., & Chermiti, B. (2016). Attract-and-kill systems efficiency against *Ceratitis capitata* (Diptera: Tephritidae) and effects on non-target insects in peach orchards. *Journal of Applied Entomology*, *140*(1–2), 28–36. https://doi.org/10.1111/jen.12259

Hafsi, A., Facon, B., Ravigné, V., Chiroleu, F., Quilici, S., Chermiti, B., & Duyck, P.-F. (2016). Host plant range of a fruit fly community (Diptera: Tephritidae): Does fruit composition influence larval performance?*BMC Ecology*, *16*, 40. https://doi.org/10.1186/s12898-016-0094-8

Hart, S. P., Freckleton, R. P., & Levine, J. M. (2018). How to quantify competitive ability. *Journal of Ecology*, *106*(5), 1902–1909. https://doi.org/10.1111/1365-2745.12954

Hassani, I. M., Raveloson-Ravaomanarivo, L. H., Delatte, H., Chiroleu, F., Allibert, A., Nouhou, S., Quilici, S., & Duyck, P. F. (2016). Invasion by *Bactrocera dorsalis* and niche partitioning among tephritid species in Comoros. *Bulletin of Entomological Research*, *6*, 1–10. https://doi.org/10.1017/S0007485316000456

Hulme, P. E. (2010). Biosecurity: The changing face of invasion biology. In D. M. Richardson (Ed.), *Fifty years of invasion ecology* (pp. 301–314). Wiley-Blackwell.

Hulme, P. E. (2021). Unwelcome exchange: International trade as a direct and indirect driver of biological invasions worldwide. *One Earth*, *4*(5), 666–679. https://doi.org/10.1016/j.oneear.2021.04.015

Leblanc, L., Vueti, E. T., & Allwood, A. J. (2013). Host plant records for fruit flies (Diptera: Tephritidae: Dacini) in the Pacific islands: 2. Infestation Statistics on Economic Hosts. *Proceedings of the Hawaiian Entomological Society*, *45*, 36.

MacLachlan, M. J., Liebhold, A. M., Yamanaka, T., & Springborn, M. R. (2021). Hidden patterns of insect establishment risk revealed from two centuries of alien species discoveries. *Science Advances*, *7*(44), eabj1012. https://doi.org/10.1126/sciadv.abj1012

Moquet, L., Payet, J., Glenac, S., & Delatte, H. (2021). Niche shift of tephritid species after the Oriental fruit fly (*Bactrocera dorsalis*) invasion in La Réunion. *Diversity and Distributions*, *27*(1), 109–129. https://doi.org/10.1111/ddi.13172

Moser, D., Lenzner, B., Weigelt, P., Dawson, W., Kreft, H., Pergl, J., Pyšek, P., vanKleunen, M., Winter, M., Capinha, C., Cassey, P., Dullinger, S., Economo, E. P., García-Díaz, P., Guénard, B., Hofhansl, F., Mang, T., Seebens, H., & Essl, F. (2018). Remoteness promotes biological invasions on islands worldwide. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(37), 9270–9275. https://doi.org/10.1073/pnas.1804179115

Mwatawala, M. W., De Meyer, M., Makundi, R. H., & Maerere, A. P. (2009). Host range and distribution of fruit-infesting pestiferous fruit flies (Diptera, Tephritidae) in selected areas of Central Tanzania. *Bulletin of Entomological Research*, *99*(06), 629–641. https://doi.org/10.1017/S0007485309006695

N'depo, O. R., Hala, N., N'da Adopo, A., Coulibaly, F., Kouassi, P. K., Vayssieres, J. F., & De Meyer, M. (2015). Effective chemical control of fruit flies (Diptera: Tephritidae) pests in mango orchards in northern Côte-d'Ivoire. *International Journal of Biological and Chemical Sciences*, *9*(3), 1299. https://doi.org/10.4314/ijbcs.v9i3.15

Paini, D. R., Sheppard, A. W., Cook, D. C., De Barro, P. J., Worner, S. P., & Thomas, M. B. (2016). Global threat to agriculture from invasive species. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(27), 7575–7579. https://doi.org/10.1073/pnas.1602205113

Phillips, C. (2013). Living without fruit flies: Biosecuring horticulture and its markets. *Environment and Planning A: Economy and Space*, *45*(7), 1679–1694. https://doi.org/10.1068/a45274

Popa-Báez, Á.-D., Catullo, R., Lee, S. F., Yeap, H. L., Mourant, R. G., Frommer, M., Sved, J. A., Cameron, E. C., Edwards, O. R., Taylor, P. W., & Oakeshott, J. G. (2020). Genome-wide patterns of differentiation over space and time in the Queensland fruit fly. *Scientific Reports*, *10*(1), 10788. https://doi.org/10.1038/s41598-020-67397-5

Putulan, D., Sar, S., Drew, R., Raghu, S., & Clarke, A. (2004). Fruit and vegetable movement on domestic flights in Papua New Guinea and the risk of spreading pest fruit-flies (Diptera: Tephritidae). *International Journal of Pest Management*, *50*(1), 17–22. https://doi.org/10.1080/09670870310001626329

Qin, Y., Paini, D. R., Wang, C., Fang, Y., & Li, Z. (2015). Global establishment risk of economically important fruit fly species (Tephritidae). *PLoS One*, *10*(1), e0116424. https://doi.org/10.1371/journal.pone.0116424

R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Ram, R. (2021). Community responses to biosecurity regulations during a biosecurity outbreak: An Auckland, New Zealand case study. *Community Development*, *52*(1), 42–60. https://doi.org/10.1080/15575330.2020.1831564

Rasolofoarivao, H., Raveloson Ravaomanarivo, L. H., & Delatte, H. (2021). Host plant ranges of fruit flies (Diptera: Tephritidae) in Madagascar. *Bulletin of Entomological Research*, *112*(1), 1–12. https://doi.org/10.1017/S0007485321000511

Russell, J., Meyer, J., Holmes, N., & Pagad, S. (2017). Invasive alien species on islands: Impacts, distribution, interactions and management. *Environmental Conservation*, *44*(4), 359–370. https://doi.org/10.1017/S0376892917000297

Rwomushana, I., Ekesi, S., Gordon, I., & Ogol, C. K. (2008). Host plants and host plant preference studies for *Bactrocera invadens* (Diptera: Tephritidae) in Kenya, a new invasive fruit fly species in Africa. *Annals of the Entomological Society of America*, *101*(2), 331–340. https://doi.org/10.1603/0013-8746(2008)101[331:hpahpp]2.0.co;2

Schutze, M. K., Aketarawong, N., Amornsak, W., Armstrong, K. F., Augustinos, A. A., Barr, N., Bo, W., Bourtzis, K., Boykin, L. M., & Caceres, C. (2015). Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): Taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. *Systematic Entomology*, *40*(2), 456–471.

Seebens, H., Blackburn, T. M., Dyer, E. E., Genovesi, P., Hulme, P. E., Jeschke, J. M., Pagad, S., Pyšek, P., van Kleunen, M., Winter, M., Ansong, M., Arianoutsou, M., Bacher, S., Blasius, B., Brockerhoff, E. G., Brundu, G., Capinha, C., Causton, C. E., Celesti-Grapow, L., … Essl, F. (2018). Global rise in emerging alien species results from increased accessibility of new source pools. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(10), E2264–E2273. https://doi.org/10.1073/pnas.1719429115

Seebens, H., Blackburn, T. M., Dyer, E. E., Genovesi, P., Hulme, P. E., Jeschke, J. M., Pagad, S., Pyšek, P., Winter, M., Arianoutsou, M., Bacher, S., Blasius, B., Brundu, G., Capinha, C., Celesti-Grapow, L., Dawson, W., Dullinger, S., Fuentes, N., Jäger, H., … Essl, F. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications*, *8*(1), 14435. https://doi.org/10.1038/ncomms14435

Sikes, B. A., Bufford, J. L., Hulme, P. E., Cooper, J. A., Johnston, P. R., & Duncan, R. P. (2018). Import volumes and biosecurity interventions shape the arrival rate of fungal pathogens. *PLoS Biology*, *16*(5), e2006025. https://doi.org/10.1371/journal.pbio.2006025

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Simberloff, D., Martin, J.-L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J., Courchamp, F., Galil, B., García-Berthou, E., Pascal, M., Pyšek, P., Sousa, R., Tabacchi, E., & Vilà, M. (2013). Impacts of biological invasions: What's what and the way forward. *Trends in Ecology & Evolution*, *28*(1), 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Stephenson, B. P., Gill, G. S. C., Randall, J. L., & Wilson, J. A. (2003). Biosecurity approaches to surveillance and response for new plant pest species. *New Zealand Plant Protection*, *56*, 5–9. https://doi.org/10.30843/nzpp.2003.56.6023

Suckling, D. M. (2003). Applying the sterile insect technique for biosecurity benefits and constraints. *New Zealand Plant Protection*, *56*, 21–26. https://doi.org/10.30843/nzpp.2003.56.6026

Suckling, D. M., Kean, J. M., Stringer, L. D., Cáceres-Barrios, C., Hendrichs, J., Reyes-Flores, J., & Dominiak, B. C. (2016). Eradication of tephritid fruit fly pest populations: Outcomes and prospects: Eradication of tephritid fruit fly pest populations. *Pest Management Science*, *72*(3), 456–465. https://doi.org/10.1002/ps.3905

Vargas, R. I., Leblanc, L., Putoa, R., & Piñero, J. C. (2012). Population dynamics of three Bactrocera spp. fruit flies (Diptera: Tephritidae) and two introduced natural enemies, Fopius arisanus (Sonan) and Diachasmimorpha longicaudata (Ashmead) (Hymenoptera: Braconidae), after an invasion by Bactrocera dorsalis (Hendel) in Tahiti. *Biological Control*, *60*(2), 199–206. https://doi.org/10.1016/j.biocontrol.2011.10.012

Vargas, R. I., Piñero, J., & Leblanc, L. (2015). An overview of pest species of Bactrocera fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific region. *Insects*, *6*(2), 297–318. https://doi.org/10.3390/insects6020297

Vargas, R. I., Walsh, W. A., Kanehisa, D., Stark, J. D., & Nishida, T. (2000). Comparative demography of three Hawaiian fruit flies (Diptera: Tephritidae) at alternating temperatures. *Annals of the Entomological Society of America*, *93*(1), 75–81. https://doi.org/10.1603/0013-8746(2000)093[0075:cdothf]2.0.co;2

Vargas, R. I., Walsh, W. A., & Nishida, T. (1995). Colonization of newly planted coffee fields: Dominance of Mediterranean fruit fly over Oriental fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology*, *88*(3), 620–627. https://doi.org/10.1093/jee/88.3.620

White, E. M., Wilson, J. C., & Clarke, A. R. (2006). Biotic indirect effects: A neglected concept in invasion biology. *Diversity and Distributions*, *12*(4), 443–455. https://doi.org/10.1111/j.1366-9516.2006.00265.x

White, I. M., & Elson-Harris, M. M. (1992). *Fruit flies of economic significance: Their identification and bionomics*. CAB International.

Zhang, Y., Hughes, A. C., Zhao, Z., Li, Z., & Qin, Y. (2022). Including climate change to predict the global suitable area of an invasive pest: Bactrocera correcta (Diptera: Tephritidae). *Global Ecology and Conservation*, *34*, e02021. https://doi.org/10.1016/j.gecco.2022.e02021

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Duyck, P.-F., Jourdan, H., & Mille, C. (2022). Sequential invasions by fruit flies (Diptera: Tephritidae) in Pacific and Indian Ocean islands: A systematic review. *Ecology and Evolution*, *12*, e8880. https://doi.org/10.1002/ece3.8880

20457758, 2022, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ece3.8880 by Department For Health And, Wiley Online Library on [09/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

ANNUAL REVIEWS

Annual Review of Entomology

Fruit Flies: Challenges and Opportunities to Stem the Tide of Global Invasions

Nikos T. Papadopoulos,[1,*] Marc De Meyer,[2] John S. Terblanche,[3] and Darren J. Kriticos[4]

[1]Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Volos, Greece; email: nikopap@uth.gr

[2]Department of Biology, Royal Museum for Central Africa, Tervuren, Belgium; email: marc.de.meyer@africamuseum.be

[3]Department of Conservation Ecology & Entomology, Stellenbosch University, Stellenbosch, South Africa; email: jst@sun.ac.za

[4]Cervantes Agritech, Canberra, Australian Capital Territory, Australia; email: Darren@cervantesagritech.com

ANNUAL REVIEWS CONNECT
www.annualreviews.org
- Download figures
- Navigate cited references
- Keyword search
- Explore related articles
- Share via email or social media

Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Annu. Rev. Entomol. 2024. 69:355–73

First published as a Review in Advance on September 27, 2023

The *Annual Review of Entomology* is online at ento.annualreviews.org

https://doi.org/10.1146/annurev-ento-022723-103200

Copyright © 2024 by the author(s). This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See credit lines of images or other third-party material in this article for license information.

*Corresponding author

OPEN ACCESS (cc) BY

Keywords

interception, detection, eradication, spread, establishment, niche models, phenological models, stress response, pest risk assessment

Abstract

Global trade in fresh fruit and vegetables, intensification of human mobility, and climate change facilitate fruit fly (Diptera: Tephritidae) invasions. Life-history traits, environmental stress response, dispersal stress, and novel genetic admixtures contribute to their establishment and spread. Tephritids are among the most frequently intercepted taxa at ports of entry. In some countries, supported by the rules-based trade framework, a remarkable amount of biosecurity effort is being arrayed against the range expansion of tephritids. Despite this effort, fruit flies continue to arrive in new jurisdictions, sometimes triggering expensive eradication responses. Surprisingly, scant attention has been paid to biosecurity in the recent discourse about new multilateral trade agreements. Much of the available literature on managing tephritid invasions is focused on a limited number of charismatic (historically high-profile) species, and the generality of many patterns remains speculative.

INTRODUCTION

Eradication: application of measures that lead to complete and permanent elimination of a pest from an area

Detection: record of an invasive pest, accomplished through adult trapping and/or fruit sampling, in a new area based on official survey

Interception: detection of invasive, exotic (alien) species in commercial consignments or luggage of travelers at ports of entry

Globally, there are more than 5,000 fruit fly species (Diptera: Tephritidae) (6), including approximately 200 species of economic significance (133). In a recent pest categorization, over 250 species of tephritids were considered as potential quarantine pests threatening the European Union (6), and tephritids top the lists of quarantine pests for Australia, China, New Zealand, Africa, South America, Asia, and North America (5, 53, 86). In many fruit-producing areas, fruit flies are considered to be one of the main threats to economic production and trade in horticultural crops, and consequently pose a huge challenge for regulators, legislators, and managers (23).

The global trade in fresh fruits and vegetables and the intensification of human mobility have increased the rate of biological invasions, including those of fruit flies (36). Incursions and invasions are increasing in frequency (89; **http://b3.net.nz/gerda**), stimulating intense debates regarding establishment versus eradication success (8–10, 69, 89, 102, 137). Fruit flies are the most frequently intercepted organisms in fruit and vegetable commodities in European ports of entry (**https://food.ec.europa.eu/plants/plant-health-and-biosecurity/europhyt_en**). The recent detections and outbreaks of the Oriental fruit fly (*Bactrocera dorsalis*) in Italy and France exemplify their invasiveness (27, 78). Climatic changes are shifting the potential ranges of fruit flies, exposing new jurisdictions to invasion threats, especially in middle latitudes.

SOCIOECONOMIC IMPACTS OF FRUIT FLY INVASIONS

Tephritids can cause substantial direct production losses, impede noncommercial horticultural activities, and severely impact small growers' incomes in developing countries if their produce becomes unmarketable.

Estimating the social and economic impacts of invasive fruit flies is challenging, since these impacts encompass (*a*) severe reduction of the agricultural produce; (*b*) the huge costs of interception, detection (extensive surveillance), eradication, and containment; and (*c*) impacts on fruit-trading and -exporting industries. The addition of a new pest species to a single export fruit incurs enormous expense when it is added to existing disinfestation protocols, especially if a new technology is required. Information on the costs of fruit fly invasions is scattered and disparate (**Supplemental Table 1**). Most estimates are imprecise; cannot be compared; and refer to different currencies, countries, and continents. The cost categories include (*a*) production, including direct fruit infestation, reduced shelf life of fresh fruit, qualitative degradation, and price reduction; (*b*) trading, including postharvest treatments, rejection of consignments, market loss, and interception and identification costs; (*c*) surveillance, including predictive modeling, trapping, fruit sampling, and identification tools; (*d*) eradication, including insecticide application, the sterile insect technique (SIT), the male annihilation technique (MAT), communication campaigns, and certifications of absence; (*e*) containment, including insecticide application, the SIT, the MAT, and intense population monitoring; and (*f*) management, including population monitoring, mass trapping, insecticide application, area-wide integrated pest management (IPM), and the SIT.

Supplemental Material >

Direct Loss of Fruit Produce

Fruit and vegetables constitute major agricultural produce annually valued at more than €21 billion in the European Union, US$22.5 billion for African countries in 2007 (3), US$25 billion in California, and AU$1 billion in Australia (86). Loss in production due to fruit flies may range from 10% to 30% (77). For example, fruit flies are estimated to cause an economic loss of more than US$2 billion across Africa (23, 77). Similar estimates have been reported for Brazil (68, 82), Pakistan (110), Egypt (139 and references therein), India (135), China (97), La Reunion, France (33), and Taiwan (50). Losses can be high even with well-coordinated management interventions

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

such as that executed against the Mediterranean fruit fly (medfly), *Ceratitis capitata*, in Valencia, Spain, which consisted mainly of aerial malathion spraying; despite the intervention, the pest caused an estimated loss of up to approximately 4% of Oriental persimmon production (76). In contrast, a well-coordinated area-wide management project against several fruit flies in Hawaii reduced field infestation rates dramatically; these rates often ranged above 10–20% before the intervention (38, 125).

Fruit Trade

Horticultural trade implications encompass various geographically distinct regions of the world. An embargo by Asian countries on fruit commodities from California was estimated to cost US$564 million and over 15,000 jobs in 1990 (103). The outbreak of *B. dorsalis* in only one county in Florida in 2015–2016, because of the costs of quarantine implementation and the losses from not planting, was estimated to cost tens of millions of US dollars in losses for the fruit-production sector and up to 726 jobs (110). Interception of medfly-infested Spanish clementines in the United States in 2001 resulted in a ban on imports, with an estimated loss of €300 million (93). Additional examples of bans on imports exist for avocado exports from Kenya (83), banana exports from Mozambique (13, 40), and mango exports from West Africa (75) (for additional details, see **Supplemental Table 1**). Bans on fruit exports because of fruit fly interceptions may have dramatic consequences for small- and medium-scale farmers in developing countries. For example, as Europe is the main destination for tropical fruits like mangoes from Africa, high numbers of interceptions of fruit flies at EU points of entry can lead to the destruction of full shipments and import bans (**https://food.ec.europa.eu/plants/plant-health-and-biosecurity/europhyt/interceptions_en**). The presence of an invasive fruit fly can even have an impact on the export industry of nonsusceptible commodities such as kiwi fruit (85).

Supplemental Material >

Interception

The costs of interceptions are related to regular inspection activities conducted at ports of entry or devanning sites by authorized personnel and include inspection of fruit commodities, parcel shipments, and passengers' luggage (84) (**Supplemental Table 1**). Adoption of noninvasive sensing technologies, such as scanning systems (e.g., spectroscopic techniques, visible light sensing, hyperspectral imaging, X-ray imagining), and electronic noses, to detect volatiles of infested fruit; development and use of identification tools; and expert consultation to identify intercepted specimens all carry costs (1 and references therein). Delays in completing an inspection event may result in large costs, as sensitive crops may deteriorate and/or completely lose their value.

Surveillance and Detection

Surveillance activities to detect invasive fruit flies are costly operations, since several species are considered in most countries, and dense trapping networks (using protein-baited or male-attractant lures) are established and serviced year-round or during a period of several months. For example, since 1989, New Zealand has deployed traps in more than 3,450 sites for the detection of three fruit fly species, at a cost of more than NZ$1 million (106). The fruit fly detection program in California deploys more than 94,000 traps state-wide each year, and has run for several decades at a huge cost to taxpayers (102).

Eradication

An eradication attempt is the most common response to incursions of invasive fruit flies. The cost of eradication programs against medfly in California is estimated at US$500 million over

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

the past 25 years (120). Incursions by alien tephritids typically elicit expensive control campaigns. These campaigns often cost millions of US dollars and involve intense insecticide spraying even in residential areas, with direct negative health and environmental effects, as well as the long-term danger of insecticide resistance. The cost of a typical fruit fly eradication campaign is estimated to be US$12 million but may exceed US$100 million (113). There are several examples of costly eradication campaigns against fruit flies, e.g., in Australia against *B. dorsalis* (7), Japan against *B. dorsalis* and *Zeugodacus cucurbitae* (81), and California and Florida against several species (9, 119), and these campaigns may run for decades (e.g., the regional program for the eradication of medfly from Mexico and Guatemala) (26).

Risk assessment: analysis of the potential of establishment and spread of an invasive/exotic species, the potential negative impact, and possible mitigating measures

Increased Cost of Interventions

The failure to eradicate or contain a fruit fly pest results in permanent population establishment that requires continuous management input. Large commodity losses are frequently avoided with pesticide use, but this comes at a high cost. In the European Union, costs of control are estimated from a few to several hundred euros/ha. The regional government of Valencia spends €9.5 million a year on the control of medfly, but the costs are much higher without a centrally organized IPM program (93). Additional estimates regarding costs of interventions have been obtained for the control of medfly in the Hex River valley in South Africa and in Israel, Jordan, and the Palestinian Authority (25, 74). The invasion of the Nearctic species *Rhagoletis completa* into Europe is associated with an increase of 13% and 430% in the costs of pest management in conventional and organic walnut orchards, respectively, making the production costs for organic farmers uneconomical (128).

INVASION PROCESS: BARRIERS, RISKS, AND MANAGEMENT

Transport

Interception data in Europe and the United States suggest that long-distance fly movement is mostly associated with commercial or passengers' importation of plant material (e.g., fruits, soil) (6, 56). Thus, greater trade and transport connectivity allows fruit flies to overcome geographical barriers to spread. Importantly, despite the strong focus on developing greater trade connectivity, the concomitant need for increased biosecurity measures has not featured in discussions about new initiatives such as the Belt and Road Initiative (**https://www.ebrd.com/what-we-do/belt-and-road/overview.html**) or the Trans-Pacific Partnership (80).

Risk assessments for fruit flies vary in scope and breadth. Most risk assessments have focused on the climate suitability dimension of the problem, using bioclimatic models to estimate the potential distribution under historical and, in some cases, future climate scenarios (14–16, 48, 49, 52, 57, 58, 116, 118, 127, 134). Kriticos (46) examined the potential for each of six *Bactrocera* species to establish in New Zealand under current and future climate scenarios, concluding that, under historical climate conditions, New Zealand was at least marginally suitable for establishment for half of the species, and under the future climate scenario, another two could potentially establish. Subsequently, one of these species, *Bactrocera tryoni*, was detected and eradicated from the Auckland area of New Zealand (**http://b3.net.nz/gerda**).

While there are some invasive temperate fruit flies (e.g., *Rhagoletis cerasi*, *Rhagoletis cingulata*, *R. completa*, and *Rhagoletis suavis*), most fruit flies are adapted to tropical or subtropical climates. In recent times, probably due in part to climatic changes and changes in host availability, many tropical fruit flies have been observed expanding their ranges poleward into cooler Mediterranean and warm temperate regions. Examples include *B. tryoni* in southern Australia (20); *C. capitata* in France, Italy, and possibly Austria and Germany (22, 30, 44); and *B. dorsalis* in northern China (98).

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Introduction

Once a non-native fruit fly has overcome geographical barriers via human-induced transport or natural dispersal and avoided interception at points of entry, it can potentially spread into a novel habitat. Studies have been conducted on how to detect and track these new introductions (64, 101). Given the adult stage's relatively mobile and exposed life history, it is predominantly this stage that is targeted for detection. However (and excluding natural dispersal from adjacent areas), as anthropogenic transport is predominantly of the juvenile stage (either as larvae inside infested fruit or, less often, as pupae in soil), the moment that an adult is captured will likely lag far behind the actual introduction event. Given the developmental time for most (sub)tropical pests, this detection lag is usually a matter of weeks or months (but see the discussion on lag phase in the section titled Establishment), but for fruit flies with an overwintering diapause, such as representatives of the genus *Rhagoletis* (73, 90, 129), it can be several seasons long. This time lag has substantial consequences for mitigation and control measures (**Figure 1**). For example, traceback to understand the likely invasion pathway may be difficult or impossible due to the passage of time.

Trapping efficiency depends on the type of trap, the attractant used, and the emission time and efficiency of the attractant carrier, along with species' biology (e.g., temperature dependence

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

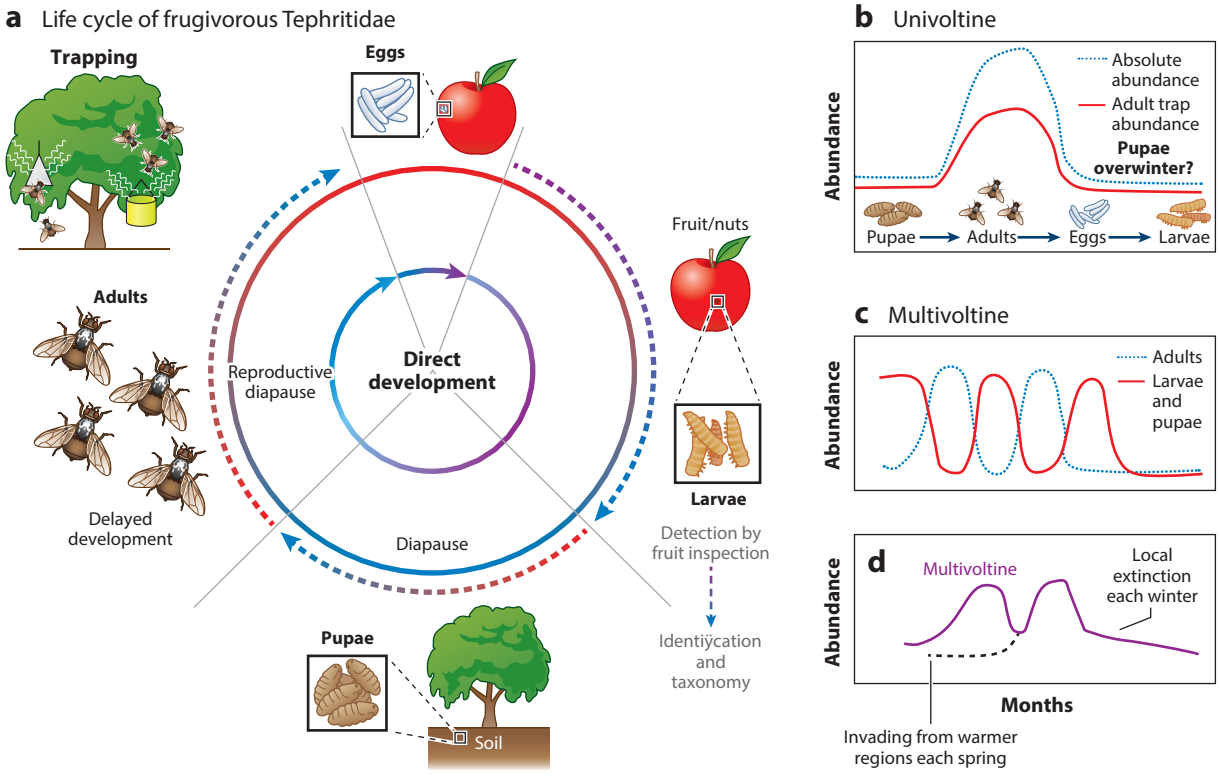


Figure 1

(*a*) Generalized frugivorous fruit fly life cycle, illustrating key life stages and the main microhabitat sites and typical detection or trapping methods associated with each of them. (*b–d*) Adult trap abundance and absolute population abundance may be related and (*b*) synchronized (for univoltine adults) or (*c*) asynchronized (for multivoltine adults), which introduces lags between the event and the detection thereof, thus limiting inference of key invasion processes or population dynamics. (*d*) A population may appear multivoltine when in fact it is simply invading from a warmer region each spring.

of flight ability, age of flight maturation, senescence rates, age structure of wild populations). A plethora of trapping devices are available commercially, and more are in development (65, 99). There are two major groups of attractants: protein-based lures (providing a protein source for both sexes but predominantly targeting females) and male-specific attractants (often referred to as para-pheromones) (28, 101, 121). The former are more general in their attractiveness but less effective in that they attract flies over shorter distances. Male-specific lures attract a smaller range of taxa but can be effective over longer distances. They are mainly based on natural compounds found in the wild and naturally sourced by males. Several new lures that are chemically related to the traditional ones but more efficient for targeted taxa are being developed and tested (65, 99). Nevertheless, even the most efficient lures and traps still capture only a small proportion of the fly population (an overview of surveillance sensitivity tests through release-recapture gives an exceptional maximum recapture percentage of close to 23%, but the percentage is usually between 1–4%; see 101).

Extirpation: complete elimination or removal of a pest from a defined area that may not necessarily lead to eradication

Another limiting factor is the time and costs (transport, personnel) required to maintain trapping surveys. Currently, automated systems (including electronic traps furnished with digital cameras that can send images through mobile networks) that detect, identify, and report the presence of target species are being developed (17, 18). Other automated traps that have been developed for fruit flies use optoelectronic sensors to count and detect species-specific patterns of wing beat (96, 100) and light-sensing transistors (infrared LED emitters and receivers) to count captured insects that break a light beam (31). When these automated trapping systems are commercially available and deployed at scale, they promise to substantially improve the detection and response times for insect invasions and the associated costs.

Establishment

Establishment can be hard to define and quantify, especially given the trapping and detection issues discussed above; its identification typically follows a long, unpredictable lag phase (89). Survival, self-propagation, and persistence in a novel area are challenging and involve an interaction among several biological, climatic, social, and stochastic factors that have been poorly disentangled for tephritids to date.

Propagules that escape interceptions may end up in a hostile environment (e.g., unfavorable climate, lack of host, lack of mating partners, and management aimed at extirpation) and thus become locally extinct or remain undetected. Initial breeding populations are typically small and genetically restricted. Although they form the first main step in establishment and spread, they do not ensure establishment in a novel environment, since additional biological processes need to be achieved; these processes include year-round survival in an environmental mosaic of stochastic resources and breeding opportunities (59). To establish in marginally suitable novel environments, such as temperate areas, tropical invasive fruit flies must survive cold winters, with limited breeding opportunities (e.g., lack of host fruits) for several months (87). The existence of established populations at low levels that fall below detection densities for several months has been shown for several species, including medfly in northern Greece and the Queensland fruit fly in southeastern Australia (12, 88). Furthermore, individual-based stochastic modeling considering various degrees of site fragmentation and cool environmental conditions demonstrated variable population growth rates and fluctuations that can remain at low densities for months to a few years (59). Thus, the exponential population growth of the r-selected invasive tropical fruit flies is rarely achieved in the wild, at least within several generations following an invasion event (69). There can be a long lag between an introduction or invasion event and the population building up to a level detectable through trapping. Thus, the lag phase from arrival to establishment, population

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

growth to detectable levels, and dispersion may well hold for fruit flies (9, 54, 89). Between the Allee effect (i.e., lower population density that still leads to establishment and population viability) and exponential population growth, there are several processes that can suppress population densities of invasive fruit flies to low levels even in climatically suitable environments. Preventive management efforts, such as the sterile insect release program that has been executed for decades in Southern California against the establishment of *C. capitata*, may further contribute to hindering innate population growth, suppressing populations below detection levels but above levels that lead to stochastic extinction (for an extended review, see 137). Eradication campaigns involving the extensive use of pesticides may also suppress populations to low densities. Repeated invasion events, occurring within a reasonable amount of time to allow overlapping reproduction or mating events, may further facilitate naturalization by contributing fresh genetic material that could enhance adaptation to a new environment (55).

Detections of only a few individuals are often officially reported as a transient population, i.e., nonbreeding and established populations that require no further action as far as eradication and containment are concerned. For example, the detections of *B. dorsalis* in Naples, Italy in 2018 and in France in 2019 were both reported as "transient actionable, under surveillance" (78). The subsequent outbreak of 2022 in the same area of Naples (**https://gd.eppo.int/taxon/DACUDO/distribution/IT**) may have been related to previous detections stemming from a cryptic (undetected) population that went through a naturalization process after a lag phase of a few years. Misclassification of populations as transient may lead to poor control and delayed intervention. Detection of invasive fruit flies is often followed by aggressive eradication campaigns that aim to extirpate any breeding population in a large area; it is widely accepted that an early detection, rapid response strategy is a cost-effective management approach for invasive species, but this strategy has not been widely adopted for fruit fly control (54). Successful eradication is often declared if no detection in the specific area is recorded for at least three life cycles, considering prevailing temperatures and generic degree-day growth models [e.g., Measure 26 of the FAO International Standards for Phytosanitary Measures (ISPMs)]. For example, the eradication campaign against *B. dorsalis* in South Africa in 2010 was officially declared successful four months after the end of the campaign (66). Later work on the *B. dorsalis* invasion in South Africa revealed a sequence of several isolated male detections before any action was initiated (2007 and 2008), as well as an increase in incursions following the eradication campaign that changed the status of the pest in the area from "eradicated" to "present" and that ultimately raised questions about the apparent eradication achieved by the previous campaigns (67). The northern parts of South Africa border Botswana, Zimbabwe, and Mozambique, each of which experienced *B. dorsalis* invasions. In Mauritius, eradication was attempted following detections of *B. dorsalis* in 1996 and 2013 and was declared successful in 1999 and 2013, respectively, following the international standards. Nevertheless, additional detections in 2015, followed by major outbreaks since 2016, revealed that the fly was established on the island (104). Repeated detections of *B. dorsalis*, *C. capitata*, and a few other fruit flies in the same areas of California over decades, based on recurrence and spatial and demographic analysis, have been interpreted as stemming from established, self-sustained, low-density populations (9, 51, 89, 138, 139); however, others argue that these are the result of repeated introductions (69, 102, 137).

The existence of endemic or established fruit fly species in an area may also affect the establishment of arriving propagules of an invasive pest, especially if a superior competitor is present (12). The fruit fly literature includes several interesting cases of competitive displacement of resident species by invaders (72, 137). The presence of a superior competitor such as *B. dorsalis* may lower the risk of establishment of inferior competitors such as *C. capitata* (35).

Transient population: an exotic pest that is present (detected) but that is not expected to become established in an area; often not considered actionable

Phytosanitary measures: all activities supervised and/or operated by the IPPC aiming to reduce the risk of fruit fly pest introduction, spread, and impact

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Spread

Factors influencing the dispersal of fruit flies have been the subjects of great interest for a long time (e.g., 19, 132). Natural dispersal of larvae is likely insignificant; thus, the focus has been on understanding the movement of adult flies, particularly (*a*) propensity to move and explore the local environment (perhaps equivalent to boldness in behavioral syndromes) (108); (*b*) ability, performance, and proportion of the population that typically moves under various conditions; and (*c*) duration of (and recovery from) walking and flying various distances. There are two major factors that are widely accepted as influencing local adult dispersal: population density and nutrition. Low density plays a key role via Allee effects but also because flies need other flies to mate with (and rarely travel in pairs), and moving away from others in a population translates into a lower probability of finding mates (19). Adequate nutrition via larval host resources can result in a vigorous, flight-capable, and sexually mature fly that can withstand relatively long periods of resource limitation (either water or adult food) during dispersal (132), while low host availability promotes dispersal to new areas if environmental conditions are permissive. Consequently, while poor nutrition might create a greater propensity to move, it also likely results in a less physiologically robust fly that is incapable of long-distance, self-sustained movement. It is widely expected that sexes differ in dispersal propensity and ability, although this is not the case in *B. tryoni* and *B. dorsalis* (61). Flight mill studies often find sex effects in morphology or performance. While many studies have sought morphological correlates or biomarkers of dispersal-prone flies (e.g., 11, 62), dispersal syndromes remain poorly studied to date (see, e.g., 108), especially across the key traits that might translate into invasion success through fragmented landscapes.

KEY ELEMENTS IN FRUIT FLY BIOLOGY THAT FACILITATE INVASION

The invasiveness and overall ability of Tephritidae to occupy diverse hosts and a broad range of environments may be facilitated by a range of intrinsic and extrinsic factors, such as (*a*) life-history traits, (*b*) environmental stress response traits, (*c*) dispersal traits, and (*d*) a novel genetic admixture aiding in establishment and spread (45, 126) (**Supplemental Table 2**). The literature is patchy, and the traits that can confer an advantage to specific invasive taxa remain unclear. This advantage predominantly includes traits of fecundity, temperature dependence of growth rate and reasonably broad lower and upper developmental temperature thresholds, and early onset and delayed duration of reproductive maturity, in addition to stress resistance to, recovery from, or tolerance of stress perturbations (e.g., climatic factors such as seasonality, brief or repeated high-temperature events). Life-history traits have been demonstrated to have a strong impact on invasiveness, although, to our knowledge, there are no formal systematic comparative studies or meta-analyses of effect sizes for different traits (but see, e.g., 131, 39 for broader comparisons).

Supplemental Material >

It is generally accepted that environmental stress tolerance provides an advantage during the transport, establishment, and spread phases of biological invasions. In *C. capitata*, which possesses broad thermal tolerance and great flexibility to adjust tolerances upon exposure to novel conditions, there is good evidence of broader tolerance, more rapid thermal acclimation, and longer persistence of an acquired stress response, and evolutionary adaptation to climate stress could perhaps yield comparable fitness benefits over congeners such as *Ceratitis rosa* (79). Adult *C. capitata* also possesses the overwintering capacity to persist in many temperate environments, giving them a springtime or early season advantage as soon as temperature increases (87). By contrast, *B. dorsalis*, while considered by some to be an exemplar invader and able to outcompete *C. capitata* in tropical Africa, does not appear to have an exceptionally pronounced thermal advantage over *Ceratitis* species when thermal limits for activity and survival are compared (92).

Downloaded from www.annualreviews.org Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Some research groups working on the functional genomics of *B. dorsalis* suggest that it is genetically predisposed to and has unusually high adaptive capacity for thermal stress tolerance (e.g., 136). However, the whole-animal phenotypes assayed to date do not necessarily support such a view, finding thermal tolerances are inferior compared to several *Ceratitis* species. Regardless, at present, no studies have determined whether the native-range populations underwent a fundamental climatic niche shift or tested whether niche shifts are typical of the genus or characteristic of highly invasive tephritid species more generally.

In the case of dispersal, only a subset of individuals in a tephritid population exhibit dispersal behavior. Of those that disperse willingly, most individuals fly a few hundred meters over several small flight bouts, but a rather small proportion of the population (<10%) will engage in sustained, long-distance dispersal of several kilometers (11–35 km) in their lifetime (61). Long-distance dispersal is also likely to come with substantial costs; it remains unknown whether body condition is depleted so far as to impact fitness upon arrival in a poor-quality environment, so the invasion significance of such events is unclear. Automatic flight mills can log distance traveled under controlled conditions over a short timeframe and have frequently been used to assess dispersal ability and the effects of temperature, body size, irradiation, and mating status (e.g., 61). In the field, flies are typically marked with, e.g., fluorescent powder; released at a central location; and then recaptured at a range of distances to infer dispersal patterns under varying conditions or over longer timescales (21). Studies of Tephritidae have increasingly probed the impact of different handling protocols or thermal treatments on recapture rates or dispersal patterns (107). For invasiveness, the evidence is mixed or weak, and it is therefore rather unclear if dispersal traits play a strong role in tephritid invasions; indeed, we are unaware of any studies that have directly compared the relevant traits across populations or species varying in invasion success.

One mechanism proposed to explain the invasiveness of several cosmopolitan insects is the invasion bridgehead hypothesis, where successive introductions result in a novel genetic admixture that gives rise to a population with fitness advantages in the invasive range, increasing its invasiveness (137). However, Bertelsmeier & Keller (4) argue that this observed increase in invasiveness has more to do with the increased abundance at the bridgehead population and emphasized that adequate tests of this hypothesis are lacking. In Tephritidae, there is some weak evidence to suggest that genetically unusual or atypical populations with high levels of heterozygosity were the source for a particular geographic range expansion or niche shift (42); in other words, novel genetic mixture may have contributed some key genetic material to the invasion process. However, this idea is contentious and requires further testing coupled with comparisons of functional traits. In addition to novel genetic admixtures of the metazoan organism, the role of host–microorganism interactions in the invasion process is a relatively new field of investigation. Recent studies show that microorganism commensals contribute to the feeding success of phytophagous organisms such as fruit flies by supporting rapid diet shifts (41), which could allow fruit flies to exploit novel hosts in their newly invaded environment (2).

MODELING FRUIT FLY POPULATIONS TO INFORM TEPHRITID INVASIONS

There has been considerable effort applied to modeling fruit flies to inform management questions at different stages of the invasion process (**Supplemental Table 3**). Interestingly, much of this effort has been focused on a few high-profile, charismatic species, with different modeling groups completing similar models on the same few species.

Supplemental Material >

Bioclimatic models are used to understand the potential distribution of invasive fruit flies. This knowledge allows each jurisdiction to understand what invasion hazard they face. Combined with

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

information on the distribution of assets at risk, invasion pathways, and propagule pressure, this understanding allows a full estimate of the invasion risks. These bioeconomic assessments are frequently used to justify phytosanitary and other measures to attenuate the risks or surveillance and reporting measures to maintain market access.

There are two paradigms in bioclimatic modeling (115): process-based or process-oriented niche models such as CLIMEX (34, 47, 117) and correlative species distribution models (SDMs) such as GARP (109) and MaxEnt (91). Niche models can draw on information from multiple knowledge domains to achieve robust cross-validation (e.g., 134). In contrast, SDMs are trained solely on species distribution data and thus are sensitive to the frequent errors or biases in these data (32). A frequent problem in tephritid modeling is the inclusion of location records from xeric locations where flies and their hosts only persist because of artificial irrigation, with the resulting model overstating the risks of invasion into xeric habitats. SDMs are also prone to overfitting, where the modeler makes a choice to use more covariates than is prudent, resulting in a model that fits the input data (too) closely and consequently understates the establishment risks elsewhere (e.g., 60).

Mathematical models can inform biosecurity management at multiple points in the invasion process. For example, phenological models can be used to inform border surveillance, as well as the seasonal timing of scouting and pesticide application. Similarly, analytical models of life stage vulnerability can be used to target control efforts during eradication campaigns, as well as in post-border pest management.

Kean & Stringer (43) developed a growth index–style model to inform the seasonal deployment of traps to detect flies at the biosecurity border, delivering significant surveillance savings by not maintaining the surveillance during inclement seasons. The same type of model could be used to inform post-border pest surveillance.

The SIT is a mainstay of eradication and suppression programs (21, 111). To be effective, the ratio of sterile male to wild male flies must be maintained at high levels throughout the area of the infestation. Variance in this ratio in time or space can rapidly undermine the system (94). Models have been developed to inform the spatial and temporal deployment of SIT releases. The relatively poor dispersal of released flies and their short lifespan indicate that releases should be made every 200–400 m (70, 95). Roving releases and aerial releases could improve the coverage and reduce the spatial variance in the overflooding ratio substantially (71). Because of the negative exponential nature of the survival and dispersal factors, reducing the variance in coverage is far more cost effective than increasing the numbers of sterile flies released (95).

There are several techniques available to control tephritid incursions. The challenge is to understand when it is appropriate to deploy each technique and how it should be deployed. Modeling has suggested that management actions targeted at interfering with egg laying are the methods that are most likely to be effective at reducing populations of *B. tryoni* (111). This is logical, since adult female flies are numerically the smallest component of the population, and they are accessible and relatively detectable. When used concurrently, the MAT interferes with the SIT because it kills the sterile males. However, if deployed prior to the SIT, the MAT can reduce the number of wild males, improving the overflooding ratio for the SIT. Protein bait sprays targeting both males and females can enhance control slightly over the SIT alone (111).

An important question for eradication campaigns is the stopping rule, i.e., how to define the end of the campaign. MED-FOES (63) is an agent-based model designed to dynamically simulate the eradication of *C. capitata* in California. Modeling using MED-FOES suggests that the regulatory rule for declaring eradication success after three generations, estimated by degree-day modeling, likely resulted in premature cessation in some cases, while other campaigns were prolonged unnecessarily (63).

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Wang and colleagues (130) describe an individual-based model focused on *B. tryoni* host-finding behavior to inform the spatial deployment of fruit fly traps. The model indicated that the best location to place a trap depended primarily on the fly species and the canopy architecture. Placing the trap as high in the canopy as practicable and on the edge of the canopy should maximize fly catch for closed-canopy trees, while placing the trap in the mid- to upper canopy should maximize catch for vase-shaped trees.

In a tephritid surveillance program, it is often economically desirable to survey for multiple species at the same time, to reduce the average cost of servicing traps for each species (112). While there is more work to be done on this topic, it appears possible to combine male lures for some tephritid species. System-wide sensitivity can be maintained by increasing the density of the traps, but this will reduce the cost savings; in addition, attention needs to be paid to potential interference between lures (112).

A critical element of creating mass trapping networks is to understand the effective area of a trap. Suckling et al. (114) describe a simple method for assessing the appropriate trap density, identifying the critical density at which trap interference occurs.

Degree-day phenological models have been developed for several tephritid species to inform pesticide applications (**Supplemental Table 3**). In other settings, this style of modeling could be used to inform pest scouting and trapping, as well as IPM decision making.

Supplemental Material >

CURRENT METHODS TO MANAGE FRUIT FLY INVASIONS

For many geographical regions, regulations or strategies for tephritid management are not clearly defined or publicly available. In cases where they are available, the interpretation can vary by country and at different governmental levels, making a standardized approach difficult. Internationally, the International Plant Protection Convention (IPPC), an intergovernmental treaty, plays an important role in setting out global standards for plant health management. This is the result of the Sanitary and Phytosanitary Agreement, which defined the role of the IPPC in the development and harmonization of such regulations and standards (29). These are presented as ISPMs. While most of the ISPMs are generic, many of these standards apply specifically to fruit flies (e.g., ISPM26, concerning the establishment of pest-free areas for fruit flies; ISPM35, concerning a systems approach for pest risk management of fruit flies; and ISPM37, concerning determination of the host status of different fruit species for fruit flies). In addition, several appendices to ISPM27 (diagnostic protocols for regulated pests) and ISPM28 (phytosanitary treatments for regulated pests) deal with specific fruit fly taxa. In the United States, the Plant Protection Act of 2000 (also called the Agriculture Risk Protection Act; Public Law 106–224) regulates all activities at the federal level to prevent the introduction into or dissemination within the United States of invasive species. This act combines responsibilities that were previously dispersed over several pieces of legislation. This federal act can be supplemented by additional legislation at the state level. For the European Union, the most important recent regulation is EU 2016/2031 on protective measures against pests of plants (officially in place since December 2019 and introducing a proactive approach to prevent introduction of non-EU pest organisms into the European Union). One of the requirements of this regulation is that member states develop a surveying program in their territory that will allow rapid detection of the presence of specified non-EU pest organisms if they pose a threat of establishment to the member state. The European Union also provides a listing of quarantine organisms, with regulation EU 2021/2285 including 75 tephritid taxa. In addition, the delegated regulation EU 2019/1702 dealing with priority organisms includes four tephritids (*Anastrepha ludens*, *B. dorsalis*, *Bactrocera zonata*, and *Rhagoletis pomonella*). Any actions and the ways in which they are developed are the responsibility of the individual member state, but several

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

bodies within the European Union aim to coordinate some of the necessary tools and measures, such as pest survey cards for each priority pest compiled by the European Food Safety Agency or identification standards developed by the European Reference Laboratory for Insects and Mites. Other countries with large horticultural activities that are vulnerable to invasive plant pests have developed their own policies, such as Australia's Plant Quarantine Pest and Official Control National Policy (123). In developing countries in Africa, most management actions are at the national level, but the current state of development is variable from country to country. Such country-specific action programs are described by Ekesi et al. (24). In recent years, overarching regional programs have been developed, in particular in western Africa, by the Regional Agency for Agriculture and Food of ECOWAS, through the SyRIMAO program funded by the European Union and the French Government (**https://capacity4dev.europa.eu/projects/desira/info/syrimao**).

The first step to address fruit fly invasions is the development of a comprehensive pest risk assessment (PRA) to assess the risk, impact, pathways of introduction, and direct preventive interventions at point and time of entry (37). Scenario-based PRAs consider data regarding propagule pressure and potential for establishment and dispersion into new areas (see above) and may include assessment of the risk of importing infested fruit. A recent biosecurity PRA model has been developed for *B. zonata* in New Zealand considering two scenarios: (*a*) with current biosecurity measures and (*b*) an alternative with no management applied (37). Several other PRAs have been developed for other fruit flies, such as *B. zonata*, *Ceratitis quilicii*, and *C. rosa* (122, 139). Four elements to reduce risk (i.e., minimizing exposure and vulnerability of a host commodity to pests and reducing infestation rates and establishment risk) at three production stages (preharvest, at harvest, and postharvest) have been recently organized in a systems framework to address invasive fruit fly pests (124). Of the 60 protocols reviewed, 40 dealt with fruit flies and imposed measures and actions to put in place pest-free or low-prevalence areas, cover the crop (netting), harvest and trade fruits at early ripening stages (e.g., banana), and implement quarantine postharvest treatments (e.g., cold treatment, hot treatment, irradiation), among others. Detections of specimens that break the above barriers are categorized as either transient, requiring no actions, or incursions, often resulting from a breeding or an established population, which can trigger aggressive eradication or containment campaigns. The fruit fly invasion literature reports a list of eradication efforts that encompass different tools and approaches. The sterile insect release method has been used as the main management tool in short- and long-term eradication campaigns executed for medfly in California, Florida, South Australia, and Mexico (8, 25, 26). Male annihilation based on strong male-specific attractants in lure-and-kill methods has been used to eradicate *B. dorsalis* from California, Florida, northeastern Australia, Mauritius, and other areas (104, 105). Pesticides have also been used in eradication campaigns as a stand-alone tool or to reduce population densities before the application of the SIT. Likewise, inundative releases of parasitoids have been combined with the SIT.

FUTURE ISSUES

1. We recommend establishing a global database of fruit fly invasions, under the aegis of the International Plant Protection Convention, focused on post-border detections that includes details of each event in time and space (e.g., number of individuals, geographical coordinates, host, management tactics, cost of intervention) to support heuristic learning on how to best manage fruit fly invasions. An International Standard for Phytosanitary Measures could be developed to define data standards and reporting procedures.

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

2. We recommend investing in developing enhanced tools with sufficient geographical coverage to analyze local and global biological invasions (e.g., genetic and genomic tools) to (*a*) trace the geographic origin of intercepted or detected alien fruit flies, (*b*) resolve seasonal population dynamics, and (*c*) develop a reference genetic database covering the native and invaded range of the invasive fruit flies.
3. We recommend refining and developing modeling methods and establishing flexible systems to estimate dynamic spatiotemporal risks at various levels that are related to fruit fly invasion (e.g., *Bactrocera dorsalis* detection in Europe). This capability can inform efficient and effective border surveillance activities and aid in early detection and rapid response.
4. We recommend establishing comprehensive, real-time online platforms to share information on tephritids (and potentially other pests) and run identification, modeling, and management operations. For efficiency, these would ideally be global resources.
5. We recommend investing more in understanding the invasion traits and adaptive capacity of fruit fly species, including efforts on the lesser-studied species.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

We thank Ms. Eleni Savvidou (University of Thessaly, Greece) for help in drafting Figure 2 and Ms. Elma Bali for assistance in compiling information in the tables. This review was supported by the Horizon 2020 via EU funded project FF-IPM (818184).

LITERATURE CITED

1. Adedeji AA, Ekramirad N, Rady A, Hamidisepehr A, Donohue KD, et al. 2020. Non-destructive technologies for detecting insect infestation in fruits and vegetables under postharvest conditions: a critical review. *Foods* 9:927
2. Awad M, Ben Gharsa H, ElKraly OA, Leclerque A, Elnagdy SM. 2023. COI haplotyping and comparative microbiomics of the peach fruit fly, an emerging pest of Egyptian olive orchards. *Biology* 12:27
3. Badii KB, Billah MK, Afreh Nuamah K, Obeng Ofori D, Nyarko G. 2015. Review of the pest status, economic impact and management of fruit-infesting flies (Diptera: Tephritidae) in Africa. *Afr. J. Agric. Res.* 10:1488–98
4. Bertelsmeier C, Keller L. 2018. Bridgehead effects and role of adaptive evolution in invasive populations. *Trends Ecol. Evol.* 33:527–34
5. Bradshaw CJA, Hoskins AJ, Haubrock PJ, Cuthbert RN, Diagne C, et al. 2021. Detailed assessment of the reported economic costs of invasive species in Australia. *NeoBiota* 67:511–50
6. Bragard C, Dehnen-Schmutz K, Di Serio F, Gonthier P, Jacques MA, et al. 2020. Pest categorisation of non-EU Tephritidae. *EFSA J.* 18:e05931
7. Cantrell BK, Cahill A, Chadwick B. 2002. *Fruit Fly Fighters: Eradication of the Papaya Fruit Fly*. Clayton, Aust.: CSIRO Publ.
8. Carey JR. 2010. The Mediterranean fruit fly (*Ceratitis capitata*). *Am. Entomol.* 56:116–21
9. Carey JR, Papadopoulos NT, Plant R. 2017. The 30-year debate on a multi-billion-dollar threat: tephritid fruit fly establishment in California. *Am. Entomol.* 63:101–13

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

10. Carey JR, Papadopoulos NT, Plant R. 2017. Oriental fruit fly outbreaks in California: 48 consecutive years, 235 cities, 1,500 detections—and counting. *Am. Entomol.* 63:232–36
11. Chen M, Chen P, Ye H, Yuan R, Wang X, Xu J. 2015. Flight capacity of *Bactrocera dorsalis* (Diptera: Tephritidae) adult females based on flight mill studies and flight muscle ultrastructure. *J. Insect Sci.* 15:141
12. Clarke AR, Measham PF. 2022. Competition: a missing component of fruit fly (Diptera: Tephritidae) risk assessment and planning. *Insects* 13:1065
13. Cugala D, Tostão E, Affognon H, Mutungi C. 2012. Postharvest losses in Africa—analytical review and synthesis: the case of Mozambique. *Afr. Insect Sci. Food Health* 2015:1–62
14. De Meyer M, Robertson MP, Mansell MW, Ekesi S, Tsuruta K, et al. 2010. Ecological niche and potential geographic distribution of the invasive fruit fly *Bactrocera invadens* (Diptera, Tephritidae). *Bull. Entomol. Res.* 100:35–48
15. De Villiers M, Hattingh V, Kriticos DJ. 2012. Combining field phenological observations with distribution data to model the potential range distribution of the fruit fly *Ceratitis rosa* Karsch (Diptera: Tephritidae). *Bull. Entomol. Res.* 103:60–73
16. De Villiers M, Hattingh V, Kriticos DJ, Brunel S, Vayssières J-F, et al. 2016. The potential distribution of *Bactrocera dorsalis*: considering phenology and irrigation patterns. *Bull. Entomol. Res.* 106:19–33
17. Diller Y, Shamsian A, Shaked B, Altman Y, Danziger B-C, et al. 2023. A real-time remote surveillance system for fruit flies of economic importance: sensitivity and image analysis. *J. Pest Sci.* 96:611–22
18. Doitsidis L, Fouskitakis GN, Varikou KN, Rigakis II, Chatzichristofis SA, et al. 2017. Remote monitoring of the *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae) population using an automated McPhail trap. *Comput. Electron. Agric.* 137:69–78
19. Dominiak BC. 2012. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. *Ann. Entomol. Soc. Am.* 105:434–46
20. Dominiak BC, Mapson R. 2017. Revised distribution of *Bactrocera tryoni* in eastern Australia and effect on possible incursions of Mediterranean fruit fly: development of Australia's Eastern Trading Block. *J. Econ. Entomol.* 110:2459–65
21. Dominiak BC, Taylor PW, Rempoulakis P. 2023. Marking and identification methodologies for mass releases of sterile Queensland fruit fly *Bactrocera tryoni* (Diptera: Tephritidae) an overview. *Crop Prot.* 166:106173
22. Egartner A, Lethmayer C, Gottsberger RA, Blumel S. 2019. Recent records of the Mediterranean fruit fly, *Ceratitis capitata* (Tephritidae, Diptera), in Austria. *IOBC-WPRS Bull.* 146:143–52
23. Ekesi S, De Meyer M, Mohamed SA, Virgilio M, Borgemeister C. 2016. Taxonomy, ecology, and management of native and exotic fruit fly species in Africa. *Annu. Rev. Entomol.* 61:219–38
24. Ekesi S, Mohamed SA, De Meyer M, eds. 2016. *Fruit Fly Research and Development in Africa—Towards a Sustainable Management Strategy to Improve Horticulture*. Berlin: Springer
25. Enkerlin W. 2021. Impact of fruit fly control programmes using the sterile insect technique. In *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*, ed. VA Dyck, J Hendrichs, AS Robinson, pp. 979–1006. Boca Raton, FL: CRC Press
26. Enkerlin WR, Gutiérrez Ruelas JM, Pantaleon R, Soto Litera C, Villaseñor Cortés A, et al. 2017. The Moscamed Regional Programme: review of a success story of area-wide sterile insect technique application. *Entomol. Exp. Appl.* 164:188–203
27. EPPO. *New findings of* Bactrocera dorsalis *in Italy*. Rep., EPPO, Paris. **https://gd.eppo.int/reporting/article-7419**
28. Epsky ND, Kendra PE, Schnell EQ. 2014. History and development of food-based attractants. See Reference 101, pp. 75–118
29. Food Agric. Org. U. N., Int. At. Energy Agency. 2022. *General guidelines to facilitate the opening of international markets for fruits and vegetables that are fruit fly hosts based on International Standards for Phytosanitary Measures*. Rep., Food Agric. Org. U. N./Int. At. Energy Agency, Rome/Vienna
30. Gilioli G, Sperandio G, Colturato M, Pasquali S, Gervasio P, et al. 2021. Non-linear physiological responses to climate change: the case of *Ceratitis capitata* distribution and abundance in Europe. *Biol. Invasions* 24:261–79

31. Goldshtein E, Cohen Y, Hetzroni A, Gazit Y, Timar D, et al. 2017. Development of an automatic monitoring trap for Mediterranean fruit fly (*Ceratitis capitata*) to optimize control applications frequency. *Comput. Electron. Agric.* 139:115–25
32. Graham CH, Elith J, Hijmans RJ, Guisan A, Townsend Peterson A, et al. 2008. The influence of spatial errors in species occurrence data used in distribution models. *J. Appl. Ecol.* 45:239–47
33. Grechi I, Preterre A-L, Lardenois M, Ratnadass A. 2022. *Bactrocera dorsalis* invasion increased fruit fly incidence on mango production in Reunion Island. *Crop Prot.* 161:106056
34. Gutierrez AP, Ponti L, Neteler M, Suckling DM, Cure JR. 2021. Invasive potential of tropical fruit flies in temperate regions under climate change. *Commun. Biol.* 4:1141
35. Hassani IM, Delatte H, Ravaomanarivo LHR, Nouhou S, Duyck PF. 2022. Niche partitioning via host plants and altitude among fruit flies following the invasion of *Bactrocera dorsalis*. *Agric. For. Entomol.* 24:575–85
36. Hulme PE. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *J. Appl. Ecol.* 46:10–18
37. Jamieson LE, Woodberry O, Mascaro S, Meurisse N, Jaksons R, et al. 2022. An integrated biosecurity risk assessment model (IBRAM) for evaluating the risk of import pathways for the establishment of invasive species. *Risk Anal.* 42:1325–45
38. Jang EB, McQuate GT, McInnis DO, Harris EJ, Vargas RI, et al. 2008. Targeted trapping, bait-spray, sanitation, sterile-male, and parasitoid releases in an areawide integrated melon fly (Diptera: Tephritidae) control program in Hawaii. *Am. Entomol.* 54:240–50
39. Jarošík V, Kenis M, Honěk A, Skuhrovec J, Pyšek P. 2015. Invasive insects differ from non-invasive in their thermal requirements. *PLOS ONE* 10:e0131072
40. José L, Cugala D, Santos L. 2013. Assessment of invasive fruit fly fruit infestation and damage in Cabo Delgado Province, Northern Mozambique. *Afr. Crop Sci. J.* 21:21–28
41. Jose PA, Yuval B, Jurkevitch E. 2023. Maternal and host effects mediate the adaptive expansion and contraction of the microbiome during ontogeny in a holometabolous, polyphagous insect. *Funct. Ecol.* 37:929–46
42. Karsten M, Addison P, Jansen van Vuuren B, Terblanche JS. 2016. Investigating population differentiation in a major African agricultural pest: Evidence from geometric morphometrics and connectivity suggests high invasion potential. *Mol. Ecol.* 25:3019–32
43. Kean JM, Stringer LD. 2019. Optimising the seasonal deployment of surveillance traps for detection of incipient pest invasions. *Crop Prot.* 123:36–44
44. König S, Steinmöller S, Baufeld P. 2022. Origin and potential for overwintering of *Ceratitis capitata* (Wiedemann) captured in an official survey in Germany. *J. Plant Dis. Prot.* 129:1201–15
45. Krainacker DA, Carey JR, Vargas RI. 1987. Effect of larval host on life history traits of the Mediterranean fruit fly, *Ceratitis capitata*. *Oecologia* 73:583–90
46. Kriticos DJ. 2007. *Risks of Establishment of Fruit Flies in New Zealand under Climate Change*. Rotorua, N. Z.: Ensis
47. Kriticos DJ, Maywald GF, Yonow T, Zurcher EJ, Herrmann NI, Sutherst R. 2015. *Exploring the Effects of Climate on Plants, Animals and Diseases*. Canberra: CSIRO
48. Kriticos DJ, Stephens AEA, Leriche A. 2007. Effect of climate change on Oriental fruit fly in New Zealand and the Pacific. *N. Z. Plant Protect.* 60:271–78
49. Kriticos DJ, Zalucki MP, Mills JA, Alcaraz SA. 2007. *Modelling the Climatic Potential for* Bactrocera *(*Dacus*)* cucumis *to Establish Viable Populations in New Zealand*. Rotorua, N. Z.: Ensis
50. Kuo K.-C. 2008. *Management of red invasive fire ants and fruit flies: the Taiwan experience*. Rep., Food Fertil. Technol. Cent., CAB Int., Wallingford, UK
51. Larsen CC. 2021. *Flying under the radar: using spatial analytical approaches to track non-native tephritid fruit fly populations in California*. Rep., Univ. Calif., Davis
52. Li B, Ma J, Hu X, Liu H, Zhang R. 2009. Potential geographical distributions of the fruit flies C*eratitis capitata*, *Ceratitis cosyra*, and *Ceratitis rosa* in China. *J. Econ. Entomol.* 102:1781–90
53. Li Z, Jiang F, Ma X, Yan F, Qin Y, et al. 2013. Review on prevention and control technique of Tephritidae invasion. *Plant Quar.* 27:1–10

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

54. Liebhold AM, Berec L, Brockerhoff EG, Epanchin-Niell RS, Hastings A, et al. 2016. Eradication of invading insect populations: from concepts to applications. *Annu. Rev. Entomol.* 61:335–52
55. Liebhold AM, Tobin PC. 2008. Population ecology of insect invasions and their management. *Annu. Rev. Entomol.* 53:387–408
56. Liebhold AM, Work TT, McCullough DG, Cavey JF. 2006. Airline baggage as a pathway for alien insect species invading the United States. *Proc. North Cent. Branch Entomol. Soc. Am.* 52:48–54
57. Liu J-H, Xiong X, Pan Y, Xiong Z, Deng Z, Yang L. 2011. Predicting potential distribution of oriental fruit fly, *Bactrocera dorsalis* in Jiangxi Province, South China based on maximum entropy model. *Sci. Res. Essays* 6:2888–94
58. Lu W, Deng Y, Li Z, Lin W, Wan F, et al. 2010. A predication of potential geographical distribution of guava fruit fly, *Bactrocera* (*Bactrocera*) *correcta* (Bezzi) in China. *Zhiwu Baohu Xuebao* 37:529–34
59. Lux SA. 2017. Individual-based modeling approach to assessment of the impacts of landscape complexity and climate on dispersion, detectability and fate of incipient medfly populations. *Front Physiol.* 8:1121
60. Machado Teixeira C, Krüger AP, Nava DE, Mello Garcia FR. 2022. Global potential distribution of *Anastrepha grandis* (Diptera, Tephritidae) under climate change scenarios. *Crop Prot.* 151:105836
61. Makumbe LDM, Moropa TP, Manrakhan A, Weldon CW. 2020. Effect of sex, age and morphological traits on tethered flight of *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) at different temperatures. *Physiol. Entomol.* 45:110–19
62. Manoukis NC, Carvalho L. 2020. Flight burst duration as an indicator of flight ability and physical fitness in two species of tephritid fruit flies. *J. Insect. Sci.* 20:11
63. Manoukis NC, Hoffman K. 2014. An agent-based simulation of extirpation of *Ceratitis capitata* applied to invasions in California. *J. Pest Sci.* 87:39–51
64. Manrakhan A. 2016. Detection and monitoring of fruit flies in Africa. See Reference 24, pp. 253–73
65. Manrakhan A, Daneel JH, Beck R, Love CN, Gilbert MJ, et al. 2021. Effects of male lure dispensers and trap types for monitoring of *Ceratitis capitata* and *Bactrocera dorsalis* (Diptera: Tephritidae). *Pest Manag. Sci.* 77:2219–30
66. Manrakhan A, Hattingh V, Venter JH, Holtzhausen M. 2011. Eradication of *Bactrocera invadens* (Diptera: Tephritidae) in Limpopo Province, South Africa. *J. Entomol. Soc. South. Afr.* 19:650–59
67. Manrakhan A, Venter JH, Hattingh V. 2015. The progressive invasion of *Bactrocera dorsalis* (Diptera: Tephritidae) in South Africa. *Biol. Invasions* 17:2803–9
68. Marchioro CA. 2016. Global potential distribution of *Bactrocera carambolae* and the risks for fruit production in Brazil. *PLOS ONE* 11:e0166142
69. McInnis DO, Hendrichs J, Shelly TE, Barr N, Hoffman K, et al. 2017. Can polyphagous invasive tephritid pest populations escape detection for years under favorable climatic and host conditions? *Am. Entomol.* 63:89–99
70. Meats A, Smallridge CJ. 2007. Short- and long-range dispersal of medfly, *Ceratitis capitata* (Dipt., Tephritidae), and its invasive potential. *J. Appl. Entomol.* 131:518–23
71. Meats A, Smallridge CJ, Dominiak BC. 2006. Dispersion theory and the sterile insect technique: application to two species of fruit fly. *Entomol. Exp. Appl.* 119:247–54
72. Moquet L, Payet J, Glenac S, Delatte H. 2021. Niche shift of tephritid species after the Oriental fruit fly (*Bactrocera dorsalis*) invasion in La Réunion. *Divers. Distrib.* 27:109–29
73. Moraiti CA, Nakas CT, Papadopoulos NT. 2014. Diapause termination of *Rhagoletis cerasi* pupae is regulated by local adaptation and phenotypic plasticity: escape in time through bet-hedging strategies. *J. Evol. Biol.* 27:43–54
74. Mumford JD. 2021. Design and economic evaluation of programmes integrating the sterile insect technique. In *Area-Wide Integrated Pest Management: Development and Field Application*, ed. J Hendrichs, R Pereira, MJB Vreysen, pp. 731–52. Boca Raton, FL: CRC Press
75. Mutamiswa R, Nyamukondiwa C, Chikowore G, Chidawanyika F. 2020. Overview of oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Africa: from invasion, bio-ecology to sustainable management. *Crop Prot.* 141:105492
76. Navarro-Llopis V, Dominguez-Ruiz J, Zarzo M, Alfaro C, Primo J. 2010. Mediterranean fruit fly suppression using chemosterilants for area-wide integrated pest management. *Pest Manag. Sci.* 66:511–19

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

77. Niassy S, Ekesi S, Migiro L, Otieno W, eds. 2020. *Sustainable Management of Invasive Pests in Africa*. Berlin: Springer
78. Nugnes F, Russo E, Viggiani G, Bernardo U. 2018. First record of an invasive fruit fly belonging to *Bactrocera dorsalis* complex (Diptera: Tephritidae) in Europe. *Insects* 9:182
79. Nyamukondiwa C, Weldon CW, Chown SL, le Roux PC, Terblanche JS. 2013. Thermal biology, population fluctuations and implications of temperature extremes for the management of two globally significant insect pests. *J. Insect Physiol.* 59:1199–211
80. Off. U. S. Trade Represent. 2015. *Summary of the Trans-Pacific Partnership agreement*. Press Release, Off. U. S. Trade Represent., Washington, DC. **https://ustr.gov/about-us/policy-offices/press-office/press-releases/2015/october/summary-trans-pacific-partnership**
81. Ohishi T, Matsuyama T, Himuro C, Ohno S, Sadoyama Y, et al. The eradication projects and preventative control of quarantine pests in Okinawa, Japan. In *Proceedings of the 2018 International Symposium on Proactive Technologies for Enhancement of Integrated Pest Management of Key Crops*, pp. 31–48. Taichung City, Taiwan: Taiwan Agric. Res. Inst.
82. Oliveira CM, Auad AM, Mendes SM, Frizzas MR. 2013. Economic impact of exotic insect pests in Brazilian agriculture. *J. Appl. Entomol.* 137:1–15
83. Otieno W. 2009. EPHIS experience with market access and compliance with official standards. In *Proceedings of the All Africa Horticultural Congress*, pp. 73–76. Leuven, Belg.: Int. Soc. Hortic. Sci.
84. Pace R, Ascolese R, Miele F, Russo E, Griffo RV, et al. 2022. The bugs in the bags: the risk associated with the introduction of small quantities of fruit and plants by airline passengers. *Insects* 13:617
85. Papachristos D, Papadopoulos N, Maglaras E, Michaelakis A, Antonatos S. 2013. Susceptibility of kiwifruit (*Actinidia* spp.) cultivars to *Ceratitis capitata* (Diptera: Tephritidae) infestation. *J. Appl. Entomol.* 138:433–40
86. Papadopoulos NT. 2014. Fruit fly invasion: historical, biological, economic aspects and management. See Reference 101, pp. 219–52
87. Papadopoulos NT, Carey JR, Katsoyannos BI, Kouloussis NA. 1996. Overwintering of the Mediterranean fruit fly (Diptera: Tephritidae) in northern Greece. *Ann. Entomol. Soc. Am.* 89:526–34
88. Papadopoulos NT, Katsoyannos BI, Carey JR, Kouloussis NA. 2001. Seasonal and annual occurrence of the Mediterranean fruit fly (Diptera: Tephritidae) in northern Greece. *Ann. Entomol. Soc. Am.* 94:41–50
89. Papadopoulos NT, Plant RE, Carey JR. 2013. From trickle to flood: the large-scale, cryptic invasion of California by tropical fruit flies. *Proc. R. Soc. B* 280:20131466
90. Papanastasiou SA, Nestel D, Diamantidis AD, Nakas CT, Papadopoulos NT. 2011. Physiological and biological patterns of a highland and a coastal population of the European cherry fruit fly during diapause. *J. Insect Physiol.* 57:83–93
91. Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. *Ecol. Model.* 190:231–59
92. Pieterse W, Terblanche JS, Addison P. 2017. Do thermal tolerances and rapid thermal responses contribute to the invasion potential of *Bactrocera dorsalis* (Diptera: Tephritidae)? *J. Insect Physiol.* 98:1–6
93. Plá I, García de Oteyza J, Tur C, Martinez MÁ, Laurín MC, et al. 2021. Sterile insect technique programme against Mediterranean fruit fly in the Valencian Community (Spain). *Insects* 12:415
94. Plant RE. 1986. The sterile insect technique; a theoretical perspective. In *Pest Control: Operations and Systems Analysis in Fruit Fly Management*, ed. M Mangel, JR Carey, RE Plant, pp. 361–86. Berlin: Springer
95. Plant RE, Cunningham RT. 1991. Analyses of the dispersal of sterile Mediterranean fruit flies (Diptera: Tephritidae) released from a point source. *Environ. Entomol.* 20:1491–503
96. Potamitis I, Rigakis I, Fysarakis K. 2014. The electronic McPhail trap. *Sensors* 14:22285–99
97. Qin Y, Ullah F, Fang Y, Singh S, Zhao Z, et al. 2021. Prediction of potential economic impact of *Bactrocera zonata* (Diptera: Tephritidae) in China: peaches as the example hosts. *J. Asia Pac. Entomol.* 24:1101–6
98. Qin Y, Wang C, Zhao Z, Pan X, Li Z. 2019. Climate change impacts on the global potential geographical distribution of the agricultural invasive pest, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae). *Clim. Change* 155:145–56
99. Royer JE, Agovaua S, Bokosou J, Kurika K, Mararuai A, et al. 2018. Responses of fruit flies (Diptera: Tephritidae) to new attractants in Papua New Guinea. *Austral Entomol.* 57:40–49

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

100. Sandrini Moraes F, Nava DE, Scheunemann T, Santos da Rosa V. 2019. Development of an optoelectronic sensor for detecting and classifying fruit fly (Diptera: Tephritidae) for use in real-time intelligent traps. *Sensors* 19:1254
101. Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R. 2014. *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies: Lures, Area-Wide Programs, and Trade Implications*. Berlin: Springer
102. Shelly TE, Lance DR, Tan KH, Suckling DM, Bloem K, et al. 2017. To repeat: Can polyphagous invasive tephritid pest populations remain undetected for years under favorable climatic and host conditions? *Am. Entomol.* 63:224–31
103. Siebert J, Cooper T. 1995. If medfly infestation triggered a trade ban: embargo on California produce would cause revenue, job loss. *Calif. Agric.* 49:7–12
104. Sookar P, Patel N, Ramkalawon P. 2021. *Bactrocera dorsalis*, an invasive fruit fly species in Mauritius. *Fruits* 76:269–75
105. Steck GJ, Fox AJ, Casrrillo D, Dean D, Roda A, et al. 2019. Oriental fruit fly eradication in Florida 2015–2016: program implementation, unique aspects, and lessons learned. *Am. Entomol.* 65:108–21
106. Stephenson B, Gill G, Randall J, Wilson J. 2003. Biosecurity approaches to surveillance and response for new plant pest species. *N. Z. Plant Prot.* 56:5–9
107. Steyn VM, Mitchell KA, Nyamukondiwa C, Terblanche JS. 2022. Understanding costs and benefits of thermal plasticity for pest management: insights from the integration of laboratory, semi-field and field assessments of *Ceratitis capitata* (Diptera: Tephritidae). *Bull. Entomol. Res.* 112:458–68
108. Steyn VM, Mitchell KA, Terblanche JS. 2016. Dispersal propensity, but not flight performance, explains variation in dispersal ability. *Proc. R. Soc. B* 283:20160905
109. Stockwell D, Peters D. 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *Int. J. Geogr. Inf. Sci.* 13:143–58
110. Stonehouse JM, Mumford JD, Mustafa G. 1998. Economic losses to tephritid fruit flies (Diptera: Tephritidae) in Pakistan. *Crop Prot.* 17:159–64
111. Stringer LD, Kean JM, Beggs JR, Suckling DM. 2017. Management and eradication options for Queensland fruit fly. *Popul. Ecol.* 59:259–73
112. Stringer LD, Soopaya R, Butler RC, Vargas RI, Souder SK, et al. 2019. Effect of lure combination on fruit fly surveillance sensitivity. *Sci. Rep.* 9:2653
113. Suckling DM, Kean JM, Stringer LD, Caceres-Barrios C, Hendrichs J, et al. 2016. Eradication of tephritid fruit fly pest populations: outcomes and prospects. *Pest Manag. Sci.* 72:456–65
114. Suckling DM, Stringer LD, Kean JM, Lo PL, Bell V, et al. 2015. Spatial analysis of mass trapping: How close is close enough? *Pest Manag. Sci.* 71:1452–61
115. Sutherst RW, Bourne AS. 2009. Modelling non-equilibrium distributions of invasive species: a tale of two modelling paradigms. *Biol. Invasions* 11:1231–37
116. Sutherst RW, Collyer BS, Yonow T. 2000. The vulnerability of Australian horticulture to the Queensland fruit fly, *Bactrocera* (*Dacus*) *tryoni*, under climate change. *Aust. J. Agric. Res.* 51:467–80
117. Sutherst RW, Maywald G. 1985. A computerised system for matching climates in ecology. *Agric. Ecosyst. Environ.* 13:281–99
118. Sutherst RW, Maywald GF. 1989. *An analysis of CLIMEX predictions of establishment of* Dacus *spp in New Zealand*. Consult. Rep. 12, CSIRO, Canberra, Aust.
119. Szyniszewska AM, Leppla NC, Manoukis NC, Collier TC, Hastings JM, et al. 2020. CLIMEX and MED-FOES models for predicting the variability in growth potential and persistence of Mediterranean fruit fly (Diptera: Tephritidae) populations. *Ann. Entomol. Soc. Am.* 113:114–24
120. Szyniszewska AM, Tatem AJ. 2014. Global assessment of seasonal potential distribution of Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). *PLOS ONE* 9:e111582
121. Tan KH, Nishida R, Jang EB, Shelly TE. 2014. Pheromones, male lures, and trapping of tephritid fruit flies. See Reference 101, pp. 15–74
122. Tanga CM, Khamis FM, Tonnang HEZ, Rwomushana I, Mosomtai G, et al. 2018. Risk assessment and spread of the potentially invasive *Ceratitis rosa* Karsch and *Ceratitis quilicii* De Meyer, Mwatawala & Virgilio sp. nov. using life-cycle simulation models: implications for phytosanitary measures and management. *PLOS ONE* 13:e0189138

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

123. Troy S, de Majnik J, Coates M. 2017. *Plant quarantine pest and official control national policy*. Rep., Dept. Agric. Water Res., Canberra, Aust.
124. van Klinken RD, Fiedler K, Kingham L, Collins K, Barbour D. 2020. A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. *Crop Prot.* 129:104994
125. Vargas RI, Piñero JC, Mau RFL, Jang EB, Klungness LM, et al. 2010. Area-wide suppression of the Mediterranean fruit fly, *Ceratitis capitata*, and the Oriental fruit fly, *Bactrocera dorsalis*, in Kamuela, Hawaii. *J. Insect Sci.* 10:145
126. Vargas RI, Walsh WA, Kanehisa D, Stark JD, Nishida T. 2000. Comparative demography of three Hawaiian fruit flies (Diptera: Tephritidae) at alternating temperatures. *Ann. Entomol. Soc. Am.* 93:75–81
127. Vera MT, Rodriguez R, Segura DF, Cladera JL, Sutherst RW. 2002. Potential geographical distribution of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae), with emphasis on Argentina and Australia. *Environ. Entomol.* 31:1009–22
128. Verheggen F, Verhaeghe A, Giordanengo P, Tassus X, Escobar-Gutiérrez A. 2016. Walnut husk fly, *Rhagoletis completa* (Diptera: Tephritidae), invades Europe: invasion potential and control strategies. *Appl. Entomol. Zool.* 52:1–7
129. Wakie TT, Yee WL, Neven LG. 2018. Assessing the risk of establishment of *Rhagoletis cerasi* (Diptera: Tephritidae) in the United States and globally. *J. Econ. Entomol.* 111:1275–84
130. Wang M, Cribb B, Clarke AR, Hanan J. 2016. A generic individual-based spatially explicit model as a novel tool for investigating insect-plant interactions: a case study of the behavioural ecology of frugivorous Tephritidae. *PLOS ONE* 11:e0151777
131. Weaving H, Terblanche JS, Pottier P, English S. 2022. Meta-analysis reveals weak but pervasive plasticity in insect thermal limits. *Nat. Commun.* 13:5292
132. Weldon CW, Schutze MK, Karsten M. 2014. Trapping to monitor Tephritid movement: results, best practice, and assessment of alternatives. See Reference 101, pp. 175–217
133. White IM, Elson-Harris MM. 1992. *Fruit Flies of Economic Significance: Their Identification and Bionomics*. Wallingford, UK: CAB Int.
134. Yonow T, Sutherst RW. 1998. The geographical distribution of the Queensland fruit fly, *Bactrocera* (*Dacus*) *tryoni*, in relation to climate. *Aust. J. Agric. Res.* 49:935–53
135. Zhang Y, Hughes AC, Zhao Z, Li Z, Qin Y. 2022. Including climate change to predict the global suitable area of an invasive pest: *Bactrocera correcta* (Diptera: Tephritidae). *Glob. Ecol. Conserv.* 34:e02021
136. Zhang Y, Liu S, De Meyer M, Liao Z, Zhao Y, et al. 2023. Genomes of the cosmopolitan fruit pest *Bactrocera dorsalis* (Diptera: Tephritidae) reveal its global invasion history and thermal adaptation. *J. Adv. Res.* In press
137. Zhao Z, Carey JR, Li Z. 2024. The global epidemic of *Bactrocera* pests: mixed-species invasions and risk assessment. *Annu. Rev. Entomol.* 69:219–37
138. Zhao Z, Hui C, Plant RE, Su M, Carpenter T, et al. 2019. Life table invasion models: spatial progression and species-specific partitioning. *Ecology* 5:e02682
139. Zingore KM, Sithole G, Abdel-Rahman EM, Mohamed SA, Ekesi S, et al. 2020. Global risk of invasion by *Bactrocera zonata*: implications on horticultural crop production under changing climatic conditions. *PLOS ONE* 15:e0243047

Downloaded from www.annualreviews.org. Guest (guest) IP: 203.6.146.44 On: Sat, 06 Sept 2025 00:11:49

Ormsby *CABI Agric Biosci* (2021) 2:23
https://doi.org/10.1186/s43170-021-00043-w

CABI Agriculture and Bioscience

METHODOLOGY Open Access

Establishing criteria for the management of tephritid fruit fly outbreaks

Michael D. Ormsby*

Abstract

Tephritid fruit flies (Diptera; Tephritidae) represent a group of insects that include some of the most economically important pests in horticulture. Because of their economic importance, the financial impacts of an incursion of tephritid fruit flies into a new area can often result in restrictions to trade. The economic impacts of any trade restrictions imposed by importing countries are confounded by the current absence of consistent and accepted criteria for the strength and extent of any trade restrictions and declaring the end of an incursion. The author has developed models that can be used to establish criteria for the management of tephritid fruit fly outbreaks as outlined in international standards. A model enables criteria on when to recognise an incursion has occurred and establish export restrictions. Another model determines what area or radius an export restriction zone (ERZ) should cover. And a third model establishes criteria for the conditions required to enable an ERZ to be rescinded and the area's pest free status reinstated. The models rely primarily on fruit fly biology and the effectiveness of surveillance trapping systems. The adoption of these proposed criteria internationally for establishing a control system and responding to fruit fly outbreaks would provide considerable economic benefits to international trade. Additionally, these criteria would enable countries to make more informed cost–benefit decisions on the level of investment in fruit fly control systems that better reflects the economic risks fruit flies represent to their economy.

Background

Tephritid fruit flies (Diptera: Tephritidae) represent a group of insects that include some of the most economically important pests in horticulture. There are an estimated 4,000 species of tephritid fruit flies world-wide, but only around an estimated 350 are considered potentially economically significant (Plant Health Australia, 2016), and around 70 of notable economic importance (Garcia 2009; Vargas et al. 2015; Qin et al. 2015; Doorenweerd et al. 2018). The incursion of a tephritid fruit fly species that is of notable economic importance into a new area can often result in restrictions to trade. The economic impacts of any trade restrictions imposed by importing countries are confounded by the absence of consistent and accepted criteria for the degree and duration of any trade restrictions. For example, differences between countries in the size of the area upon which export restrictions are imposed (the *export restriction zone* or ERZ) increases the transaction costs to exporters as they are forced to implement multiple layered compliance systems (Dominiak and Fanson 2014) (see Table 1 for examples).

Horticultural producers and exporters worldwide require pre-agreed generic bilateral market access conditions in the event of future fruit fly incursions, to significantly reduce the economic impact of trade restrictions on tephritid fruit fly incursions. Substantial benefits would accrue if one arrangement was accepted by all. However, sound scientific reasoning is required to support the development of a framework that can be applied across the range of fruit fly species and potential outbreak scenarios. A good scientific basis is required by trading partners to agree in advance to the parameters of any trade response.

*Correspondence: Michael.Ormsby@MPI.govt.nz
Ministry for Primary Industries, PO Box 2526, Wellington 6140, New Zealand

© The Author(s) 2021. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Table 1 Difference amongst countries in criteria to declare a fruit fly incursion, the size of the area to be treated and for declaring eradication (c 2015)

Criteria	New Zealand system (for *Bactrocera tryoni* and *Bactrocera dorsalis*)	Australian system (for *Bactrocera tryoni*)	Californian system (for *Bactrocera dorsalis*)
Trigger for a fruit fly incursion	Detection of any juvenile life stage found in locally ground fruit or gravid female fly for eradication OR Detection of 1 or more* adult male flies for eradication * depends on the circumstance of the finds	Detection of any juvenile life stage found in locally ground fruit or gravid female fly for eradication OR Detection of 5 or more adult male flies in 14 days within 1 km radius	Detection of any juvenile life stage found in locally ground fruit or gravid female fly for eradication OR Detection of 6 (urban) or 8 (commercial) adult (non-gravid) flies within 28 days and 4.8 km
Size of *ERZ*	Depends on the circumstance of the eradication and largely dictated by trading partners	15 km radius	8.2 km radius
Declaring a Successful Eradication	Depends on the circumstance of the eradication and largely dictated by trading partners	The greater period of trapping with zero flies detected (of any life stage) within the *ERZ*®: One generation (egg to egg) plus 4 weeks OR 12 weeks (No minimum trapping density is specified)	Three fruit fly generations (egg to egg) with zero flies detected (of any life stage) (No minimum trapping density is specified)

Two fruit fly species in the *Bactrocera* genus are considered internationally amongst the most economically important (Schutze et al. 2015; Doorenweerd et al. 2018; Dominiak and Fanson 2020). Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) is the most important fruit fly pest in eastern Australia (Dominiak et al. 2015; Plant Health Australia 2016) and is currently known to infest more than 100 native and introduced hosts (Hancock et al. 2000). Oriental fruit fly *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is known for its extreme polyphagy, with over 209 recorded larval hosts across 51 plant families (Clarke et al. 2005).

Any internationally agreed framework for the management of these fruit flies would need to align with the international standard FAO (2016). This international standard provides a high-level framework for the establishment or reinstatement and maintenance of Pest Free Areas (PFA) for tephritid fruit flies. The international standard outlined three actions that occur when a PFA is invaded by a tephritid fruit fly. Here I present models that can be used to establish criteria for the three actions outlined in FAO (2016) (Fig. 1), namely:

1. Criteria for determining when an outbreak has occurred; the number of adult flies that are detected before an ERZ is implemented and the pest-free status of the localised area is suspended (often referred to as the trigger);
2. Criteria for determining the size (area or radius) of the eradication area and therefore the ERZ, outside of which any host material grown would still be deemed to be within a pest free area; and
3. Criteria for the conditions required to enable an ERZ to be rescinded and the area's pest free status reinstated.

Criteria for the fruit fly outbreak "trigger"

FAO (2016) stated that for all fruit flies of economic importance the number of detected fruit flies that indicate a breeding population may exist in the area, and therefore trigger the need to establish an ERZ, is as follows:

a. Detection of any gravid female flies or any juvenile life stage (excluding immature (teneral) adults) not directly associated with imported produce, should indicate the need to establish an ERZ;
b. For fruit flies attracted to any of the (male) lures included in a fruit fly surveillance system, the detection of 2 or more male flies should be considered a potential outbreak (FAO 2016).

For the second trigger, the upper number of male fruit flies detected in lure-baited traps that indicates the need to establish an ERZ (the trigger number) needs to be resolved for each fruit fly species (see Meats 2014).

While criteria (a) is clear, for criteria (b), can we define "two or more fertile adults" more precisely to ensure any imposition of an ERZ is appropriate to the risk? The

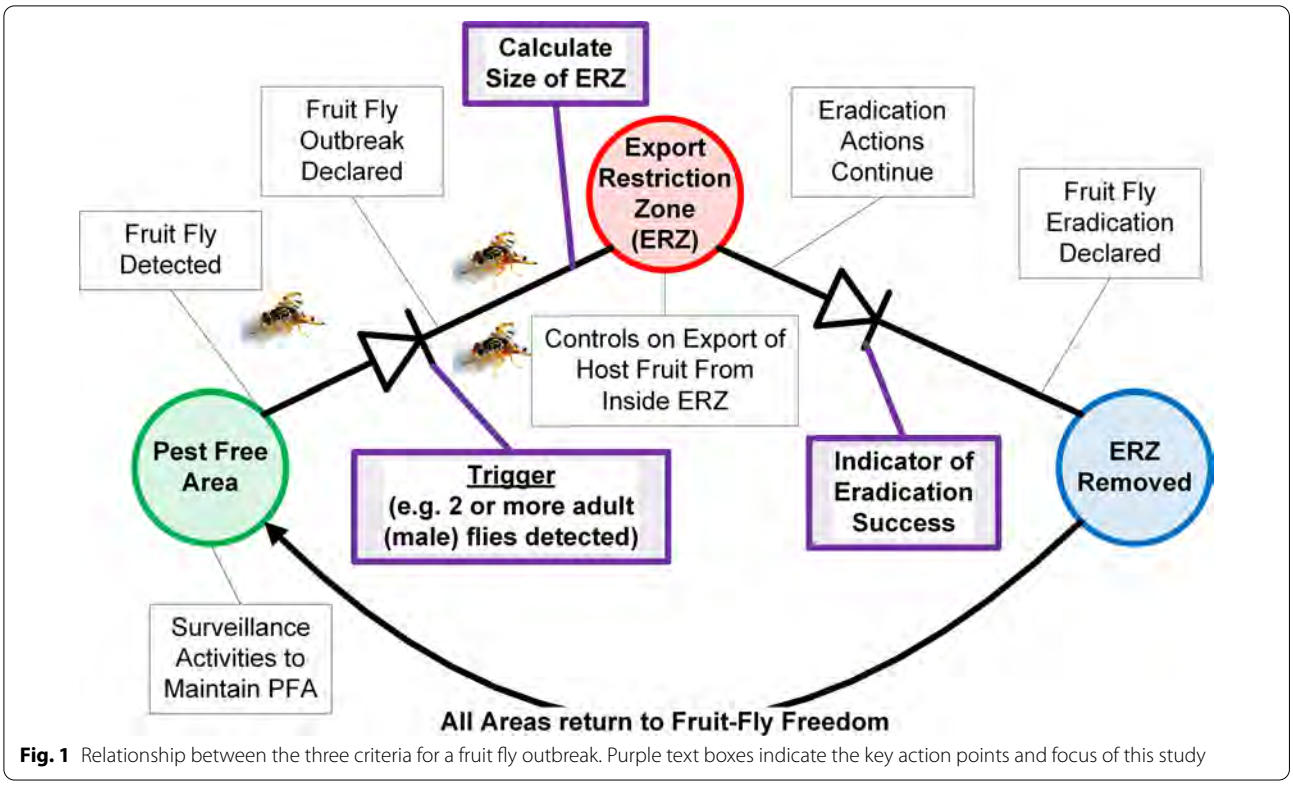


Fig. 1 Relationship between the three criteria for a fruit fly outbreak. Purple text boxes indicate the key action points and focus of this study

risk with regards to market access could be described as being: The unacceptable likelihood of there being a population of fruit fly (present in the area) that is of sufficient size to result in host material becoming infested, being exported, establishing a population in an export market, and causing unwanted impacts. For the purposes of this paper, the market access risk will be simplified to: The unacceptable likelihood of there being a breeding population of fruit fly present in the area.

The size of the population of flies constituting a risk to export markets, otherwise stated in this paper as the '*breeding population size*', will therefore need to be determined for each fruit fly species. The '*breeding population size*' can be considered the minimum number of fruit flies in an area at which mating is likely to occur and potentially result in eggs being laid in host material (e.g. based on the probability of success). This is similar to the concepts of '*Allee threshold*' used in population dynamics, as well as the '*minimum viable population size*' used in conservation ecology (Tobin et al. 2011).

Criteria for the size of the ERZ

The aim here is to determine a scientifically justified size for the ERZ around the detection site for the population of flies of each fruit fly species that may be present at the time of detection. FAO (2016) stated that the "*eradication area should cover the infested area. In addition, a buffer zone should be established in accordance with this standard, and as determined by delimiting surveys, taking into account the natural dispersal capability of the target fruit fly species, its relevant biological characteristics, and other geographic and environmental factors.*" The combined *eradication area* and *buffer zone* can be considered the ERZ; movement of all host material should be restricted within this area.

FAO (2016) further stated that a "*circle delimiting the minimum size of the eradication area should be drawn, centred on the actual target fruit fly species detection and with a radius large enough to comply with the above considerations*".

Therefore, an ERZ is a circle on a map that is centred on the site of a fruit fly detection and encompasses an area that covers the natural dispersal capability of the target fruit fly species. The size of the ERZ can vary greatly between countries as is evident in Table 2. An analysis of Australian *B. tryoni* trapping data found that a single fly of this species of fruit fly was unlikely to naturally disperse more than 1.5 km suggesting that the current 15 km infestation radius employed by Australia could be reduced substantially to 3 or 4 km (Dominiak and Fanson 2020).

Table 2 Summary of current surveillance and response procedures in New Zealand, Australia and California for *B. tryoni* and B. dorsalis

Procedures	New Zealand (*B. tryoni* and *B. dorsalis*)	Australia (*B. tryoni*)	California (*B. dorsalis*)
Surveillance Trapping to Maintain PFA	For *B. tryoni*, a 400 m trapping grid which equates to a density of 6.5 traps per km^2 or 0.065 traps per hectare For *B. dorsalis*, a 1200 m trapping grid which equates to a density of 0.72 traps per km^2 or 0.0072 traps per hectare	For urban areas, a 400 m trapping grid which equates to a density of 6.5 traps per km^2 or 0.065 traps per hectare For production areas, a 1000 m trapping grid which equates to a density of 1.04 traps per km^2 or 0.0104 traps per hectare	For urban areas, a 1000 m trapping grid which equates to a density of 1.04 traps per km^2 or 0.0104 traps per hectare For production areas, a 2000 m trapping grid which equates to a density of 0.26 traps per km^2 or 0.0026 traps per hectare
Response Triggers	Detection of any juvenile life stage or gravid female fly for eradication OR Detection of 1 adult male fly for delimitation OR Detection of 2 or more* adult male flies for eradication * depends on the circumstance of the finds	Detection of any juvenile life stage or gravid female fly for eradication OR Detection of 2 to 4 adult male flies within 14 days and 1 km for delimitation OR Detection of 5 or more adult male flies in 14 days within 1 km for eradication	Detection of any juvenile life stage or gravid female fly for eradication OR Detection of 2 adult (non-gravid) flies within 28 days and 4.8 km for delimitation OR Detection of 6 (urban) or 8 (commercial) adult (non-gravid) flies within 28 days and 4.8 km for eradication
Size of Export Restriction Zone	Depends on the circumstance of the eradication and largely dictated by trading partners	15 km radius	8.2 km radius
Surveillance Trapping to Reinstate the PFA	For *B. tryoni*, a trapping density of 0.283 traps per hectare For *B. dorsalis*, a trapping density of 0.142 traps per hectare	For urban and production areas, a trapping density of 6.5 traps per km^2 or 0.065 traps per hectare	For urban areas, a trapping density of 0.029 traps per hectare For commercial production areas, a trapping density of 0.022 traps per hectare
Pest Free Area Reinstatement (after last fly detection)	Depends on the circumstance of the eradication and largely dictated by trading partners	Zero detections within one *B. tryoni* generation (egg to egg) and 28 days, or 12 weeks (whatever is the longer). No minimum trapping density is specified	Zero detections within three *B. dorsalis* generations (egg to egg) No minimum trapping density is specified

Criteria for indicating eradication success

The aim here is to establish the evidence threshold required to provide sufficient confidence that eradication has been successful and the ERZ can be removed. FAO (2016) stated that the eradication can be considered successful and the area declared free of the target fruit fly when there have been "*no further detections of the target fruit fly species for a period determined by its biology and prevailing environmental conditions, as confirmed by surveillance*".

The aim of this paper, therefore, is to provide a method of determining the criteria for the management of tephritid fruit fly outbreaks as outlined in international standards.

Methods

Model development

To estimate aspects of establishing and removing fruit fly ERZs, my model relies primarily on aspects of fruit fly biology and epidemiology along with a measure of lure + trap efficacy referred to as the *effective sampling area* (ESA). Turchin and Odendaal (1996) refer to the ESA as both a translation coefficient between population density and insect captures in a single trap, and the area by which we need to divide trap catch in order to obtain an estimate of population density. This relationship between trap catch and insect density is particularly useful when considering the effectiveness of surveillance and population delimitation programmes.

The ESA is (approximately) equal to the proportion of trappable individuals that are captured (over a set period of time) divided by the trapping density (Kean 2015a).

Equation 1: Calculating the effective sampling area (ESA)

$$ESA \approx \frac{CaptureProportion}{TrappingDensity} \quad (1)$$

The ESA can be estimated for each fruit fly species using published records of fruit fly release and recapture rates into areas that contain trapping grids of a known density (traps/ha). The ESA will vary between fruit fly species, therefore the requirements for the ERZ will also vary between fruit fly species. Additionally, the ESA may vary with habitat, weather, season, lure age, etc., but the derived values are assumed to cover the range of conditions likely to be encountered in urban and production environments.

A survey from 2002 to 2010 of the use of the '5 male files trapped over two weeks' trigger used by Australia to declare outbreaks of *B. tryoni* identified 439 incursions (detections) of which 48 (10.9%) achieved the 5-fly trigger and were declared as outbreaks. The remaining 391 incursions (89.1%) were not declared as outbreaks, and all subsequently died out without intervention (Dominiak and Fanson 2014). These results indicate that the 5-fly trigger for *B. tryoni* has ensured all potential outbreaks were responded to appropriately. My initial calculations of the trigger number for *B. tryoni* using the conservative value for the ESA (0.5 ha) indicated that the detected fly trigger number would be '1' over a period longer than 2 weeks. I wanted to ensure the outputs of the model aligned more closely with the observed situation in Australia, so I have used the median estimated value for ESA (ESA_{med}) as a closer approximation of the true ESA value.

I used published data to estimate the ESA of standard lure-based traps, as used in fruit fly surveillance programmes, for the two species of interest. When using a cue-lure trapping lure, I calculated that the ESA for *B. tryoni* was between 0.5 and 2.5 ha, with a median of 1.5 ha over a two-week period. When using a methyl eugenol trapping lure, I calculated that the ESA for *B. dorsalis* was between 5 and 12 ha, with a median of 9 ha over a two-week period. Full details of this are given in the Supplementary information. Other authors have calculated the ESA for *B. tryoni* at 0.214 ha per day using one data source converted to a daily catch rate, equating to an ESA of 3 ha over a two-week period (Stringer et al. 2017).

Determining the total emergent population size

Using area dispersion data for fruit fly species generated from single point release and area recapture studies, we can determine the proportion of the total fruit fly population that will be present in the highest densities. In all cases the highest density area is at the centre of the distribution, taken here as the central 1 hectare approximated as a 60-m radius (r) circle (1.13 hectares). By increasing the number of lure responsive flies, we can determine the threshold for detecting a population that exceeds the threshold for an outbreak in that highest density area (centre 60 m circle (1.13 hectares)) using Eq. 2.

Equation 2: Calculating the density of flies within a specified radius from a known fly population distribution

$$Dr = N_t x \frac{C_r}{A_r} \quad (2)$$

where D_r = the density of flies (per hectare) in the centre 60 metre radius (r) of the site of population emergence. N_t = the number of detectable (male) flies assumed to be in the area, which can be taken as the number of invading or emerging male flies in the area. C_r = The proportion of the total fruit fly population present in the centre 60 metre radius (r), based on results from single point release and area recapture studies. A_r = the area (ha) of the centre 60 metre radius (r) (1.13 hectares).

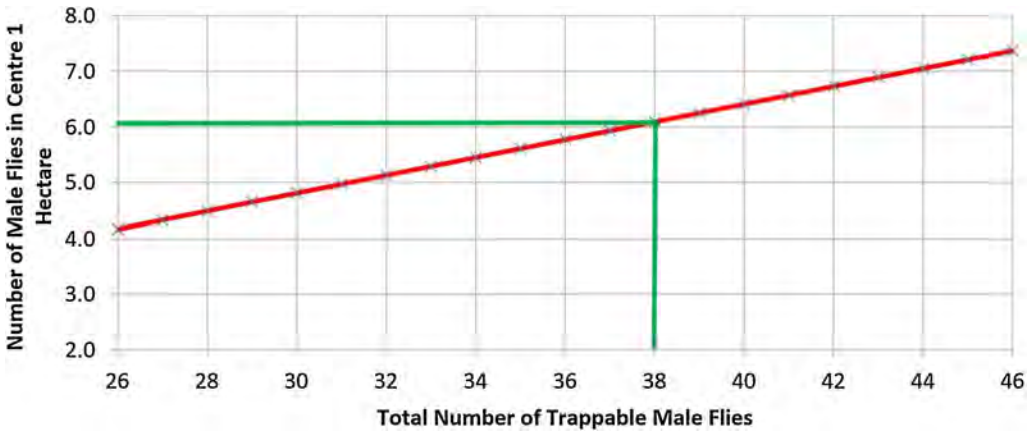


Fig. 2 Determining the population of male flies in a region required to exceed the founder population density in the centre of the outbreak. Red line is the estimated total number of male files present (x axis) with a given number of male flies in the centre 1 hectare. Green lines indicate the founder population density given a founder population size of 6 male flies

The results derived from Eq. 2 applied to example data calculated from another fruit fly (e.g. *Ceratitis capitata*) are provided in Fig. 2. In this example the number of male flies in any 1-hectare area considered sufficient to more-than-likely result in an establishment event (the founder population size) is 6 flies (e.g. the minimum number of files required to establish a population).

From Fig. 2 it is apparent that based on this example a founder population size of 6 flies, a total population of 38 adult male flies or more may result in a density of flies at the centre of the outbreak that exceeds that founder population size. The *breeding population size* for this example would therefore be taken to be 38 adult male files, or 76 male and female adult flies assuming the sex ratio is 1:1.

Analysis of Triggers for Initiating an Export Restriction Zone

If we know the size of the population of flies in an area that would be a risk to export markets (the *breeding population size*), we can calculate the number of flies we would be most likely to detect at a given detection probability (sensitivity of the surveillance trapping system). I assumed that capture is random, therefore the probability of trapping a certain number of flies in an area over a set period, based on a predetermined existing population, can be calculated using the binomial distribution (see Eq. 3). When more than one trap is deployed, I define trap cover as the total area sampled (number of traps × ESA) as a proportion of the total area (ESA × trap density). As trap cover will not equate to probability of capture if trap sampling areas overlap, for a range of trap configurations the expected proportion trapped, which is equivalent to the probability of capturing an individual, is closely approximated by an exponential function (1 − exp (− trap cover)) or $(1 - exp(-ESA_{med} \times T_d))$ (Kean 2015a, b). This exponential function arises from the zero term of the Poisson distribution and appears in a wide range of studies on the detectability of organisms (see Kean 2015a, b).

Equation 3: The conditional probability of trapping exactly f (male) flies given that there are N_t detectable (male) flies in the area.

$$P\left(f|N_t\right)_f = N_t! \div \left(f!\left(N_t - f\right)!\right) \times \left(p^f (1-p)^{N_t - f}\right) \tag{3}$$

where $P\left(f|N_t\right)_f$ = the conditional probability of detecting f flies given the total number of detectable (male) flies in the area is N_t. f = the number of (male) flies detected in any of the traps within the area. N_t = the number of detectable (male) flies assumed to be in the area, considered for the purposes of this paper to be the *breeding population size*. ! is the factorial function in statistics. p = the probability of trapping a male fly, which equals $1 - exp(-ESA_{med} \times T_d)$ where T_d is the surveillance trapping density (number of traps per hectare) and the ESA_{med} is the median value for the effective sampling area for each fruit fly species and $(-ESA_{med} \times T_d)$ the trap cover.

Plotting the calculated values for P_f (the probability) against f (the number of flies detected) provides a distribution as shown by the example in Fig. 3 (where N_t equals 52 and p equals 0.1319) based on data from a fruit fly species with an ESA of 0.5 and 0.283 traps per ha. This curve should be interpreted as showing that, at a given probability of trapping male flies in an area (p); when the population of the flies in an area is N_t the probability (P_f) is highest (at 16%) you will detect either 6 or 7 flies over

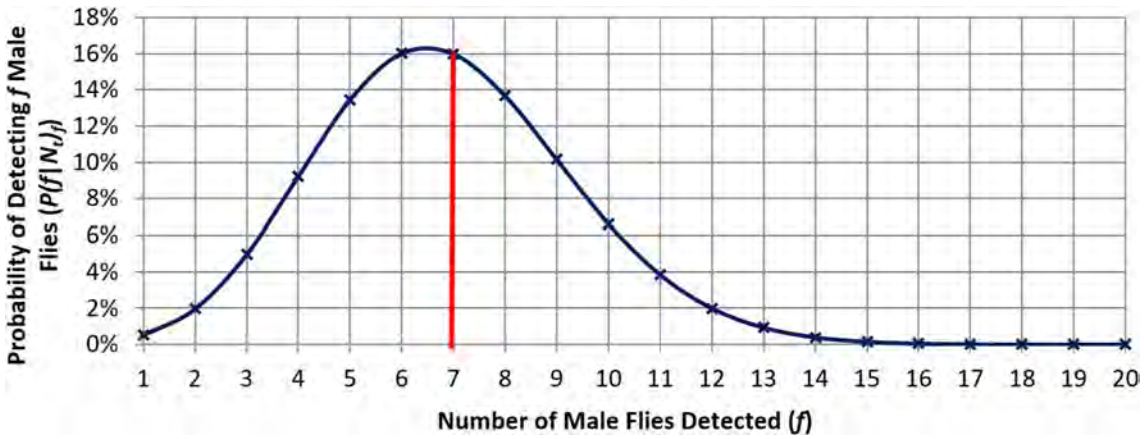


Fig. 3 An example of the probability of a specified trapping grid detecting *f* male flies ($P(f|N_t)_f$) from a breeding population size (N_t) of 52 and a capture probability (p) of 0.1319. The red line indicates the number of flies detected with the greatest probability

Fig. 4 An example of the cumulative probability of a specified trapping grid detecting f male flies (P_f) from a breeding population size (N_t). The red line indicates the number of flies detected with the greatest probability

the duration of trapping i.e. there is a lower probability of detecting only one fly or 10 flies. The curve can also be plotted as a cumulative distribution, with the threshold being the number of flies detected above the 50% level (7 flies in this case).

Based on Fig. 3, we can estimate that, once seven (male) flies have been detected (the probability of catching 7 flies is > 0.5), there is a greater than 50% probability that the total number of files in the area may exceed the breeding population size of 52 (in this example). For instance from the example provided in Fig. 3 the trigger that would lead to establishing an ERZ for export markets would be seven male fruit flies (the red line) over the trapping period. An alternative method of plotting the same information is to use a cumulative probability for the vertical (y) axis (see Fig. 4).

The next questions to consider are:

a) Over what period the trigger is relevant (i.e. what is an appropriate trapping period), and
b) Over what area (radius) should any detections count toward the trigger?

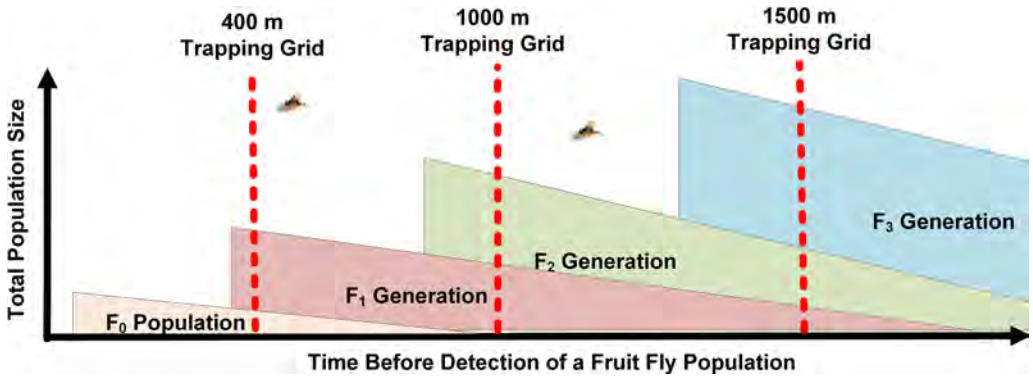


Fig. 5 A conceptual example of how decreasing density of surveillance trapping grids may allow one or more fruit fly generations to occur prior to detection. Wedges indicate population size per generation over time

The ESA of the traps for each fruit fly species is based on the length of time the researchers recorded trap catches when gathering the data to estimate the trap sensitivity. However the majority of adult fruit flies survive or remain available to be trapped for only a relatively short time in optimal conditions (Vargas and Carey 1990; Yonow et al. 2004).

Therefore, I propose that the maximum period of fly capture (trigger) to determine if a breeding population exists in the area (and an ERZ is required) should be equivalent to the lesser of:

- The time it takes for a cohort of adult flies to decrease by 50% due to natural mortality, minus the duration of adult male fly maturation;
- OR
- The length of time the researchers recorded trap catches when gathering the data to estimate the level of trap sensitivity (the ESA) (assuming the researchers released mature flies) (e.g. 2 weeks).

Further, I propose that, to ensure a timely response to a potential establishment event is maintained, the time limit for the trigger should (where possible) be no more than two weeks (14 days) of the initial fruit fly detection. The area over which any detected fruit flies should be included in the trigger count is equivalent to the maximum area the fruit fly outbreak is likely to be contained.

Calculating the size of an export restriction zone (ERZ)

The ERZ is an area established for the purposes of providing assurance that host material grown and exported from outside the zone remain within a pest free area. Therefore, to be effective, the ERZ needs to delimit the probable area in which a breeding population may exist, if there is one present, with the assumption that we do not know the population distribution from the first few detections. From a risk-in-trade perspective, only juvenile (egg, larval) life stages are likely to move internationally, and the ERZ need only delimit the probable area within which a breeding population of flies may exist.

Generally, for small expanding populations the area occupied by a population increases as the number of individuals increase. Studies on the distribution of *B. tryoni* in Australia found that dispersal distances often followed an inverse-square relationship or analogous model (Meats 1998a). The more flies in a small incipient population, the greater the area covered by the population before the inverse-square becomes less than one (no flies present). Therefore, it is assumed that the size of the ERZ should be proportional to the number of flies estimated to be present at the time the zone is established. The greater the time between the fruit fly establishing a population in an area and the population being detected by the surveillance system (and an ERZ being established), the greater the size and spatial extent of the population likely to be present. This relationship between fruit fly population size and surveillance system (trapping grid) sensitivity is supported by Meats et al. (2003), who noted "*Effective quarantine radii for suspension of fly-free status should be related to the number of flies trapped around the epicentre and the density of the trap array*". An illustration of this relationship is provided in Fig. 5.

When no more than one generation (F_1) of fruit flies are likely to have begun emerging in an area (Fig. 6a), the relationship between the maximum dispersal distance (based on a probability distribution before the inverse-square becomes less than one) and the ERZ can be demonstrated by the diagram provided by Fig. 6b. In this example the single fly caught in the surveillance trap could have originated from a population of flies anywhere within the radius of the maximum

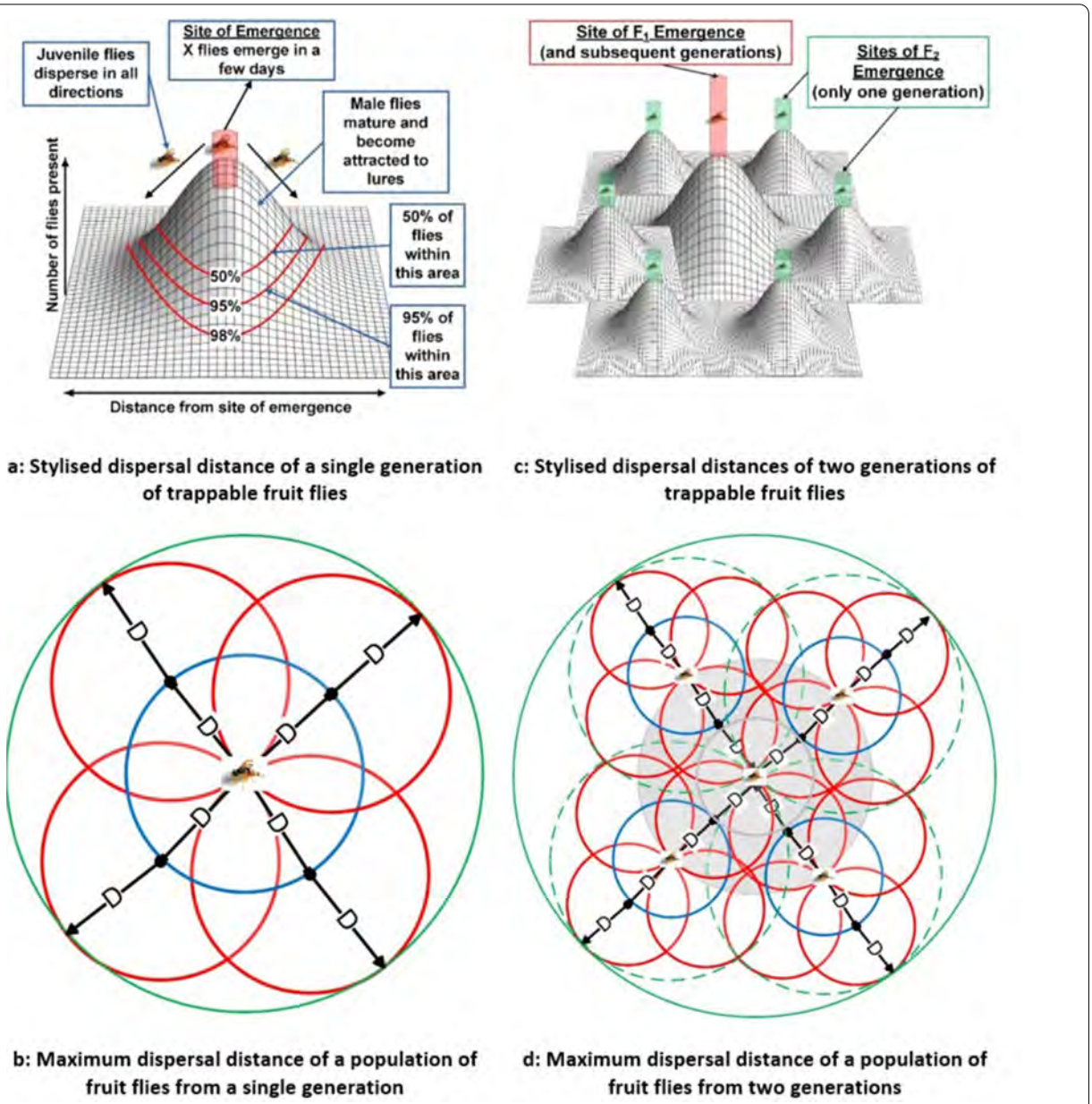


Fig. 6 Examples of a maximum potential fruit fly dispersal distance based on the detection of a single specimen (adult or juvenile). **a**, **c** Provide illustrative contour maps for trappable fly densities from the site of first emergence. **b**, **d** Provide maximum dispersal distances (red circles) from potential sites of emergence (blue circles) based on the location of the first fly detection. The black lines labelled "D" indicate the overall maximum dispersal (green circle)

dispersal distance (the blue circle) from the point the fly was trapped. If (in a worst case scenario) the fly had flown the maximum dispersal distance (e.g. the population epicentre on the outer line of the blue circle), the population of first generation of emergent flies could have dispersed anywhere within the red circle (four red circles are drawn here as examples). The green circle encases all the possible areas the population of flies could exist based on the detection of the single fly. The green circle with a radius of twice the maximum dispersal distance therefore represents a worst-case scenario for possible fruit fly population distribution when only a single generation (F_1) of fruit flies have emerged. Maximum dispersal distance can only be achieved if the fly flies in a straight line with minimum death rate; flies usually have a more random series of flights, so the

maximum dispersal distance is already overly optimistic (Dominiak pers. comm.).

If detection of a population of fruit flies is sufficiently delayed to potentially allow two generations (F_2) of flies to emerge (Fig. 6c), the relationship between the maximum dispersal distance and the ERZ can be demonstrated by the diagram provided by Fig. 6d. The green circle encases all the possible areas the population of flies could exist based on the detection of the single fly. The green circle with a radius of four times the maximum dispersal distance (twice the radius of a single generation) therefore represents a worst-case scenario for possible fruit fly population distribution when two generations (F_2) of fruit flies have emerged.

The question then becomes: How do we know if the surveillance system is likely to detect a population in or before the first (F_1) or second (F_2) generations?

This could be answered using the calculations which determine the potential size of the population present when a detection is made by the surveillance system. If the potential size of the population detected by the surveillance system is greater than the population size needed to enable a breeding pair to successfully establish a new population, then the confidence is lower that a second generation of flies has not arisen. For example: when the breeding population size is 50 flies but the surveillance system is most likely to only detect a population of 85 individuals or more, then there is the potential for a breeding pair from the first generation to have established a second generation (85 > 50).

The sensitivity of the surveillance trapping system to detect a fruit fly population can be calculated using Eq. 4.

Equation 4: Calculating the sensitivity of a fruit fly surveillance system in detecting a fruit fly population.

$$S = 1 - exp(-ESA_{med} \times T_d \times N_t) \quad (4)$$

where S = the sensitivity of the fruit fly trapping grid measured as the probability of detecting one or more male flies given a population of N_t adult males of a particular fruit fly species. ESA_{med} = the median effective sampling area (ha) of each trap in the trapping grid for a fruit fly species. T_d = the trap density of the surveillance grid (traps per hectare). N_t = the total number of detectable (male) flies assumed to be in the area.

When a detection occurs in a surveillance trap, the greatest likely number of adult male fruit flies of a particular species in the area (N_t) can be estimated for each fruit fly species as the number present when the probability of detecting one male fly (S) exceeds 95%. Then, the size of the *ERZ* can be estimated based on this value of $\boldsymbol{N_t}$ and the known distribution pattern of the fruit fly population ($\boldsymbol{P_r}$) (see Eq. 5).

Equation 5**:** Calculating the number of flies outside an area with a specified radius for a fruit fly population of known size and pattern of distribution.

$$N_r = N_t - (N_t \times P_r) \quad (5)$$

where N_r =the number of male flies likely to be outside of the area with a radius of r. N_t =the total number of detectable (male) flies assumed to be in the area. P_r =the cumulative percentage of flies found within the area that has a radius of r. This parameter is based on the adult fly distribution curves calculated for each fly species.

The value of N_r can be estimated for areas with an increasing radius. Therefore, the radius of the ERZ is two or more times the radius required to ensure the number of male flies outside of the area (N_r) is less than one i.e. zero male flies (see Fig. 6).

Determining when to Remove an Export Restriction Zone

The current practice for determining when to end an eradication programme (and remove an *ERZ*) specifies a time interval during which no further fruit fly detections are recorded, and should be based on the biology of the fruit fly and prevailing environmental conditions (FAO 2016). Meats and Clift (2005) noted that these time intervals have used a physiological time scale (day-degrees) which was equivalent to one generation plus 28 days (e.g. Australia) or up to three generations (e.g. USA) or more and can only usually be determined at the time of the response (see Kean (2015b) for a meta-analysis of fruit fly development times). Meats and Clift (2005) proposed an alternative method which used a pre-determined time interval, based on measured trap sensitivity and trapping density, and does not require the calculation of generation length under different temperature scenarios. The authors further suggest that time periods during which temperatures fall below adult maturation (life-cycle development) and/or effective movement thresholds (and therefore adult attraction to trap lures) should not be included when calculating the length of zero trapping.

I propose that one criterion for the time interval to remove the ERZ be based on trapping sensitivity, and is achieved when the probability that the area is free of a population of the target fruit fly species is equal to or greater than a 95% level of confidence. Additionally, I propose that a minimum time equivalent to one generation (egg to mature (trap sensitive) adult fly) and 4 weeks (a single trapping period) under existing climatic conditions and under a continuous (uninterrupted) trapping period should be required to ensure that if any immature fruit flies are present they will be detected. A similar approach for declaring areas free of insects has been proposed previously by Barclay and Hargrove (2005) where trapping periods are interrupted by a suitably long

winter, and the fruit fly species in question over-winters in the adult life stage. Therefore, the minimum requirement of a single generation may not be necessary as no juvenile life stages will be present when climatic conditions become suitable for trapping once more.

This level of confidence in fruit fly freedom can be achieved via two main routes:

a. For non-persistent populations, the onset of cold weather seasons will remove the population and ensure the next production season is free of that fruit fly species;
b. A sufficient period of zero fruit fly detections (of any life stage) providing at least a 95% level of confidence that the area within the *ERZ* is free of the fruit fly in question.

For the first situation (a), the information required to determine if a fruit fly is only able to form a seasonal population in an area is determined by the climate of that region (winter temperatures and duration).

For the second situation (b), the probability that an area does not have an established population for each period of zero trapped flies can be calculated using Eq. 6.

Equation 6: Calculating the sensitivity of a fruit fly surveillance system in detecting one or more flies in a population over multiple periods.

$$P_n = 1 - exp(-N \times ESA_{med} \times T_d)^a \quad (6)$$

where P_n =The probability of detecting n trappable insects that arise within the trapping area over a trapping periods. ESA_{med} = The median effective sampling area (ha) of each trap in the trapping grid for a fruit fly species. N = The threshold number of trappable insects arising independently within the surveillance area, which in this instance would be the minimum number required to establish a population. T_d = The trapping density of the trapping area for each fruit fly species (traps per hectare) during the eradication phase of the response. a = The number of trapping periods.

In these calculations each trapping period is equivalent to the length of time taken to lure the adult males used in the experiments to determine the level of trap sensitivity, and only applies to periods when the environmental conditions (e.g. temperature) are sufficient to support adult fly attraction to lures (e.g. sufficient maturation and/or effective flight). For the purposes of this analysis, I assumed that the minimum possible number of adult male fruit flies required to establish a population in a new area is 2 (or more). This is a very conservative number and is different from the breeding population size which provides a more realistic estimate of the number of flies required to establish a population.

Fruit fly data for models

For the purposes of demonstrating the use of these models, I collated relevant data on two of economically important tephritid fruit fly species: Queensland fruit fly (*B. tryoni*) and Oriental fruit fly (*B. dorsalis*).

In all tephritid fruit fly species, the adult is the only stage capable of dispersal independently of its host (or vector in the case of pupae). Eggs are laid below the skin of the host fruit. Generally, these hatch within 1–3 days, and the larvae feed for 10–31 days (Garcia 2009). Ripe fruit falls to the ground, or larvae leave the hanging fruit and drop to the ground and pupation is in the soil under the host plant (Bateman 1972). The lure-based traps used in the fruit fly surveillance systems almost exclusively attract only mature (sexually active) male flies (Royer 2015).

Data for Queensland fruit fly

Queensland fruit fly (*B. tryoni*) is very destructive to a wide range of fruit hosts and is the most costly and serious insect pest of horticulture in Australia (Dominiak et al. 2015; Dominiak and Mapson 2017).

Adult fly dispersal behaviour is influenced by many factors, including availability of food (primarily sugars and protein), temperature, humidity, wind, odours, life span, escaping predators, and fruit suitable for oviposition (Yonow et al. 2004; Clarke et al. 2011). Additionally, dispersal is influenced by sexual status, though not necessarily sex (Weldon 2005). Sexually immature (post-teneral) adult *B. tryoni* males tend to disperse away from the site of pupal emergence, regardless of the suitability of the immediate habitat for survival and reproduction (Weldon 2005). Movement by sexually mature adult *B. tryoni* is typically non-dispersive, involving local movements to search for food, mates and oviposition sites. However dispersive movement has been reported in sexually mature adult *B. tryoni* in response to adversity, including lack of adequate oviposition sites (Weldon 2005).

Most studies have concluded that the lifetime dispersal distance of *B. tryoni* rarely exceeds 600 m (Dominiak 2012; Dominiak and Fanson 2020), although two studies indicate that longer dispersal distances of a small number of individuals may occasionally occur: Fletcher (1974) claimed that *B. tryoni* could disperse up to 22.7 km, and MacFarlane et al. (1987) reported a single *B. tryoni* was found 94 km from the release point. Weldon (2005), in release/recapture experiments in New South Wales, Australia, found that recaptures of most male and female *B. tryoni* were made within 500 m of the release point, although a small proportion of males were found over 1000 m from the release point two weeks after release. Weldon

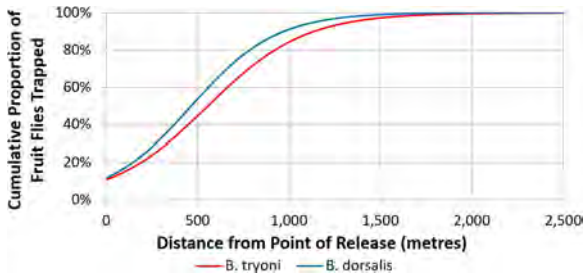


Fig. 7 The cumulative dispersal distance of *B. tryoni* and *B. dorsalis* adults from a single point of release or emergence

(2005) also found that laboratory-rearing and sterilisation did not significantly affect dispersal ability of post-teneral male *B. tryoni* relative to wild flies. Meats and Edgerton (2008) indicated that these long-distance dispersals became over dispersed and did not participate in matings. I therefore consider that these over-dispersed flies do not contribute to ERZ calculations, recognising that equivalent studies on gravid female fly dispersal distances are not available. These short dispersal distances are consistent with findings for other fruit fly species (Dominiak 2012; Dominiak and Fanson 2020). Long-distance dispersal has been linked to isolated favourable habitats separated by resource poor country that forced dispersing flies to make longer flights. In favourable habitats, such as large urban areas or well-managed orchards, dispersal distances are likely to be relatively short (Raghu et al. 2000; Dominiak 2012; Dominiak and Fanson 2020).

Dominiak et al. (2013) reviewed historical release and capture data from a programme of work in New South Wales Australia in 1998/99. Of the 19,758 sterile flies released over the summer months, 95% of those trapped were within 1360 m of their point of release, 98% within 1574 m, and 100% within 5553 m. The authors estimated that 99.9% of the released flies that were caught were within 2159 m of the point of release. From distribution data provided by the review of Dominiak et al. (2013), an adult fly distribution model was developed for *B. tryoni* using a generalised linear model with a binomial error distribution which accounts for over-dispersion. The predicted distribution curve developed from this model is shown in Fig. 7.

Based on Fig. 7, I estimate that after two to three weeks of emergence (once the male flies mature and become attracted to the trapping lures), 95% of the emergent flies can be found within a radius of 1340 m of the point of release and 99% of the flies can be found within a radius of 1770 m.

Data for Oriental Fruit Fly

Oriental Fruit Fly (*B. dorsalis*) forms part of a species complex, within which over 50 species have been described in Asia (EPPO 2009). Schutze et al. (2015) recently synonymised *Bactrocera papayae* Drew & Hancock and *Bactrocera invadens* Drew, Tsuruta & White with *B. dorsalis* sensu stricto. Prior to this Drew and Romig (2013) synonymised *Bactrocera philippinensis* Drew & Hancock with *B. papaya*. The data included in this paper pre-dated the synonymizing and as such is *B. dorsalis* sensu stricto only (as at 2014).

The *B. dorsalis* adult is a strong flyer, recorded to travel up to 50 km in search of food and sites to lay eggs. In studies on foraging behaviour, adult flies of *B. dorsalis* was recorded moving up to 600 m between areas of food and non-food plants in field experiments in Taiwan (Chiu 1983), where observations found that bamboo stands were the most preferred sites for resting. The transport of infested fruits is the main means of global movement and dispersal to previously uninfested areas (EPPO 2009).

Froerer et al. (2010) studied the long-distance dispersal of *B. dorsalis* in Hawaii:

- Unassisted long-distance flights of between 2 and 11.39 km were reliably recorded, but these were very rare events. A total of 217,560 adult flies were released in 4 releases, of which only 30 (0.000137%) were recovered at distances over 2 km.
- Only one of the four releases looked at median distance dispersal: 90,078 flies were released and a total of 1,887 flies were recovered from the fourth release at distances ranging from 0.02 to 1.90 km.
- While short-distance movement occurred for over 2 weeks, long-distance movement seems to have occurred within a short period of time after a release.

Using a generalised linear model with a binomial error distribution which accounts for over-dispersion, the predicted distribution curves for *B. dorsalis* are shown in Fig. 7.

Country data for models

New Zealand and B. tryoni/B. dorsalis

The base-line level of assurance supporting New Zealand's fruit fly free status is provided by the New Zealand's fruit fly surveillance programme. Approximately 7,500 lure traps (Lynfield design) are set up and maintained from September to June of each year (Quilici and Donner 2012; Acosta and White 2011). Traps are placed in arrays, concentrating in populated areas serving as centres for tourism and/or trade, areas of significant horticultural activity, and areas climatically conducive to the

establishment of fruit flies (MPI 2014). The density of traps in the arrays reflects to a degree the effective trapping distances of each trapping lure. A summary of the details on New Zealand's surveillance and response system (MPI 2014) are provided in Table 2.

Australia and B. tryoni

The surveillance system for *B. tryoni* was established by each of the states of Australia under the Fruit Fly Code of Practice (COP 2014). In areas where freedom from *B. tryoni* is being maintained, male cure-lure baited Steiner or Lynfield traps are placed in 1000 m grids within commercial host growing areas (e.g. orchards) and in 400-m grids in urban areas (COP 2014).

Additionally, the federal standard for response to *B. tryoni* in Australia are contained in COP (2014). As *B. tryoni* is now considered endemic to coastal areas of Queensland, New South Wales and Victoria, Australia, COP (2014) for this fruit fly applies to areas outside of this distribution range. For a *B. tryoni* response COP (2014) requires the use of cue-lure based surveillance. A summary of the details on Australia's surveillance and response system (COP 2014) are provided in Table 2.

USA (California) and B. dorsalis

Little detail could be found on the Californian surveillance system for *B. dorsalis*, for the purposes of this paper, I assumed that it meets the minimum requirements for maintaining a PFA as detailed in RSPM 17 (2010). This standard requires for methyl eugenol-responsive species (e.g. *B. dorsalis*) that the trap density in high risk areas (entry points etc.) is three traps per km^2, urban areas is one trap per km^2 (1000 m trapping grid), and in commercial production areas is two traps per 2 km^2 (2000 m trapping grid). The State of California's response to *B. dorsalis* occurs under the guidelines provided in the USDA APHIS Action Plan for Oriental Fruit Fly (USDA APHIS 1989).

For the purposes of this paper, I assume that after the date of the last fruit fly detection surveillance for fruit flies will return to the trapping system described above for the delimitation area (the 1000 m trapping grid with a further 400 traps out to a 8.2 km radius in urban areas and the 2000 m trapping grid with a further 400 traps out to a 8.2 km radius in commercial production areas). A summary of the details on California's surveillance and response system (USDA APHIS 1989) are provided in Table 2.

Simplification of surveillance and response scenarios used in this analysis

Each surveillance system provides a level of sensitivity in its ability to detect a fruit fly population based on the nature of the lures and traps used and the density of the trapping grid. The minimum number of traps deployed in each surveillance area has been simplified for each fruit fly species within each country to determine the trigger numbers, size of an ERZ, and the criteria for removing an ERZ. Detection sensitivities across surveillance areas can only be modelled when the distribution of the targeted fruit fly is known with some accuracy. In most eradication scenarios the distribution of the fruit fly only becomes apparent part way through the eradication campaign. To avoid situations where trapping densities vary across a surveillance or eradication areas, each of the surveillance and response scenarios considered in this analysis was simplified (using conservative (worst-case) trapping densities by understating the number of traps in each area) as detailed in Table 2.

Results

Calculations for response criteria for Queensland Fruit Fly (*B. tryoni*)

Population size required for establishment

Meats (1998b) calculated that for *B. tryoni* the *founder population size* to successfully establish was 12 flies per hectare containing host material. As the sex ratio in *B. tryoni* is 1:1 (Clarke and Dominiak 2012; Fanson et al. 2014), a population of 12 adult flies is most likely to contain 6 male flies. As the highest population concentration of *B. tryoni* male flies in any single outbreak scenario is at its centre, from the distribution data shown in Fig. 7 we can determine the total trappable population size required to achieve or exceed 12 adult flies (6 male flies) in the centre 1 hectare of the population.

From the distribution model shown in Fig. 7, we can determine that the proportion of the total fruit fly population present in the centre 60 m radius (r), which for B. tryoni is 13.2%. By increasing the number of flies emerging we can determine the threshold for achieving more than 6 male flies in that centre 60 m circle using Eq. 2.

The results derived from this Eq. 2 applied to the data for B. tryoni are provided in Fig. 8.

From Fig. 8, I found that a population of 52 adult male flies (104 adult flies) or more may result in a density of flies at the centre of the outbreak that exceeds the founder population size (6 male flies) as determined by Meats (1998b). Therefore, I assume the *breeding population size* for *B. tryoni* was 52 male files or 104 male or female adult flies (given the sex ratio in *B. tryoni* is 1:1 (Meats 1998b)).

Trigger for imposing an export restriction zone for *B. tryoni*

From the response parameters and the biological description of *B. tryoni*, the variables required to determine the probability of detecting male flies using a trapping grid

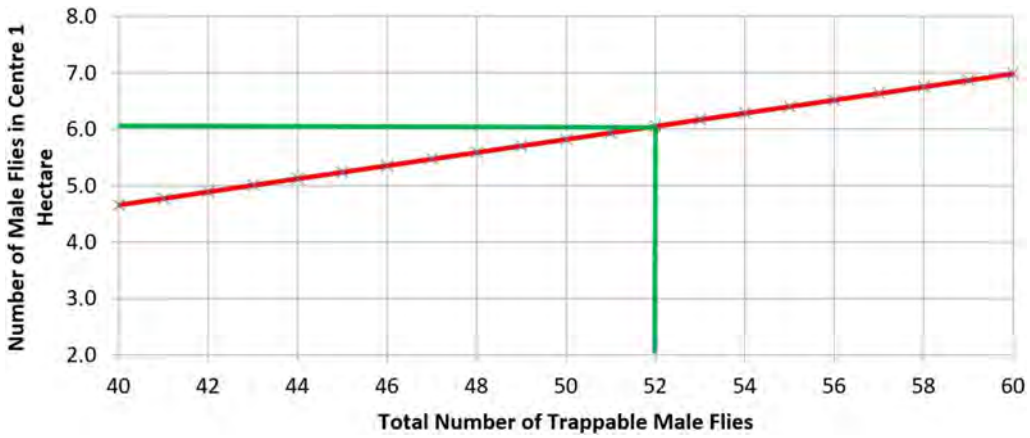


Fig. 8 Determining the population of adult *B. tryoni* males in a region required to exceed the founder population density in the centre 1 hectare of the outbreak. Red line is the estimated total number of male files present (x axis) with a given number of male flies in the centre 1 hectare. Green lines indicate the founder population density given a founder population size of 6 male flies

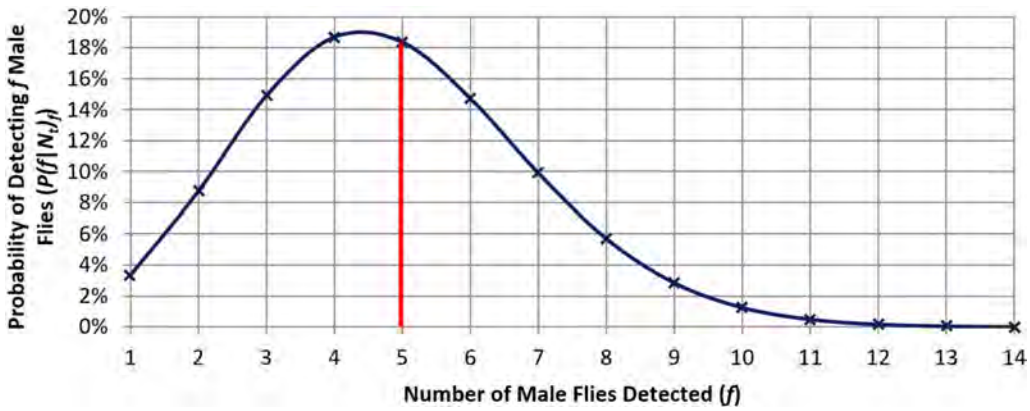


Fig. 9 The probability of detecting *f* male flies from a total population of 52 adult *B. tryoni* males using a 400 m trapping grid over the life of the traps

during *intelligence gathering activities* (surveillance) for Australia and New Zealand and are as follows:

- The number of detectable (male) flies in the area estimated to be required to establish a breeding population (N_t) of *B. tryoni* is 52 (the *breeding population size*).
- For New Zealand and urban areas in Australia, the minimum trap density (T_d) in the delimitation zone for *B. tryoni* is 0.065 traps per hectare.
- For production areas in Australia, the minimum trap density (T_d) in the delimitation zone for *B. tryoni* is 0.0104 traps per hectare.
- A median estimate of the effective sampling area (ESA_{med}) of each trap in a trapping grid for *B. tryoni* using the cue-lure bait is 1.5 ha.
- For New Zealand and urban areas in Australia, the probability (p) of trapping a single male *B. tryoni* in the delimitation area can be calculated from the ESA_{med} and trap density (T_d) as $1 - exp(-ESA_{med} \times T_d)$, which equates to 0.0929.
- For production areas in Australia, the probability (p) of trapping a single male *B. tryoni* in the delimitation zone can be calculated from the ESA_{med} and trap density (T_d) above as $1 - exp(-ESA_{med} \times T_d)$, which equates to 0.02.

Using Eq. 3, the probability ($P(f|N_t)_f$) of detecting f flies in New Zealand and urban areas in Australia can be determined for a range of values of f and the trigger number determined by observing when the results achieve the highest level of detection (see Fig. 9).

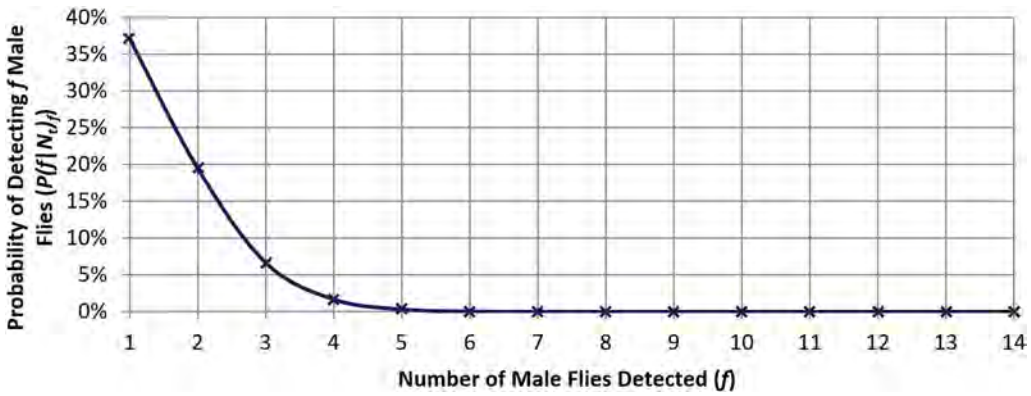


Fig. 10 The probability of detecting *f* male flies from a total population of 52 adult *B. tryoni* males using a 1000-m trapping grid over the life of the traps

Measurements that were taken to determine the level of trap sensitivity were based on laboratory-reared sterile (non-fertile) flies that were captured over a 4-week period after release (Dominiak et al. 2013). This is less than the estimated 7 weeks required for a population to be reduced to 50% of its original level, although *B. tryoni* male adults require around two weeks to mature (to become attracted to trap lures) (Meats 1998b), leaving around 4 to 5 weeks of trapping mature lure-attracted male flies.

From Fig. 9, I found that the detection of 5 male *B. tryoni* in a 4-week period would suggest that it is more likely than not that the maximum acceptable population size is exceeded. This provides a fly trigger level of 5 adult flies within 4 weeks (28 days) for New Zealand and urban areas in Australia. For the two-week trigger period, around half the flies are required for half the length of time,[1] which equates to 3 adult *B. tryoni* males within 2 weeks (14 days) providing an equivalent trigger for establishing an ERZ.

For production areas in Australia, where the trapping density is only 0.0136 traps per hectare and the probability of trapping a single male *B. tryoni* is 0.02; the detection probability is so low (see Fig. 10) that detecting any male flies would indicate the maximum acceptable population size has been exceeded.

Calculating the size of an export restriction zone for *B. tryoni*

From the response parameters and the biological description of *B. tryoni* provided, the variables required to determine the sensitivity of the surveillance trapping system used in New Zealand and Australia to detect *B. tryoni* populations are as follows:

- A median estimate of the effective sampling area (ESA_{med}) of each trap in a trapping grid for *B. tryoni* using the cue-lure bait is 1.5 ha.
- In New Zealand and in urban areas of Australia they use a 400 m surveillance grid to detect *B. tryoni*, which provides a trap density ($\boldsymbol{T_d}$) of 0.065 traps per hectare.
- In production areas in Australia they use a 1000 m surveillance grid to detect *B. tryoni*, which provides a trap density ($\boldsymbol{T_d}$) of 0.0104 traps per hectare.

The calculations from applying Eq. 4 predict that the 400-m surveillance grids used in New Zealand and urban areas of Australia have at least a 95% probability of detecting one fly in a population of 31 or more male *B. tryoni* flies in an area. The same calculations predict that the 1000-m surveillance grid used in production areas of Australia has at least a 95% probability of detecting one fly in a population of 192 or more male *B. tryoni* flies in an area.

The population size likely to be detected by the 400-m surveillance grids in New Zealand and urban areas of Australia (31) is less than the *breeding population size* for *B. tryoni* of 52, indicating only one generation of flies is likely to be present. However, the population size likely to be detected by the 1000-m surveillance grids in urban areas of Australia (192) is considerably more than the *breeding population size* for *B. tryoni* of 52, indicating more than one generation of flies may be present.

Therefore, to determine the size of the *ERZ* for *B. tryoni* detected using a 400-m surveillance grid it is proposed that, before an *ERZ* is established:

[1] Calculations not shown.

a) The population size likely to be in the area would be the breeding population size: namely 52 adult male flies; and
b) The trigger number of 3 flies would need to be captured over 14 days; and
c) Only one generation (F_1) of flies may have emerged in the area.

Using Eq. 5, values for the number of male flies outside a trapping area ($\boldsymbol{N_r}$) can be calculated over a range of increasing distances from the population epicentre ($\boldsymbol{P_r}$). The results suggest that under a 400-m trapping grid there are unlikely to be any male flies (or gravid female files or both) more than 1600 m from the epicentre. The radius of the ERZ for only one generation (F_1) of *B. tryoni* would then equal twice this radius (see Fig. 6b) or 3200 m.

To determine the size of the *ERZ* for *B. tryoni* detected using a 1000-m surveillance grid it is proposed that, before an *ERZ* is established:

a) The population size likely to be in the area would be 192 adult male flies; and
b) The trigger number of 1 fly would need to be captured over 14 days; and
c) Two generations (F_2) of flies may have emerged in the area (e.g. 192 > 52).

Using Eq. 5 above, values for the number of male flies outside a trapping area (N_r) can be calculated over a range of increasing distances from the population epicentre (P_r). The results suggest there are unlikely to be any male flies more than 1950 m from the epicentre. The radius of the *ERZ* for two generations (F_2) of *B. tryoni* would then equal four times this radius (see Fig. 6d) or 7,800 m.

Criteria for removing an export restriction zone for *B. tryoni*

From the response parameters and the biological description of *B. tryoni* provided above, the variables required to determine the length of trapping period required to provide a 95% level of confidence that the ERZ can be removed from New Zealand and Australia are as follows:

- New Zealand applies a surveillance trap density (Td) of 0.283 traps per hectare to detect *B. tryoni* after the last fruit fly has been detected.
- Australia uses a 400-m surveillance grid to detect B. tryoni after the last fruit fly has been detected, which provides a trap density (Td) of 0.065 traps per hectare.
- A median estimate of the effective sampling area ($\boldsymbol{ESA_{med}}$) of each trap in a trapping grid for *B. tryoni* using the cue-lure bait is 1.5 ha.

By plotting the cumulative probabilities of detecting two male flies in a trap density ($\boldsymbol{T_d}$) of 0.283 traps per hectare (New Zealand scenario) over more than one trapping period (4 weeks) using Eq. 6, I found that 3.5 trapping periods or just under 14 weeks of no fly detections would provide > 95% probability that a breeding fly population (> 2 male flies) no longer exists in the area.

Doing the same under the Australian scenario of detecting two male flies in a trap density ($\boldsymbol{T_d}$) of 0.065 traps per hectare over more than one trapping period (4 weeks), I found that 15.4 trapping periods or just under 61.6 weeks of zero fly detections would provide > 95% probability that a breeding fly population (> 2 male flies) no longer exists in the area covered by 0.065 traps per hectare.

Calculations for response criteria for *B. dorsalis*

Population size required to enable establishment

Meats (1998a, b) calculated that for *B. tryoni* the '*founder population size*' was 12 flies per hectare. To do this, Meats (1998a, b) had to determine several biological characteristics for *B. tryoni* that would also need to be found for *B. dorsalis* to complete the same assessment. I could find no equivalent analysis for *B. dorsalis* in the literature. Baker et al. (1990) noted that three sexually mature adult flies were required to have any likelihood of a population establishing in an area. As the sex ratio in *B. dorsalis* is 1:1 (Binay and Agarwal 2005), a population of > 3 adult flies was most likely to contain > 1 male fly. For the purposes of this analysis, I will conservatively assume that the number of emerging adult flies required to establish a population in a new area contains 2 (or more) male flies.

As the highest population concentration of *B. dorsalis* male flies in any single outbreak scenario is at its centre, and using the distribution data shown in Fig. 7, we can determine the total emergent population size required to achieve or exceed > 3 adult flies (2 male flies) in the centre 1 hectare of the population. A circle with a radius of 60 m is just over 1 hectare (1.13 ha) in area. From the distribution model shown in Fig. 7, we can determine that the proportion of the total fruit fly population present in the centre 60 m radius (r), which for *B. dorsalis* is 11.7%. We can determine the threshold for achieving more than 2 male flies in that centre 60 m circle using Eq. 2 by increasing the number of invading or emerging flies.

We can calculate values for the threshold number of detectable flies in the area over a range of increasing populations of invading or emerging flies (N_t) when the density of flies in the centre 60 m radius circle (D_r) exceeds 2

male files. I found that a population of 16 adult male flies (32 adult flies) or more may result in a density of flies at the centre of the outbreak that exceeds the founder population size (2 male flies or 3 flies in total). I will therefore assume the *establishment population size* for *B. dorsalis* is 16 male files or 32 adult flies (given the sex ratio in *B. dorsalis* is 1:1 (Binay and Agarwal 2005)).

Trigger for *B. dorsalis Export Restriction Zone*

Using the response parameters and the biological description of *B. dorsalis*, I found that the variables required to determine the probability of detecting male flies using a trapping grid during surveillance for California, USA, and New Zealand were as follows:

- The number of detectable (male) flies in the area estimated to be required to establish a breeding population (N_t) of *B. dorsalis* is 16 (the *breeding population size*).
- For New Zealand, the minimum trap density (T_d) in the delimitation zone for *B. dorsalis* is 0.0077 traps per hectare.
- For urban areas in California, the minimum trap density (T_d) in the delimitation zone for *B. dorsalis* is 0.0104 traps per hectare.
- For production areas in California, the minimum trap density (T_d) in the delimitation zone for *B. dorsalis* is 0.0026 traps per hectare.
- A median estimate of the effective sampling area (ESA_{med}) of each trap in a trapping grid for *B. dorsalis* using the methyl eugenol bait is 9 ha.
- For New Zealand, the probability (p) trapping a single male *B. dorsalis* in the New Zealand surveillance grid can be calculated from the ESA_{med} and trap density (T_d) above as $1 - exp(-ESA_{med} \times T_d)$, which equates to 0.0667.
- For urban areas in California, the probability (p) of trapping a single male *B. dorsalis* in the delimitation zone can be calculated from the ESA_{med} and trap density (T_d) above as $1 - exp(-ESA_{med} \times T_d)$, which equates to 0.0894.
- For production areas in California, the probability (p) of trapping a single male *B. dorsalis* in the delimitation zone can be calculated from the ESA_{med} and trap density (T_d) above as $1 - exp(-ESA_{med} \times T_d)$, which equates to 0.023.

Using Eq. 3, the probability ($P(f|N_t)_f$) of detecting $\boldsymbol{f}$ flies in New Zealand and California can be determined for a range of values of $\boldsymbol{f}$ and the trigger number determined by observing when the results achieve the highest level of detection. The results were calculated for urban areas in California as this is the most sensitive surveillance system of the three examples.

Vargas and Carey (1990) and Vargas et al. (2000) observed laboratory-reared flies in environmental chambers and found that *B. dorsalis* adults survived for around 50 to 200 days depending on temperatures. *Bactrocera dorsalis* male adults require around two to four weeks to mature (to become attracted to trap lures) (Vargas *pers. com.*) leaving 7 to 9 weeks of effective trapping before adult population numbers declined beyond 50%. Measurements that were taken to determine the level of trap sensitivity (ESA) were based on flies that were captured up to 4 weeks after release (Froerer et al. 2010) which is less than the estimated time taken for the population to decline to 50%.

From the results I concluded that the detection of 1 male *B. dorsalis* in a 1000-m surveillance grid would suggest that it is more likely than not that the maximum acceptable population size is exceeded. As the New Zealand surveillance grid (1200 m) and the surveillance grid in production areas in California (2000 m) are less sensitive than the urban surveillance grid (1000 m), I consider that they would have a single-fly trigger.

Calculating the size of an export restriction zone for *B. dorsalis*

From the response parameters and biological description of *B. dorsalis* provided earlier, the variables required to determine the sensitivity of the surveillance trapping system used in New Zealand and California, USA, to detect *B. dorsalis* populations are as follows:

- New Zealand uses a 1,200-m surveillance grid to detect *B. dorsalis* which provides a trap density (Td) of 0.0072 traps per hectare.
- For urban areas in California, the minimum trap density (Td) in the delimitation zone for *B. dorsalis* is 0.0104 traps per hectare.
- For production areas in California, the minimum trap density (Td) in the delimitation zone for *B. dorsalis* is 0.0026 traps per hectare.
- A median estimate of the effective sampling area ($\boldsymbol{ESA_{med}}$) of each trap in a trapping grid for *B. dorsalis* using the methyl eugenol bait is 9 ha.

From the results obtained from applying Eq. 4 to calculate trapping sensitivity (S) for New Zealand (1200-m surveillance grid) over a range of adult male population sizes (N_t) I estimate that the current surveillance grid used in New Zealand to detect *B. dorsalis* populations has at least a 95% probability of detecting one fly in a population of 47 or more male flies in an area. Repeating the same calculations for urban (1000 m grid) and

Table 3 Summary of results from calculations for New Zealand, Australia and California control scenarios for *B. tryoni* and *B. dorsalis*

Fruit fly control scenarios		Trigger number for establishing an ERZ	Calculated Radius of the ERZ	Time to remove the ERZ (reinstate the PFA)
B. tryoni	New Zealand	3 flies in two weeks	3200 m	14 weeks
	Australia—urban areas	3 flies in two weeks	3200 m	61.6 weeks
	Australia—production areas	1 fly	7800 m	61.6 weeks
B. dorsalis	New Zealand	1 fly	5480 m	6 weeks
	California—urban areas	1 fly	5080 m	228 weeks
	California—production areas	1 fly	6400 m	312 weeks

production (2000 m grid) areas in California, I found the predicted population sizes at the trigger point were 32 and 128 male flies respectively.

Using Eq. 5, values for the number of male flies outside a trapping area (N_r) can be calculated over a range of increasing distances from the population epicentre (P_r). I found that there are unlikely to be any male flies more than 1370 m from the epicentre. The radius of the *ERZ* for two generations of *B. dorsalis* would then equal four times this radius or 5480 m. I repeated the same calculations for populations in urban and production areas in California containing 32 and 128 male flies and found potential distributions of 1270 m and 1600 m respectively. Therefore, the radius of the *ERZ* for two generations of *B. dorsalis* would equal four times these radii or 5080 m for 1000-m grids and 6400 m for 2000-m grids.

Criteria for removing an export restriction zone for *B. dorsalis*

From the response parameters and the biological description of *B. dorsalis* provided above, I determined the length of trapping periods required to provide a 95% level of confidence that the area is free of a breeding population of *B. dorsalis* in New Zealand and California, USA. Once the area is declared free of *B. dorsalis*, the ERZ can be removed from. The variables required are as follows:

- New Zealand uses a surveillance grid to reinstate a PFA for *B. dorsalis* which provides a trap density (Td) of 0.142 traps per hectare.
- For urban areas in California, the minimum trap density (Td) of the surveillance grid to reinstate a PFA for *B. dorsalis* is 0.029 traps per hectare.
- For production areas in California, the minimum trap density (Td) of the surveillance grid to reinstate a PFA for *B. dorsalis* is 0.022 traps per hectare.
- A median estimate of the effective sampling area ($\boldsymbol{ESA_{med}}$) of each trap in a trapping grid for *B. dorsalis* using the methyl eugenol bait is 9 ha.

I applied Eq. 6 to these variables for the New Zealand data and plotted the probabilities of detecting two male flies in ERZ over more than one trapping period. I found that 1.4 trapping periods or 6 weeks of no-fly detections would provide at > 95% probability that a breeding fly population (> 2 male flies) no longer exists in the area.

I repeated the calculations for urban and commercial production areas of California, USA, and found trapping periods of 57 (228 weeks) and 78 (312 weeks) respectively.

Summary of results from calculations

The results for the calculations for the response criteria for *B. tryoni* and *B. dorsalis* are summarised in Table 3.

Discussion

Suckling et al. (2016) reviewed 211 response programmes against 17 species of fruit flies in 31 countries to investigate factors affecting successful eradication outcomes. The authors noted that "*Eradication success generally required the combination of several tactics applied on an area-wide basis. Because the likelihood of eradication declines with an increase in the area infested, it pays to invest in effective surveillance networks that allow early detection and delimitation while invading populations are small, thereby greatly favouring eradication success*".

In this paper, I have attempted to construct decision criteria that countries can employ to design surveillance networks that enable them to more effectively manage potential and actual fruit fly outbreaks. The first criterium centres on the decision as to whether a fruit fly outbreak has occurred and an area of control or ERZ needs to be instated, what is referred to as the "trigger". The model I designed to estimate an appropriate outbreak "trigger" relies on several pieces of information, two of which come with a degree of uncertainty. The first of these is a measure of lure trap efficacy referred to as the effective sampling area (ESA). It is both a translation coefficient between population density and insect captures in a single trap, and the area by which we need to

divide trap catch in order to obtain an estimate of population density (Turchin and Odendaal 1996). Estimates for a trap and lure ESA for each fruit fly were based on records of fruit fly release and recapture rates into areas that contain trapping grids of a known density (see Additional file 1). The effectiveness of any trapping system will likely be affected by local environmental factors along with differences in trial design, and therefore the calculated estimates for each trap and lure ESA for each fruit fly ranged considerably. I applied the median ESA value to all calculations. However, undertaking more focused and controlled fruit fly release and recapture experiments would be expected to provide more accurate estimates of ESA values under different trapping configurations and environmental conditions.

The second important factor are the estimates of the *breeding population size* of each fruit fly species. An extensive literature review by the authors was only able to identify one published estimate for establishment density, namely that for *B. tryoni* provided by Meats (1998b). For all other fruit flies, I had to rely on a very conservative number for the adult fly density provided by Baker et al. (1990) of 3 flies per hectare. As with ESA, undertaking carefully designed experiments to better estimates of establishment density for different fruit fly species would enable more accurate estimates of trigger numbers to be developed. While these trigger numbers could be provided as a probability distribution given a certain incipient population size, a discrete number is required for use in regulatory decision making.

Calculated fruit fly triggers

I examined the results of applying the trigger model on *B. tryoni* and *B. dorsalis* for each country (Table 3), and I found that the trapping arrays employed in surveillance systems for *B. dorsalis* may not be sensitive enough to provide confidence that an outbreak has not already occurred when the first fly is captured. This finding contrasts with the surveillance trapping arrays in New Zealand and urban areas of Australia for *B. tryoni* where my model would allow for a further two flies to be captured after the first before the trigger for an outbreak was reached. In reality, all of the countries included in my study respond to the first fly captured by increasing their trapping density around the first find location. In the case of New Zealand, the trapping density is increased significantly from 0.065 traps per hectare to 0.283 traps per hectare for *B. tryoni* and from 0.0072 traps per hectare to 0.141 traps per hectare for *B. dorsalis*. These increases in trapping density increase the estimated trigger numbers for *B. tryoni* and *B. dorsalis* from 3 to 4 flies and 1 to 4 flies (over a two-week period) respectively. Additionally, this increase in estimated trigger numbers from increasing trapping density occurs for *B. dorsalis* in California.

An increase in trapping density would seem to be justified for surveillance trapping densities that result in outbreak trigger numbers of only one fly. Where surveillance trapping densities result in outbreak trigger numbers greater than one, countries would be justified in not investing in further trapping until the outbreak trigger had been reached. However, the investment in further trapping may still be cost effective if the increased trigger sensitivity reduced the number of false positives (false declarations of an outbreak) which can incur considerable economic impacts.

Calculated sizes of export restriction zones

When fruit fly outbreaks currently occur, importing countries can require differently sized export restrictions zones from which export of all host material may be restricted. In most cases the size of these zones is independent of the fruit fly species detected, meaning they may be established based on the worst-case fruit fly outbreak scenario. A considerable reduction in the economic costs of export restrictions zones could be achieved if these zones were sized based on species-specific fruit fly biology and trapping effectiveness. Reviews of recorded dispersal distances of *B. tryoni* by Dominiak (2012) and Dominiak and Fanson (2020) found that the Australian code of practice requirement of a 15 km radius ERZ was likely to be more than three times larger than required.

The application of the criteria developed in this paper for determining the size of export restrictions zones offers countries the opportunity to consider the costs of increasing or decreasing the density of their surveillance trapping verses the costs associated with a larger or smaller export restrictions zone. An increase in the investment in higher density surveillance trapping would be rewarded with lower costs associated with a smaller export restrictions zone. For instance, if New Zealand were to increase the density of surveillance traps for *B. dorsalis* from a 1200-m grid to an 800-m grid, the pay-off would be a reduction in the radius of any resulting ERZ from 5480 m to 4680 m, equating to as much as 2,500 hectares of orchard production not requiring treatment for export. As was noted in a report on the financial impact of a fruit fly incursion into New Zealand (Kiwifruit Vine Health 2014), a reduction in the size of an ERZ from 80 to 15 km resulted in an estimated reduction in market economic impacts of around NZ$ 200 million and a reduction in total economic impacts of around NZ$ 350 million.

Calculated periods to remove the export restriction zone

The results achieved from applying the criteria developed in this paper for the period required to once again declare fruit fly freedom and remove any ERZ were mixed. Where trapping densities were high, such as is the case with the New Zealand response system, the criteria could be used to reduce the period required before normal trade could resume. Where trapping densities are low my model results in excessively long periods to achieve the reinstatement of fruit fly freedom. It is expected that an investment in increasing trapping densities should result in a pay-off of a timelier removal of trade restrictions. However, other factors would be expected to play a role in determining this period for low trapping densities. For example, it may be expected that over extended periods any underlying population of fruit flies would increase in size, making it more likely to be detected by the surveillance system. However, Papadopoulos et al. (2013) reported that under lower density trapping scenarios, detections of fruit flies may arise from low density populations that remain at undetectable levels, sometimes for years. I recognise that this may be possible under some environmental conditions. But it is considered less likely that a fruit fly population can exist in a balanced, stable state at a very low level over such an extended period in environments where they should flourish (Suckling et al. 2016). Additionally, it should be noted that where trapping periods are interrupted by winter and the fruit fly species in question over-winters in the adult life stage, the minimum requirement of a single generation would not be necessary if winter conditions ensure no adults are present when climatic conditions become suitable for trapping once more.

Conclusion

Models have been developed that can be used to estimate the criterial parameters of any successful surveillance and response system. These models rely primarily on fruit fly biology and the effectiveness surveillance trapping systems. While the advice for each of these factors has been provided as discrete and independent outputs, they are derived from the application of a model using research-generated input data that has varying degrees of variability and uncertainty. Where the data available for model inputs has included a range of values for biological variability, conservative ("worst case") point estimates have been used in some cases. Thus, the outputs of the model are conservative in nature and support somewhat precautionary risk management decisions. As such, the use of these criteria should be considered as conservative guidance.

The adoption internationally of a standard set of criteria for establishing a control system and responding to fruit fly outbreaks would provide considerable economic benefits to international trade. Such criteria would enable countries to make more informed cost–benefit decisions on the level of investment in fruit fly control systems that better reflects the economic risks fruit flies represent to their economy. Also, these criteria would create more confidence in the importing country that imported produce is not infested with fruit fly. Additionally, agreed criteria would encourage research more focused on gaining greater confidence in the parameters of the model such as fruit fly breeding population sizes and ESA values for surveillance systems.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-021-00043-w.

Additional file 1. Calculating the Effective sampling area.

Acknowledgements

Many thanks go to John Kean, Bernie Dominiak, Roger Vargas, Andrew Robinson, Pat Gomes, Nick Manoukis, Alan Meats and Todd Shelly for reviewing and providing valuable guidance and input into earlier versions of this work. Special thanks to those within the New Zealand Ministry for Primary Industries who provided support and advice, especially Jo Berry, and to Bernie Dominiak who provided invaluable feedback on this manuscript.

Authors' contributions

Model design and development.

Funding

By employer.

Availability of data and materials

Supplementary file provided.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Consent obtained and granted.

Competing interests

The authors declare that they have no competing interests.

Received: 18 October 2020 Accepted: 1 June 2021
Published online: 15 June 2021

References

Acosta H, White P. Atlas of Biosecurity Surveillance, May 2011. Ministry of Agriculture and Forestry, Wellington, New Zealand. 2011.

Baker RT, Cowley JM, Harte DS, Frampton ER. Development of a maximum pest limit for fruit flies (Diptera: Tephritidae) in produce imported into New Zealand. J Econ Entomol. 1990;83:13–7.

Barclay HJ, Hargrove JW. Probability models to facilitate a declaration of pest-free status, with special reference to tsetse (Diptera: Glossinidae). Bull Entomol Res. 2005;95:1–11.

Bateman MA. The ecology of fruit flies. Annu Rev Entomol. 1972;17:493–518.
Biney K, Agarwal ML. Comparative biology of three *Bactrocera* species (Diptera: Tephritidae: Dacinae). Shashpa. 2005;12(2):93–8.
Chiu HT. Movements of Oriental fruit flies in the field. Chin J Entomol. 1983;3(2):93–102.
Clarke AR, Dominiak BC. Positive correlation of male and female *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) catches in orange-ammonia traps. Gen Appl Entomol. 2012;39:9–14.
Clarke AR, Armstrong KF, Carmichael AE, Milne JR, Roderick GK, Yeates DK. Invasive phytophagous pests arising through a recent tropical evolutionary radiation: The *Bactrocera dorsalis* complex of fruit flies. Annu Rev Entomol. 2005;50:293–319.
Clarke AR, Powell KS, Weldon CW, Taylor PW. The ecology of *Bactrocera tryoni* (Diptera: Tephritidae): what do we know to assist pest management? Ann Appl Biol. 2011;158:26–54.
COP. Australia's fruit fly code of practice. Subcommittee on Domestic Quarantine and Market Access, Canberra. 2014.
Dominiak BC. Review of dispersal, survival, and establishment of *Bactrocera tryoni* (Diptera: Tephritidae) for quarantine purposes. Ann Entomol Soc Am. 2012;105:434–46.
Dominiak BC, Fanson BG. Revised quarantine distances for domestic and international trading Queensland fruit fly. 9th International Symposium on Fruit Flies of Economic Importance, Bangkok, Thailand, 12–14 May, 2014.
Dominiak BC, Fanson BG. Current quarantine and suspension distances are excessive for incipient populations of Queensland fruit fly (Bactrocera tryoni (Froggatt)) (Diptera: Tephritidae) in southern New South Wales Australia. Crop Prot. 2020;138:105341.
Dominiak BC, Mapson R. Revised distribution of *Bactrocera tryoni* in eastern Australia and effect on possible incursions of Mediterranean fruit fly: development of Australia's eastern trading block. J Econ Entomol. 2017;110(6):2459–65.
Dominiak BC, Worsley PM, Nicol H. Release from a point source and dispersal of sterile Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) (Diptera: Tephritidae) at Wagga Wagga. Plant Prot Q. 2013;28(4):120–5.
Dominiak BC, Wiseman B, Anderson C, Walsh B, McMahon M, Duthie R. Definition of and management strategies for areas of low pest prevalence for Queensland fruit fly *Bactrocera tryoni* Froggatt. Crop Prot. 2015;72:41–6.
Doorenweerd C, Leblanc L, Norrbom AL, Jose MS, Rubinoff D. A global checklist of the 932 fruit fly species in the tribe Dacini (Diptera, Tephritidae). ZooKeys. 2018;730:17–54. https://doi.org/10.3897/zookeys.730.21786.
Drew RAI, Romig MC. Tropical fruit flies (Tephritidae: Dacinae) of South-East Asia: Indomalaya to North-West Australasia. In Tropical fruit flies (Tephritidae: Dacinae) of South-East Asia: Indomalaya to North-West Australasia. 2013; 653 pp.
EPPO. *Bactrocera dorsalis*. Data sheets on quarantine pests CAB International; Wallingford, UK; 2009.
Fanson BG, Sundaralingam S, Jiang L, Dominiak BC, D'Arcy G. A review of 16 years of quality control parameters at a mass-rearing facility producing Queensland fruit fly, *Bactrocera tryoni*. Entomol Exp Appl. 2014;151:152–9.
FAO. Establishment of pest free areas for fruit flies (Tephritidae). International Standard for Phytosanitary Measures No. 43. Rome. Published by FAO on behalf of the Secretariat of the International Plant Protection Convention (IPPC). 2016; 56 pp.
Fletcher BS. The ecology of a natural population of the Queensland fruit fly, *Dacus tryoni* VI. Seasonal changes in fruit fly numbers in the areas surrounding the orchard. Aust J Zool. 1974;22:189–202.
Froerer KM, Peck SL, McQuate GT, Vargas RI, Jang EB, McInnis DO. Long-Distance Movement of *Bactrocera dorsalis* (Diptera: Tephritidae) in Puna, Hawaii: How far can they go? Am Entomol. 2010;56(2):88–94.
Garcia FRM. Fruit fly: Biological and ecological aspects. In: Bandeira RRC. Current Trends in Fruit Fly Control on Perennial Crops and Research Prospects. Transworld Research Network. 2009; pp 1–35. ISBN-13: 978–8178954110.
Hancock DL, Hamacek EL, Lloyd AC, Elson-Harris MM. The Distribution and Host Plants of Fruit Flies (Diptera: Tephritidae) in Australia. Queensland Department of Primary Industries. 2000. ISSN 0727e6273.
Kiwifruit Vine Health. Financial impact of a fruit fly incursion to New Zealand's kiwifruit industry; 2014; 6. www.kvh.org.nz.
Kean J. The effective sampling area of traps: estimation and application. In: Beresford RM, Froud KJ, Kean JM, Worner SP. New Zealand Plant Protection Society. The plant protection data toolbox. New Zealand Plant Protection Society Incorporated. 2015a; 176.
Kean J. Meta-analysis, validation and application of fruit fly development times. New Zeal Plant Prot Society. 2015b;68:44–53.
MacFarlane JR, East RW, Drew RAI, Betlinski GA. Dispersal of irradiated Queensland fruit flies, *Dacus tryoni* (Froggatt) (Diptera: Tephritidae), in south-eastern Australia. Aust J Zool. 1987;35(3):275–81.
Meats A. Predicting or interpreting trap catches resulting from natural propagules or releases of sterile fruit flies. An actuarial and dispersal model tested with data on *Bactrocera tryoni*. Gen Appl Entomol. 1998a;28:29–38.
Meats A. The power of trapping grids for detecting and estimating the size of invading propagules of the Queensland fruit fly and risks of subsequent infestation. Gen Appl Entomol. 1998b;28:47–55.
Meats A. Fruit fly detection programs: the potentials and limitations of trap arrays. In: Shelly TE, Epsky N, Jang EB, Reyes-Flores J, Vargas R, eds. Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Springer; 2014. pp 643.
Meats A, Clift AD. Zero catch criteria for declaring eradication of tephritid fruit flies: the probabilities. Aust J Exp Agric. 2005;45:1335–40.
Meats A, Edgerton JE. (2008) Short- and long-range dispersal of the Queensland fruit fly, *Bactrocera tryoni* and its relevance to invasive potential, sterile insect technique and surveillance trapping. Aust J Exp Agric. 2008;48:1237–45.
Meats A, Clift AD, Robson MK. Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. Aust J Exp Agric. 2003;43:407–17.
MPI. MPI Standard: Fruit Fly Response (Field Operations). New Zealand Ministry for Primary Industries. 2014; 31 pp.
Papadopoulos NT, Plant RE, Carey JR. From trickle to flood: the large-scale, cryptic invasion of California by tropical fruit flies. Proc R Soc B. 2013;280:20131466.
Plant Health Australia. The Australian handbook for the identification of fruit flies. Version 2.1. Plant Health Australia. Canberra, ACT; 2016.
Qin Y, Paini DR, Wang C, Fang Y, Li Z. Global establishment risk of economically important fruit fly species (Tephritidae). PLoS ONE. 2015;10(1):e0116424. https://doi.org/10.1371/journal.pone.0116424.
Quilici S, Donner P. Analysis of exotic fruit fly trapping networks. EPPO Bull. 2012;42:102–8.
Raghu S, Clarke AR, Drew RAI, Hulsman K. Impact of habitat modification on the distribution and abundance of fruit flies (Diptera: Tephritidae) in Southeast Queensland. Popul Ecol. 2000;42:153–60.
Royer JE. Responses of fruit flies (Tephritidae: Dacinae) to novel male attractants in north Queensland Australia, and Improved Lures for Some Pest Species Austral. Entomology. 2015;54:411–26.
RSPM 17. Guidelines for the establishment, maintenance and verification of fruit fly pest free areas in North America. NAPPO Regional Standards for Phytosanitary Measures. The Secretariat of the North American Plant Protection Organization; 2010; 12 pp.
Schutze MK, Aketarawong N, Amornsak W, Armstrong KF, Augustinos AA. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. Syst Entomol. 2015;40(2):456–71.
Stringer LD, Kean JM, Beggs JR, Suckling DM. Management and eradication options for Queensland fruit fly. Popul Ecol. 2017;59:259–73.
Suckling DM, Kean JM, Stringer LD, Cáceres-Barrios C, Hendrichs J, Reyes-Floresg J, Dominiak BC. Eradication of tephritid fruit fly pest populations: outcomes and prospects. Pest Manag Sci. 2016;72:456–65.
Tobin PC, Berec L, Liebhold AM. Exploiting Allee effects for managing biological invasions. Ecol Lett. 2011;14:615–24.
Turchin P, Odendaal FJ. Measuring the effective sampling area of a pheromone trap for monitoring population density of southern pine beetle (Coleoptera: Scolytidae). Environ Entomol. 1996;25:582–8.
USDA APHIS. PPQ action plan: Oriental fruit fly, *Bactrocera dorsalis* Hendel (synonym = *Dacus dorsalis* Hendel). United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Cooperating State Departments of Agriculture. 1989; 56 pp.

Vargas RI, Carey JR. Comparative survival and demographic statistics for wild oriental fruit fly, Mediterranean fruit fly, and melon fly (Diptera: Tephritidae) on papaya. J Econ Entomol. 1990;83(4):1344–9.
Vargas RI, Walsh WA, Kanehisa D, Stark JD, Nishida T. Comparative demography of three Hawaiian fruit flies (Diptera: Tephritidae) at alternating temperatures. Ann Entomol Soc Am. 2000;93:75–81.
Vargas RI, Piñero JC, Leblanc L. An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the pacific region. Insects. 2015;6:297–318.
Weldon CW. Dispersal and mating behaviour of Queensland fruit fly, Bactrocera tryoni (Froggatt) (Diptera: Tephritidae): implications for population establishment and control. Ph.D. Thesis, University of Sydney; 2005. http://ses.library.usyd.edu.au/handle/2123/700.
Yonow T, Zalucki MP, Sutherst RW, Dominiak BC, Maywald GF, Maelzer DA, Kriticos DJ. Modelling the population dynamics of the Queensland fruit fly, *Bactrocera* (*Dacus*) *tryoni*: a cohort-based approach incorporating the effects of weather. Ecol Model. 2004;173:9–30.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

BMC

Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Global drivers of historical true fruit fly (Diptera: Tephritidae) invasions

Jiří Trombik (jiri.trombik@gmail.com)
Czech University of Life Sciences in Prague Faculty of Forestry and Wood Sciences: Ceska Zemedelska Univerzita v Praze Fakulta lesnicka a drevarska https://orcid.org/0000-0002-5141-3222

Samuel Ward
Mississippi State University

Allen L. Norrbom
USDA Agricultural Research Service

Andrew M. Liebhold
USDA Forest Service: US Department of Agriculture Forest Service

---

Research Article

Keywords: Tephritidae, non-native species, invasion drivers, patterns of invasions, global insect invasion dynamics, generalized linear mixed-effects models, risks of future invasions

Posted Date: February 7th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1292488/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Version of Record: A version of this preprint was published at Journal of Pest Science on April 19th, 2022. See the published version at https://doi.org/10.1007/s10340-022-01498-0.

Global drivers of historical true fruit fly (Diptera: Tephritidae) invasions

Jiří Trombik[1*], Samuel Ward[2], Allen L. Norrbom[3] and Andrew M. Liebhold[1, 4]

[1] Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, 165 00 Praha 6 - Suchdol, Czech Republic

[2] Department of Biochemistry, Molecular Biology, Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762

[3] Systematic Entomology Laboratory, USDA, ARS, c/o Smithsonian Institution, P.O. Box 37012, MRC 168, Washington, DC, 20013-7012, USA

[4] USDA Forest Service Northern Research Station, Morgantown, WV, 15349 USA

*Corresponding author:

Jiří Trombik

Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences

Kamýcká 129, 165 00 Praha 6 - Suchdol, Czech Republic

jiri.trombik@gmail.com

ABSTRACT

Given the high costs associated with fruit fly (Tephritidae) invasions, there is a need to better understand and predict the risks of future invasions. We assembled a global database of historical Tephritidae invasions with the objective to identify the biological and socioeconomic drivers that explain these invasions. We investigate the tendencies of certain species to invade and the characteristics of regions that make them more prone to invasions.

We used various published sources and online databases to assemble a database documenting the occurrence (presence/absence) and status (native/non-native) of individual species for each country in the world. Values of several socio-economic and environmental variables were also assembled and considered as explanatory variables. A generalized linear mixed-effects model framework was used to evaluate the utility of these variables for predicting the country-level occurrence of each species outside of its native range.

A total 44 species were identified as having been accidentally introduced in the world. Most species of invading Tephritidae have established in only five or fewer countries. The number of invasions has rapidly increased since the 1950s. Climatic similarity between native and invaded countries, gross domestic product of the invaded country and distance from the native range are significant predictors of tephritid invasions.

Our analysis revealed that both economic and biological factors explain patterns of historical Tephritid invasions. Despite the rising efforts to prevent new invasions, additional species may continue to invade, and many currently established species will likely continue to expand their ranges into new areas.

KEYWORDS: Tephritidae, non-native species, invasion drivers, patterns of invasions, global insect invasion dynamics, generalized linear mixed-effects models, risks of future invasions

INTRODUCTION

The emergence of advanced human civilizations in various world regions has historically been closely linked with the domestication of plants for agricultural purposes and their propagation (Rindos 1987; Sauer 1993). Many agricultural crops exhibit remarkable productivity when grown outside of their native range where they may escape the impacts of herbivores and plant pathogens. In many cases, however, such escape has been short lived as plant pests are accidentally moved outside of their native ranges and these invading species may adversely impact agricultural productivity, ultimately resulting in serious socioeconomic consequences (Paini et al. 2016; Santini et al. 2018).

Among such damaging non-native agricultural pests are the notorious true fruit flies (Diptera: Tephritidae), which comprise ca. 5,000 species worldwide (White and Elson-Harris 1992; Norrbom et al. 1999; Norrbom unpubl. data). Most tephritids share a common life history of larval feeding on living plant tissue, feeding upon seeds, flowers, fruits or within galls or mines on leaves and stems; however, about 1/3 feed on fruits. Tephritids exhibit considerable variation in other life history traits, such as pre-adult survival and duration of immature stages, as well as variation in population demographics that may affect their success as invaders (Carey et al. 1988; Malacrida et al. 2007; Papadopoulos 2014; Vargas et al. 2000). The Tephritidae includes some of the world's most damaging fruit and vegetable pest species with particularly serious pests in the genera ***Anastrepha*** (native to the Neotropical Region), ***Bactrocera*** and ***Zeugodacus*** (mainly native to Indomalayan and Australasian Regions), ***Ceratitis*** (native to the Afrotropical Region) and ***Rhagoletis*** (native to the Nearctic, Neotropical and Palearctic Regions) (Courtney et al. 2009; White and Elson-Harris 1992; Norrbom et al. 1999).

While several Tephritidae species have had massive economic impacts as a result of direct losses to agricultural yield and increased pest management costs, additional impacts have also resulted from diminished access to export markets due to quarantine bans imposed by importing countries (Siebert and Cooper 1995; Mumford 2002; Papadopoulos 2014). Because of the severe socio-economic consequences of Tephritidae invasions, many countries expend considerable resources to prevent establishment of new and potentially damaging species. Historically, the principal pathways responsible for Tephritidae invasions have been international movement of fruit and vegetables, either in trade or in passenger baggage (Kiritani and Yamamura 2003, Liebhold et al. 2006; Karsten et al. 2015). Biosecurity approaches to preventing the arrival of fruit flies include importation prohibitions, inspection and mandatory phytosanitary treatments (Li et al. 2013; Phillips 2013). In addition to these measures, biosecurity efforts include continual surveillance and, if an incursion is detected, eradication (Quilici and Donner 2012; Suckling et al. 2016).

Given the extreme costs associated with Tephritidae invasions and the limited resources that most countries have available for carrying-out biosecurity programs, there is a need to better understand and predict the risks of future invasions (Qin et al. 2015). Here we assemble a comprehensive database of all known historical Tephritidae invasions and analyze these data to identify biological and socioeconomic drivers that explain these invasions. We investigate whether there are tendencies of certain species to more successfully invade new regions and if there are characteristics of regions that make them more prone to Tephritidae invasions. These analyses provide insight into the factors that may promote new invasions and provide critical information for predicting invasions in the future.

METHODS

2.1 Tephritidae invasion records

We compiled data on the global distribution of both the native and non-native ranges of all Tephritidae species that are known to be unintentionally established outside of their native ranges. Multiple Tephritidae species have been intentionally introduced as biological control agents of weeds (Bess and Haramoto 1972; White and Clement 1987; White and Elson-Harris 1992; Turner 1996) but these species were not included in our analyses (see Table S1.1 for the list of these species). The geographical distribution of each species was recorded as non-native, native or not established in each country in the world. These data were compiled from various published sources including the scientific literature (e.g., Foote et al. 1993; Wu et al. 2009) and online databases (e.g., CoFFHI 2020; EPPO 2014, 2020; GBIF Secretariat 2021) (see Table S2.2 for details). Only records of species that have clearly established a self-sustaining population in the non-native range were included. For species where the native range is uncertain, their presence in countries was considered to be part of the native range unless there was evidence otherwise; thus, the number of non-native species and the extent of their invaded areas may be underestimated. In defining non-native ranges, the Russian Federation was divided into its European and Asian portions. Outlying states, territories and other autonomous regions (e.g., Hawaiian Islands, Guam, Puerto Rico, Christmas Island, New Caledonia, Guam) with sufficient data available were treated as separate units in the analysis.

For each record of a non-native tephritid species (excluding biocontrol agents) in a country, we recorded the year of first recorded discovery if such data were available. Furthermore, the Global Eradication and Response Database (GERDA; Kean et al. 2021) was used to summarize documented eradication attempts against non-native tephritids worldwide (Table S3.3).

To examine the inter- and intra-regional invasion dynamics and to determine the most common source-recipient combinations at the regional level, numbers of native and established non-native species were summarized for each of eight biogeographic regions: Nearctic, Neotropic, European Palearctic, Asian Palearctic, Indo-Malaya, Afrotropic, Australasia and Oceania. These regions were slightly modified from Wallace's classification to match national political boundaries in accordance with the country-level approach used here to record species distributions; for purposes of this analysis, all of any country that extends into two biogeographic regions was included in the region in which the majority of its territory occurs (Figure S4.1). Countries such as Mexico, China and Indonesia that are often split between biogeographic regions were not divided in our analysis because historical invasion data are not available for subdivisions of these countries. The Hawaiian Islands were included in the Oceania region rather than the Nearctic, which includes the continental USA. The European portion of the Russian Federation was included in the European Palearctic region and the Asian part of Russia was allocated to the Asian Palearctic region. Species that are only non-native within portions of the same countries that form part of their native ranges were excluded from these and further analyses.

The climatic distribution (combined native and non-native) of each non-native tephritid species was characterized using the proportion of georeferenced occurrence records for each species from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) recorded in each climatic subgroup of the Köppen-Geiger climate classification system (Kottek et al. 2006).

2.2 Explanatory variables

To explore possible mechanisms explaining the establishment of each non-native Tephritidae species in each country, we explored associations with a set of candidate socio-economic and

environmental variables (Table 1). Some of these variables were related to propagule pressure while others were related to habitat invasibility.

TABLE 1 List of explanatory variables for each country used for analysis of invasion probability for each tephritid species in each country

Variable	Desciption	Source
Human population	Total Human population in each country in 2015	World Bank Open Data (https://data.worldbank.org/)
Gross domestic product (GDP)	Gross domestic product in each country 2015	World Bank Open Data (https://data.worldbank.org/)
Number of visiting tourists	Number of tourist arrivals in country in 2015	World Bank Open Data (https://data.worldbank.org/)
Cumulative imports	Total value of imports to each country (adjusted USD) from all countries in the native range	Bilateral Trade Historical Series: New Dataset 1827-2014 (TRADHIST, Fouquin and Hugot, 2017)
Fruit production	Total area of agricultural land producing fruit in each country in 2015 (km^2)	Food and Agricuture Organization of United Nations (http://www.fao.org/home/en/)
Country area	Total area of the country (km^2)	GIS analysis
Distance to native range	Shortest (border-border) distance beetwen each country and the native range of species (km)	GIS analysis
Climatic similarity	Fraction of the country with suitable climate for specific Tephritidae invasion	Koppen classes; GBIF records (GBIF Secretariat 2021)
Suitable climate area	Area of the country with suitable climate for Tephritidae species invasion (km^2)	Koppen classes; GBIF records (GBIF Secretariat 2021)

Socio-economic variables considered here that serve as proxies for propagule pressure included human population, gross domestic product (GDP), tourism and cumulative value of imports 1827-2014 to each country. Because of changes in national identities, independence of former colonies and other reasons, the imports of presently non-existent countries and previously colonial territories were grouped or divided to match current national boundaries. Annual imports were expressed in USA dollars per year, adjusted to 2018 values utilizing the Consumer Price Index

(Federal Reserve Bank of Minneapolis 2021). The cumulative value of all imports from countries in the native region of each Tephritidae species to each remaining country was calculated to express total trade flow from the native region to every other country.

Variables related to country invasibility that were considered included annual fruit production and climatic suitability. From the total of 44 non-native tephritid species identified, sufficient information for further analysis of climatic suitability was found for only 36 species. Climatic suitability was calculated for each country both as the total area of suitable climate for each species and as the fraction of the country with suitable climate. This suitability was characterized based on the climatic niche for each species. The climatic niche was estimated by identifying the climatic subgroups of the Köppen-Geiger system (Kottek et al. 2006) that overlapped the range (both native and invaded) of the species. The geographic range of each species was characterized by downloading georeferenced occurrence records for each species from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) database. Only records matching the country boundaries of the native and invaded ranges for each species were used. Then, we calculated the number of occurrence records falling in each of the 30 climatic subgroups. Climatic suitability of each country outside of the species native range was calculated using the Jaccard similarity coefficient as:

$$CS_{i,j} = \frac{\sum_{KG=1}^{30} p_{KG,i}\, p_{KG,j}}{(\sum_{KG=1}^{30} p^2{}_{KG,i} + p^2{}_{KG,j})/2}$$

where $\boldsymbol{CS_{i,j}}$ is the climatic similarity of country $\boldsymbol{i}$ with the estimated climatic niche of Tephritidae species $\boldsymbol{j}$, $\boldsymbol{p_{KG,i}}$ is the fraction of country $\boldsymbol{i}$ comprised of Koppen-Geiger climate subgroup $\boldsymbol{KG}$ and $\boldsymbol{p_{KG,j}}$ is the fraction of species $\boldsymbol{j}$ GBIF records located in subgroup KG. The suitable climatic area

for each country-species combination was calculated as country area multiplied by $CS_{i,j}$. The same procedure was used to estimate the "suitable" native and invaded range of each species.

Country area and proximity to the native range of each individual species were calculated using ESRI Arcmap 10.5.1. Country borders were extracted from the GISCO database (https://ec.europa.eu) as GIS shapefiles of scale 1:10 mil. Distance to the native range was calculated for each country-species combination. The distance between the native region and each country outside of the native range was calculated as the shortest geographic distance (border to border).

2.2 Data analysis

A generalized linear mixed-effects model framework was used to analyze the incidence (0/1) of invasion for each species in each country. The analysis was based on a full matrix database such that each country was repeated in the data for each species and vice versa. To account for repeated observations on countries and unobservable effects of species, terms for country and species were fit as random intercepts. All models were fit with a binomial distribution and logit link function. Data were analyzed using the R statistical software v4.0.0 (R Core Team 2020) and mixed-effects models were fit using the lme4 package in R (Bates et al. 2014). Prior to analysis, several predictors were ln(***x***)-transformed to reduce skewness and, for predictors containing zero values, a small constant of 1 was added to all observations. Modeling was then conducted in two steps. First, we fit bivariate models between our response variable and each predictor and calculated Akaike Information Criterion (AIC) values for each model (Figure S5.2A). For the second stage, we aimed to develop a full, best-fitting model that evaluated all predictors simultaneously, but first checked for collinearity ($|\boldsymbol{r}| > 0.5$) by calculating pairwise Pearson's correlation coefficients (Table S5.4).

In instances of collinearity, predictors occurring in bivariate models with the lowest AIC were used.

While surveillance and eradication represent an important component of biosecurity measures targeting exclusion of non-native Tephritidae species, questions have been raised about the efficacy of some of these programs (Carey 1991, Papadopoulos et al. 2013). Specifically, some scientists believe that detections of insects in the same general area of the site of an earlier eradication most likely reflect the persistence of the initial population (i.e., as a result of eradication failure) rather than a new invasion following successful invasion (Zhao et al. 2019). However, this theory has been lively debated in the scientific literature (Gutierrez et al. 2014, McInnis et al. 2017). Here we attempted to remain agnostic with regard to this theory and performed two versions of our analysis. In the first analysis, we fit the mixed-effects model using species-country records for which we only recorded a country as invaded based on the presence of a self-sustaining population. In the second analysis, we fit the same model but in addition classified countries as invaded if an eradication project for the species was carried out in the country even if there were no subsequent detections. Our logic here was that had the eradication not been carried out, then the species would have established. By analyzing these data both ways we were able to avoid assumptions about the true success of eradication.

An additional analysis was conducted to determine which species, after adjusting for the effects of predictors remaining in our best-fitting model, exhibited the highest mean probability of invasion. This was achieved by estimating marginal means using the emmeans package in R (Lenth 2020). First, species were fit as a fixed (vs. random) effect with country still included as a random intercept to obtain species-level mean invasiveness, but this resulted in convergence issues in the mixed-effect framework. Thus, a simpler approach was used by (i) fitting a fixed-effects only

model that included predictors from the best fitting model (i.e., human population density, proportional climatic similarity, distance from the native range; see "Results") along with a term for species and (ii) only evaluating species for which the number of countries invaded / total countries was >10% (i.e., invaded more than 30 countries).

3 RESULTS

3.1 Intra- and Inter-regional invasions

In total, we identified 44 non-native Tephritidae species (Table 2, Table S2.2).

TABLE 2 Tephritidae species known to have established in areas outside of their native ranges (excluding biocontrol agents purposefully introduced). Biogeographic regions are abbreviated: AT – Afrotropic, AU – Australasia, AP – Asian Palearctic, EP – European Palearctic, IM – Indo-Malaya, NA – Nearctic, NT – Neotropic, OC - Oceanian

Species	Biogeographic region of native range	Biogeographic region of invaded range	N. of countries invaded
Anastrepha curvicauda*	NT	NA	1
Anastrepha fraterculus "Brazil-1 morph"	NT	NT	4
Anastrepha fraterculus "Peruvian morph"*	NT	NT	1
Anastrepha grandis	NT	NT	1
Anastrepha ludens	NT	NT	2
Anastrepha obliqua	NT	NT	13
Anastrepha suspensa	NT	NA	1
Bactrocera carambolae	IM	NT	4
Bactrocera dorsalis	AP, IM	AP, AT, AU, EP, IM, OC	54
Bactrocera frauenfeldi	AU, OC	AU	1
Bactrocera latifrons	IM	AP, AT, OC	4
Bactrocera ochrosiae	OC	OC	1
Bactrocera oleae	AT	AP, AT, EP, IM, NA, NT, OC	34
Bactrocera tryoni	AU	AU, OC	3
Bactrocera zonata	IM	AP, AT, EP	12
Campiglossa producta	AP, EP, IM	AP, IM	5
Campiglossa sororcula*	AP, AU, AT, EP, IM, OC	AU, OC	2

Carpomya incompleta*	AT, EP	AT	2
Carpomya pardalina*	AP, EP, IM	AP, EP	8
Carpomya vesuviana*	AP, EP, IM	AP, AT, EP, IM, OC	21
Ceratitis capitata	AT	AP, AT, AU, EP, NT, OC	61
Ceratitis quilicii	AT	AT	2
Chaetorellia succinea	AP, EP	NA	1
Dacus ciliatus	AT	AP, AT, EP, IM	19
Dacus frontalis	AT, EP	EP	5
Dicheniotes ternarius*	AT	AU	1
Dirioxa pornia	AU	OC	1
Ensina sonchi	AP, EP, IM	AT, IM, OC	4
Euaresta bullans	NT	AP, AT, AU, EP, NA, NT	30
Euarestoides acutangulus	NA	NT	9
Myopites tenellus*	EP	AP	1
Neoceratitis cyanescens	AT	AT	3
Rhagoletis batava	AP, EP	EP	4
Rhagoletis cerasi	AP, EP	NA	2
Rhagoletis cingulata	NA, NT	EP	12
Rhagoletis completa	NA, NT	NA, EP	14
Rhagoletis meigenii	EP	NA	2
Rhagoletis pomonella*	NA, NT	NA, NT	3
Strauzia longipennis	NA	EP	1
Terellia fuscicornis	AP, EP	EP, NA	2
Terellia ruficauda	AP, EP	NA	2
Terellia tussilaginis	AP, EP	AP	1
Urophora jaceana	AP, EP	NA	1
Zeugodacus cucurbitae	AP, IM	AP, AT, AU, EP, OC	34

* insufficient records available in GBIF database to quantify climatic range; excluded from climatic analyses

The highest number of successful invasions are documented in the European Palearctic region (15 species), followed by the Asian Palearctic region (14 species each). Indo-Malaya has the lowest number (6) of invasions (Table 3). The most intra-regional invasions are documented in the Neotropical Region (8). The European Palearctic has the highest number of native Tephritidae species that invaded elsewhere (16), while Oceania has the lowest number of species invading elsewhere (3, Table 3). Most inter-regional invasions occur between neighboring

regions such as between the Asian and European Palearctic (6) and between Indo-Malaya and the Asian Palearctic (5).

TABLE 3 Intra- and inter-regional invasions of Tephritidae between biogeographic regions. Biogeographic regions are abbreviated: AT – Afrotropic, AU – Australasia, AP – Asian Palearctic, EP – European Palearctic, IM – Indo-Malaya, NA – Nearctic, NT – Neotropic, OC – Oceania

Biogeographic region	*N. of non-native species native to the region**	*Total N. of non-native species*	*N. of intra-regional invasions***	*N. of inter-regional invasions****	*N. of native species that invaded other regions*							
					AT	AP	AU	EP	IM	NA	NT	OC
AT	9	13	5	11	—	3	2	3	2	1	2	3
AP	14	13	5	14	4	—	3	6	3	5	0	4
AU	4	8	1	4	0		—	0	0	0	0	3
EP	16	15	5	16	3	4	1	—	3	5	0	3
IM	10	6	4	10	4	5	1	2	—	0	1	4
NA	5	11	1	11	0	0	0	3	0	—	2	0
NT	11	11	8	6	1	1	1	3	0	4	—	0
OC	3	11	2	10	0	0	2	0	0	0	0	—
Total	44*	44*	—	—	—	—	—	—	—	—	—	—

* only species that invaded other regions included

** some species invaded multiple regions, hence sum of species across all regions don´t match total species

*** the native ranges of some species span multiple regions, and the origin of invading populations is unknown. Thus, some species may be listed as both intra- and inter-regional

3.2 Country-level invasions history

Most species of invading Tephritidae have established in only five or fewer countries, with 13 species only invading a single country (Figure 1A). Only six species have invaded more than 20 countries: ***Carpomya vesuviana*** (21), ***Euaresta bullans*** (30), ***Bactrocera oleae*** (34), ***Zeugodacus cucurbitae*** (34), ***Bactrocera dorsalis*** (54) and ***Ceratitis capitata*** (61). The first records of fruit fly invasion date back to the 1830s with ***Ceratitis capitata*** establishing in Madeira (Portugal) and the

Azores (Spain). For the next hundred years, only about 20 more invasions were recorded until the 1930s when the number of new species-country records doubled to around 40 (Figure 1B).

Since then, the cumulative number of Tephritidae invasions steadily increased to a total of 189 reported dated invasions in 2018 (Figure 1B). Unfortunately, dates for the first records of species in many countries (more than 200) could not be located. The complete list of records is provided in Table S2.2.

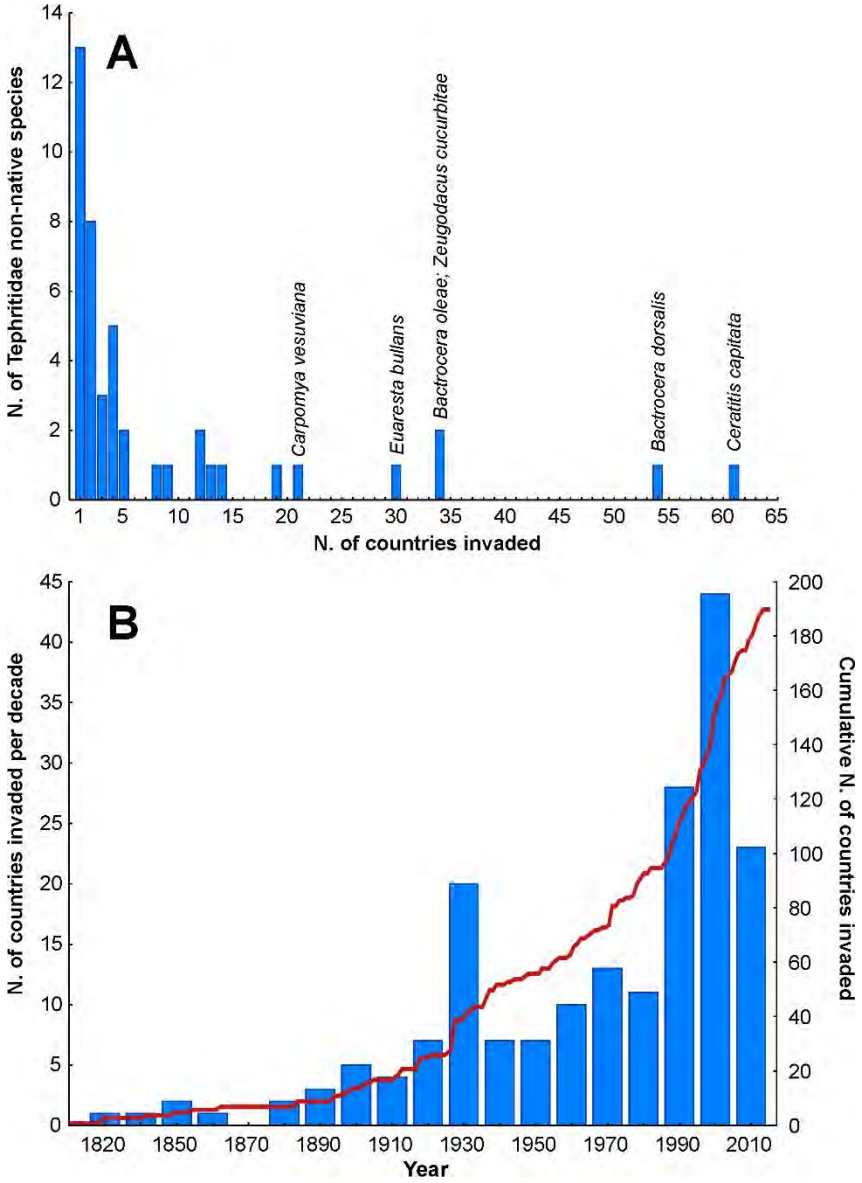


FIGURE 1 Distributions of invasions among species and through time. A. Frequencies of number of countries invaded per species; B. Number of species-country invasion discoveries per

decade (blue columns, left y-axis) and cumulative number of species-country invasion combinations since 1820 (red line, right y-axis)

Eradication attempts against non-native tephritids date to the early 1900's, and in total nearly 300 successful eradication programs are documented (Kean et al., 2021; Figure 2). Numbers of eradication programs have been steadily increasing since the 1970s with more than 60 eradications documented each decade since the 1990's (Figure 2). Most such programs were carried out against ***Ceratisis capitata*** and ***Bactrocera dorsalis***, followed by ***Bactrocera tryoni*** in the last decades (Figure 2).

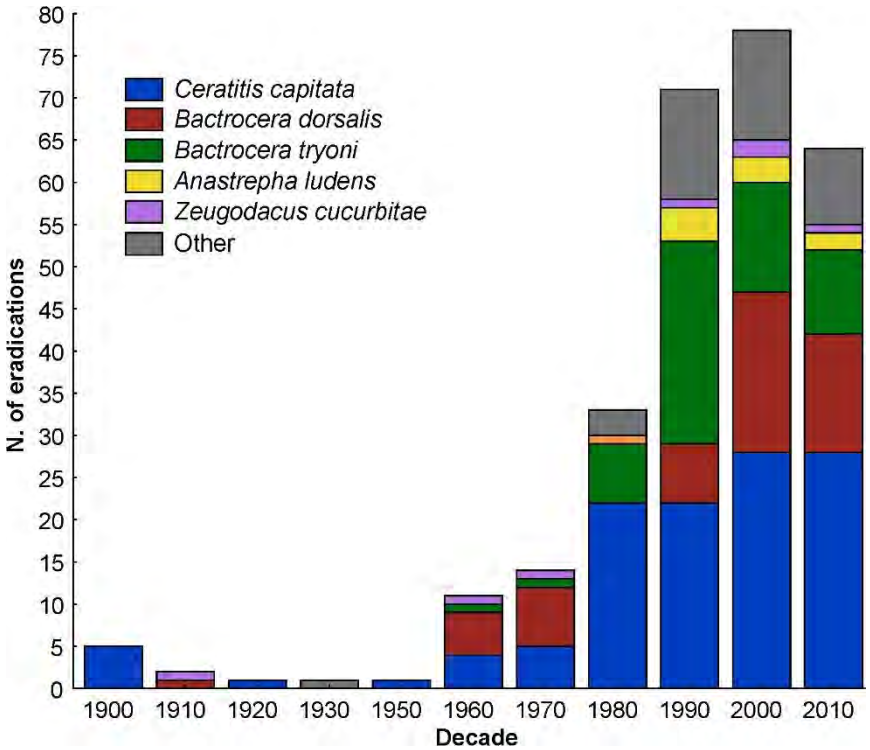


FIGURE 2 Number of successful eradication programs of Tephritidae since 1900

3.3 Native and Invaded and native ranges

The current distributions of invading Tephritidae species span four out of the five main Köppen–Geiger climatic group areas. The largest number of occurrence records fall in group C

(temperate) (62% of GBIF records), followed by group A (tropical) (16%), then group D (continental) (12%) and finally Group ***B*** (dry) (10%). There were no non-native Tephritidae records from the polar climatic group area. The climatic subgroup with the most native range records was the temperate oceanic subgroup followed by the tropical wet and humid subtropical subgroups (Figure 3). Most of the records from non-native ranges are documented from the warm- and hot-summer Mediterranean climatic subgroups.

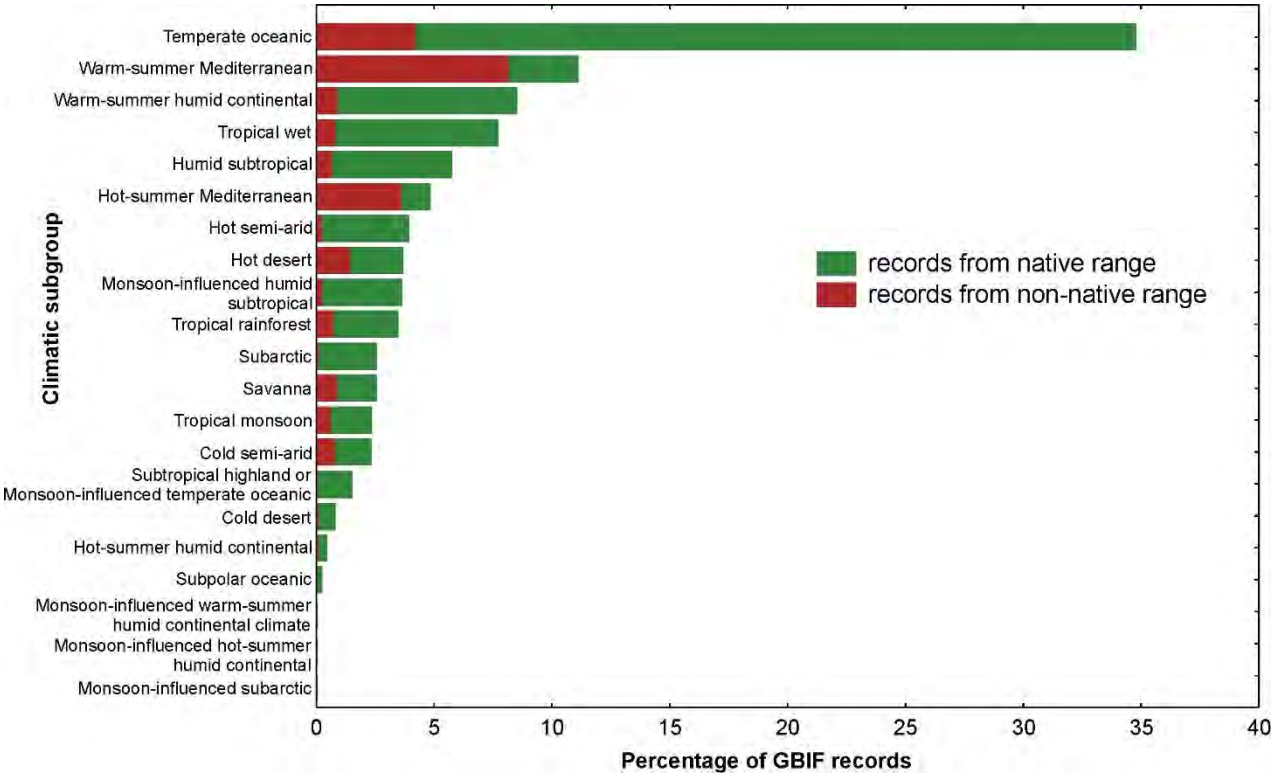


FIGURE 3 Distribution of Tephritidae GBIF records among Köppen–Geiger climate classification subgroups

Total numbers of native and non-native species present in each country are shown in Figure 4. The countries with the largest number of established non-native Tephritidae species (8) were the USA and Mauritius, though Reunion and the Hawaiian Islands were very close with 7 species. Australia, France, and several countries in the Middle East also have high numbers (6 species) of

documented invasions (Figure 4A). Overall, at least one tephritid invasion is documented in every world biogeographic region aside from Antarctica (Figure 4A). The greatest number of non-native tephritids originate from the European Palearctic region (9 from Spain and France) and Indo-Malaya (8 from India) (Figure 4B).

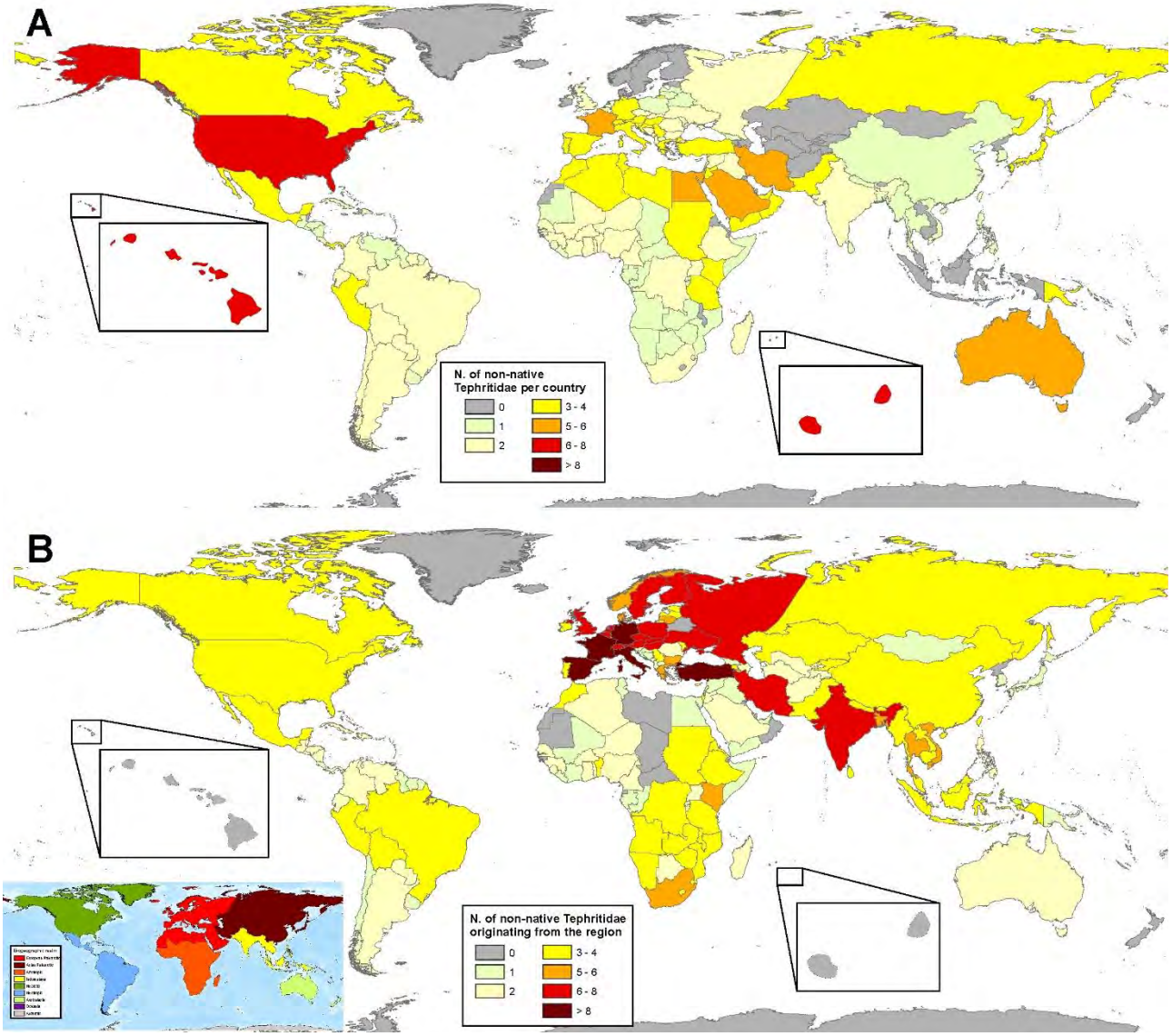


FIGURE 4 Number of known non-native tephritid species per country (A) and number of these non-native species originating from each country (B).

3.4 Generalized linear mixed-effects invasion model

We first present results from analyzing insect-country records where classification of establishment was limited to the clear presence of self-sustaining populations. Collinear predictors (Table S5.4), defined as having a correlation >|0.5|, could be split into two groups: those related to human activity (human population density, GDP, fruit production, tourism and land area) or climate (climatic similarity, suitable climate area). For consideration in the full candidate model, we selected the variable from each group that occurred in the bivariate model with the lowest AIC: GDP and proportional climatic similarity (Figure S5.2A). Thus, a full candidate model considered GDP, cumulative imports, proportional climatic similarity, and distance from the native range as fixed effects. Cumulative imports did not appear to influence the incidence of invasion ($\boldsymbol{Z} = 1.58$, $\boldsymbol{p} > 0.05$) and was consequently removed as a predictor variable; the model was refit, and all remaining predictors were associated with changes in invasion incidence ($|\boldsymbol{Z}| > 4.92$, $\boldsymbol{p} < 0.0001$; Table 4). In the final model, climatic similarity between native and invaded countries and GDP increased the incidence of invasion whereas distance to the native range significantly decreased the probability that a given country would be invaded (Table 4). Results from fitting the model to data where we included insect-country combinations based on the presence of an eradication program in addition to the presence of a self-sustaining population, yielded nearly identical results to those described above.

TABLE 4 Final generalized linear mixed-effects model of tephritid species invasion incidence per country. Model results including the eradication as successful invasions are presented in brackets. Model fit with a logit link function and binomial error structure with terms for species and country fit as random intercepts

Predictor	Coefficient	SE	*Z*	*P*
Intercept	-9.87 (-10.72)	1.25 (1.29)	-7.93 (-8.31)	<0.0001
GDP	0.21 (0.24)	0.04 (0.04)	4.92 (5.50)	<0.0001
Climatic similarity	3.47 (3.43)	0.28 (0.28)	12.26 (12.22)	<0.0001
Distance to native range	-0.15 (-0.16)	0.03 (0.03)	-5.18 (-5.65)	<0.0001

The estimated model for the mean probability of invasion (Table 5) indicated that ***Ceratitis capitata*** had the highest invasion probability (38%), followed by ***Bactrocera dorsalis*** (25%), ***Bactrocera oleae*** (18%), ***Zeugodacus cucurbitae*** (13%) and ***Euaresta bullans*** (11%).

TABLE 5 Probability of invasion for the six most widely invaded Tephritidae species according to a fixed-effects only model after adjusting for predictors (i.e., estimated marginal means)

Species	Unadjusted means		Marginal means	
	P(Inv)	SE	***P***(Inv)	SE
Euaresta bullans	0.11	0.03	0.07	0.02
Bactrocera oleae	0.18	0.03	0.13	0.02
Zeugodacus cucurbitae	0.13	0.03	0.09	0.02
Bactrocera dorsalis	0.25	0.03	0.19	0.03
Ceratitis capitata	0.38	0.04	0.30	0.05

DISCUSSION

The family Tephritidae is one of the groups of insects with the greatest impact on agriculture and thus of high biosecurity concern (White and Elson-Harris 1992; Qin et al. 2015). The genera containing the most species that have established outside of their native range are ***Anastrepha,*** ***Bactrocera*** and ***Rhagoletis*** (Table 2). Along with ***Ceratitis***, these three genera include some of the most destructive pests to global production of fresh fruit and vegetables (White and Elson-Harris 1992; Malacrida et al. 2007). Historical records show that the majority of non-native tephritids have established in only one or two countries and there are only five species (***B. dorsalis, B. oleae, C. capitata, Euaresta bullans*** and ***Zeugodacus cucurbitae***) that have invaded over 20 countries (Figure 1A). Tephritids are found in almost all fruit growing areas of the world (White and Elson-Harris 1992). While the native ranges of the most damaging non-native pests within this group are mostly concentrated in tropical and subtropical climatic zones (Papadopoulos 2014), many of these species have invaded more varied climatic regions (Figure 3,4); for example, the two pest species ***Ceratitis capitata*** and ***Bactrocera oleae*** are native to the Afrotropics, but the non-native ranges of these species are more widely distributed, including temperate and continental regions (Duyck et al. 2004; Ekesi et al. 2009). Several studies also predict further expansion of fruit fly invasions to temperate and continental habitats, which will be increasingly suitable for tropical species as a result of climate change (e.g., Stephens et al. 2007; Ponti et al. 2009; Gutierrez et al. 2010). Furthermore, it is not unusual for species to expand or shift their climatic niche in invaded territories (Guisan et al. 2014; Hill et al. 2017) and this may explain why the number of occurrences in each Koppen-Geiger classification differ between native and non-native ranges (Figure 3).

Numbers of non-native Tephritidae vary considerably among the world regions. The Indo-Malaya region has the lowest number of established non-native species (Table 3) even though

371 there are many species native to the region (it is the second largest source of invading species)
372 including half of the non-native ***Bactrocera*** spp. The Nearctic region is the second most invaded
373 region, mainly by ***Anastrepha*** spp. originating from the Neotropic region and ***Rhagoletis*** spp. from
374 the European Palearctic. Very strong historical trade connectivity and the high climatic similarity
375 between the Nearctic and European Palearctic regions partly explains the high number of invasions
376 among these regions with ***Rhagoletis*** spp. successfully invading from one region to another and
377 vice versa (Tables 2, 3).

378 Despite its relatively low total land area, Oceania (especially the Hawaiian Islands) has been
379 invaded by a large number of Tephritidae species, and these species have originated from all world
380 regions. Favorable climatic conditions in the Oceanic islands, together with an abundance of
381 cultivated non-native tropical fruit species has facilitated numerous Tephritid invasions (Jang
382 2007).

383 Historically, the first documented Tephritidae invasions date back to the early 19th century with
384 ***Ceratitis capitata*** establishing in Madeira (Portugal) and the Azores (Spain) (Fimiani 1989). These
385 invasions most likely resulted from movement of contaminated fruit among countries. Several
386 more, mostly European and Mediterranean countries, were then invaded by this species prior to its
387 discovery in Australia in 1896 (Permkam and Hancock 1995). The number of fruit fly invasions
388 accelerated as a result of increasing global movement of humans and international trade in
389 agricultural commodities (Figure 1B). Several major invasions were discovered during the early
390 20th century, including the introduction of ***Ceratitis capitata*** and ***Zeugodacus cucurbitae*** to Hawaii
391 between 1902-1907, ***C. capitata*** to Brazil in 1901 and ***Anastrepha curvicauda*** to Florida, USA in
392 1905. The number of documented invasions spiked between the two world wars (1930-1940)
393 (Figure 1B). Dramatic increases in global trade as a result of the free trade movement following

394 the Second World War, as well as the burgeoning intercontinental air passenger transport network,
395 presumably facilitated further increases in new invasions (Early et al. 2016; Paini et al. 2016). In
396 addition, there are increasingly well-documented recent invasions and interceptions of various
397 tephritid species globally despite major efforts to control their movement (Hill and Terblanche
398 2014; Papadopoulos 2014).

399 International movement of plant parts, particularly fruit, is considered the dominant pathway
400 by which Tephritidae have been accidentally introduced around the world (Gould 1995; Kiritani
401 and Yamamura 2003; Kendra et al. 2007). Fruit is moved internationally both in commercial
402 shipments but also by international air passengers. While early Tephritidae invasions may have
403 resulted from commercial shipments of contaminated fruit, modern biosecurity policies impose
404 bans on fruit imports from certain regions or require preclearance inspection in the country of
405 origin or phytosanitary treatments (fumigation, cold treatments, etc.) that greatly reduce
406 introduction risk (Hennessey et al. 2013; Peterson et al. 2013). Consequently, during the post-
407 World War II era the pathway of increasing dominance for Tephritid invasions has been movement
408 of immature life stages in fruit carried by airline passengers (Satoh et al. 1985; Liebhold et al.
409 2006; Ma et al. 2012; Papadopoulos 2014). Thus, it seems likely that the rapid acceleration of
410 invasions from 1950 onward (Figure 1B) can be attributed to the expansion of commercial air
411 passenger travel over the last 6 decades (Matsumoto 2007).

412 Successful invasion and establishment outside the natural range is a complex process influenced
413 by characteristics of the environment that affect habitat invasibility, but also external processes
414 related to propagule pressure (Simberloff 2009). For most insects, critical factors that influence
415 habitat invasibility include climatic suitability and the availability of suitable hosts (Ward and
416 Masters 2007; Bacon et al. 2014). Our analysis revealed that climate suitability is a key predictor

417 of historical Tephritid invasions (Table 4). Hill et al. (2016) used climate suitability as a
418 prerequisite for predicting future Tephritid invasions, however they pointed out that propagule
419 pressure and host availability are also critical to invasion success (Ward and Masters 2007; Bacon
420 et al. 2014). We included national fruit production as another candidate explanatory variable with
421 the expectation that it reflects Tephritid host availability in the receiving country, however it did
422 not enter as a significant factor predicting probabilities of invasion. This lack of prediction may
423 reflect the fact that commercial fruit plantations are not the only resource facilitating Tephritid
424 establishments; natural stands of native plant species and plantings of native or introduced fruit
425 trees in residential settings may also provide crucial habitat for nascent populations (Shimizu et al.
426 2007; Leblanc et al. 2014).

427 In order to capture the effect of propagule pressure as a driver of historical tephritid invasions
428 we included as explanatory variables, human population, gross domestic product, number of air
429 passengers, total cumulative imports and distance to native range (Table 1). Of these, only GDP
430 and distance to native range significantly contributed to explaining invasion probabilities in our
431 final model (Table 4). However, all of these variables were positively associated with invasion
432 incidence when fit individually (Figure S5.2B). Invasions of many types of organisms are often
433 related to human population size (Cadotte et al. 2017; Ward et al. 2019). Urbanization may be
434 closely related to propagule pressure associated with general movement of humans and their goods
435 but also with invasibility related to disturbance and habitat modification. The latter is likely
436 important in the case of tephrititd resource availability in residential gardens as described above.
437 Countries with less-developed economies typically have weaker biosecurity programs (Early et al.
438 2016) and this could increase invasion probabilities. Such an effect would act opposite of the
439 positive effect of GDP described above and possibly mask a stronger impact.

The negative effect of distance to the native range on invasion probability (Table 4) probably reflects higher levels of trade and travel from nearby countries along with natural diffusive spread. The absence of fruit imports from our final model may initially seem perplexing. However, fruit imports was a highly significant predictor when fit alone, but not as strongly correlated with invasion incidence as GDP (Figure S5.2C). Fruit imports likely represent a small, variable fraction of total imports and as discussed earlier, may no longer represent the dominant pathway by which tephritids are introduced. Unfortunately, data on cumulative fruit imports dating back to the early 1800's were not available which would have allowed more critical testing of this pathway. Furthermore, we only considered imports from native ranges whereas new invasions often originate from previously invaded regions, a phenomenon described as the "bridgehead effect" (Bertelsmeier and Keller 2018). Indeed, for widespread non-native tephritids, such as ***Ceratitis capitata,*** most new invasions may not originate from the native range (Karsten et al. 2015).

Despite the implementation of intense biosecurity efforts designed to prevent new tephritid invasions in many countries (including extensive surveillance and eradication programs, Figure 2) (Suckling et al. 2016), it can be anticipated that more invasions will continue in the future. Probably most species have not yet invaded all areas that contain suitable hosts and are climatically suitable, especially under a changing climate (Vera et al. 2002; Stephens et al. 2007). Though Figure 1B suggests a drastic decrease in numbers of new invasions since 2010, this may be an artifact of the typical delay in reporting (Smith et al. 2018). As is the case for most invading species, there is likely a considerable "invasion debt" of Tephritidae, i.e., species may have established that have not yet been discovered (Essl 2010, MacLachlan et al. 2021). Furthermore, it is probable that many of the species that so far have only invaded relatively small areas (Figure 1A) may continue to expand into much larger areas in the future.

ACKNOWLEDGEMENTS

We thank Michaela Skřivanová for technical assistance. This work was supported by grant EVA4.0, No. CZ.02.1.01/0.0/0.0/16_019/0000803 financed by OP RDE and by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1639145. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by USDA. USDA is an equal opportunity provider and employer.

REFERENCES

Bacon SJ, Aebi A, Calanca P, Bacher S (2014) Quarantine arthropod invasions in Europe: The role of climate, hosts and propagule pressure. Divers Distrib 20(1):84–94. https://doi.org/10.1111/ddi.12149

Bates DM, Mächler M, Bolker B, Walker S (2014) Fitting linear mixed-effects models using lme4. ArXiv e-prints. a&rXiv:1406. 10.18637/jss.v067.i01.

Bertelsmeier C, Keller L (2018) Bridgehead Effects and Role of Adaptive Evolution in Invasive Populations. Trends Ecol Evol 33(7):527–534. https://doi.org/10.1016/j.tree.2018.04.014

Bess HA, Haramoto FH (1972) Biological control of Pamakani, ***Eupatorium adenophorum***, in Hawaii by a tephritid gall fly, ***Procecidochares utilis***. 3. Status of the weed, fly and parasites of the fly in 1966–71 versus 1950–57. Proc Hawaii Entomol Soc 21(2):165–178.

Cadotte MW, Yasui SLE, Livingstone S, MacIvor JS (2017) Are urban systems beneficial, detrimental, or indifferent for biological invasion? Biol Invasions 19(12):3489–3503. https://doi.org/10.1007/s10530-017-1586-y

Carey JR (1991) Establishment of the Mediterranean fruit fly in California. Science 253(5026):1369-1373. https://doi.org/10.1126/science.1896848

Carey JR, Yang P, Foote D (1988) Demographic analysis of insect reproductive levels, patterns and heterogeneity: case study of laboratory strains of three Hawaiian tephritids. Entomol Exp Appl 46(1):85–91.

CoFFHI (2020) USDA Compendium of fruit fly host information (CoFFHI)**.** Edition 4.0, https://coffhi.cphst.org/.

Courtney GW, Pape T, Skevington JH, Sinclair BJ (2009) Biodiversity of Diptera. In: Adler PH, Foottit RG (eds) Insect biodiversity: Science and society. Wiley–Blackwell, pp 185–222.

494 Duyck P, David P, Quilici S (2004) A review of relationships between interspecific competition
495 and invasions in fruit flies (Diptera: Tephritidae). Ecol Entomol 29(5):511–520.
496 https://doi.org/10.1111/j.0307-6946.2004.00638.x
497 Early R, Bradley BA, Dukes JS et al (2016) Global threats from invasive alien species in the
498 twenty-first century and national response capacities. Nat Commun 7:12485. https://doi.org/
499 10.1038/ncomms12485
500 Ekesi S, Billah MK, Nderitu PW, Lux SA, Rwomushana I (2009) Evidence for competitive
501 displacement of ***Ceratitis cosyra*** by the invasive Fruit Fly ***Bactrocera invadens*** (Diptera:
502 Tephritidae) on mango and mechanisms contributing to the displacement. J Econ Entomol
503 102(3):981–991. https://doi.org/10.1603/029.102.0317
504 EPPO (2014) PQR database. Paris, France: European and Mediterranean Plant Protection
505 Organization. http://www.eppo.int/DATABASES/pqr/pqr.htm.
506 EPPO (2020) EPPO Global database. In: EPPO Global database, Paris, France: EPPO.
507 https://gd.eppo.int/.
508 Essl F, Dullinger S, Rabitsch W et al (2010) Socioeconomic legacy yields an invasion debt. Proc
509 Natl Acad Sci USA 108(1):203–207. https://doi.org/10.1073/pnas.1011728108
510 Federal Reserve Bank of Minneapolis (2018) Consumer Price Index (Estimate) 1800. Retrieved
511 November 18, 2020, from https://www.minneapolisfed.org/community/financial-and-
512 economic-education/cpi-calculator-information/consumer-price-index-1800.
513 Fimiani P (1989) Pest status: Mediterranean region. In: Robinson AS, Hooper G (eds) Fruit flies:
514 Their Biology, natural enemies and control, Volume 3A, World crop pests. Elsevier,
515 Amsterdam, The Netherlands, pp 37–50.

516 Foote RH, Blanc, FL, Norrbom A (1993) Handbook of the fruit flies (Diptera: Tephritidae) of
517 America north of Mexico. Cornell University Press.
518 Fouquin M, Hugot J (2017) Two centuries of bilateral trade and gravity data: 1827-2014. CEPII
519 Working Paper, CEPII.
520 GBIF Secretariat (2021). GBIF backbone taxonomy. Checklist dataset.
521 https://doi.org/10.15468/39omei
522 Gould WP (1995) Probability of detecting Caribbean fruit fly (Diptera: Tephritidae) infestations
523 by fruit dissection. Fla Entomol 78(3):502.
524 Guisan A, Petitpierre B, Broennimann O, Daehler C, Kueffer C (2014) Unifying niche shift
525 studies: Insights from biological invasions. Trends Ecol Evol 29(5):260–269.
526 https://doi.org/10.1016/j.tree.2014.02.009
527 Gutierrez AP, Ponti L, Gilioli G (2010) Climate change effects on plant-pest-natural enemy
528 interactions. In: Hillel D, Rosenzweig C (eds) Handbook of climate change and
529 agroecosystems, Imperial College Press, pp 209–237.
530 Gutierrez AP, Ponti L, Gilioli G (2014) Comments on the concept of ultra-low, cryptic tropical
531 fruit fly populations. Proc Royal Soc B 281(1782):20132825.
532 https://doi.org/10.1098/rspb.2013.2825
533 Hennessey MK, Jeffers L, Nendick, D et al (2013) Phytosanitary Treatments. The Handbook of
534 Plant Biosecurity. Springer Netherlands.
535 Hill MP, Terblanche JS (2014) Niche overlap of congeneric invaders supports a single-species
536 hypothesis and provides insight into future invasion risk: Implications for global management
537 of the ***Bactrocera dorsalis*** Complex. PLoS ONE 9(2):e90121.
538 https://doi.org/10.1371/journal.pone.0090121

539 Hill MP, Bertelsmeier C, Clusella–Trullas S, Garnas J, Robertson MP, Terblanche JS (2016)
540 Predicted decrease in global climate suitability masks regional complexity of invasive fruit fly
541 species response to climate change. Biol Invasions 18(4):1105–1119.
542 https://doi.org/10.1007/s10530-016-1078-5
543 Hill MP, Gallardo B, Terblanche JS (2017) A global assessment of climatic niche shifts and
544 human influence in insect invasions. Glob Ecol Biogeogr 26:679–689.
545 https://doi.org/10.1111/geb.12578
546 Jang, E. B. (2007). Fruit flies and their impact on agriculture in Hawaii. Proc Hawaii Entomol
547 Soc 39:117–119.
548 Karsten M, Jansen van Vuuren B, Addison P, Terblanche JS (2015) Deconstructing
549 intercontinental invasion pathway hypotheses of the Mediterranean fruit fly (***Ceratitis***
550 ***capitata***) using a Bayesian inference approach: are port interceptions and quarantine protocols
551 successfully preventing new invasions? Divers Distrib 21(7):813–825.
552 https://doi.org/10.1111/ddi.12333
553 Kean JM, Suckling DM, Sullivan NJ et al (2021) Global eradication and response database.
554 http://b3.net.nz/gerda.
555 Kendra PE, Hennessey MK, Montgomery WS, Jones EM, Epsky ND (2007) Residential
556 composting of infested fruit: a potential pathway for spread of ***Anastrepha*** fruit flies (Diptera:
557 Tephritidae). Fla Entomol 90(2):314–320. https://doi.org/10.1653/0015-
558 4040(2007)90[314:RCOIFA]2.0.CO;2
559 Kiritani K, Yamamura K (2003) Exotic insects and their pathways for invasion. In: Ruiz GM,
560 Carlton JT (eds) Invasive species: vectors and management strategies. Island Press,
561 Washington, DC, pp 44–67

562 Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen–Geiger
563 climate classification updated. Meteorol Zeitschrift 15(3):259–263.
564 https://doi.org/10.1127/0941-2948/2006/0130
565 Leblanc L, Graham S, McNeil S, Pohlman K, Dinneen M, Fujita B (2014) Abundance and
566 seasonal occurrence of pest fruit flies (Diptera: Tephritidae) in residential and rural areas of
567 Oahu (Hawaiian Islands). Proc ***Hawaii*** Entomol Soc 46:9–24.
568 Lenth R (2020) emmeans: Estimated Marginal Means, aka Least-Squares Means. R package
569 version 1.5.0-5. https://github.com/rvlenth/emmeans.
570 Li Z, Jiang F, Ma X, Fang Y, Sun Z, Qin Y, Wang Q (2013) Review on prevention and control
571 techniques of Tephritidae invasion. ***Plant Quarantine***, 27(2):1–10.
572 Liebhold AM, Work TT, McCullough DG, Cavey JF (2006) Airline baggage as a pathway for
573 alien insect species invading the United States. Am Entomol 52(1):48–54.
574 https://doi.org/10.1093/ae/52.1.48
575 Ma X, Li Z, Ni W, Qu W, Wu J, Wan F, Hu X (2012) The current and future potential
576 geographical distribution of the solanum fruit fly ***Bactrocera latifrons*** (Diptera: Tephritidae)
577 in China. In: Li D, Chen Y (eds) Computer and computing technologies in agriculture V,
578 Springer, Berlin, pp 157–164.
579 MacLachlan MJ, Liebhold AM, Yamanaka T, Springborn MR (2021) Hidden patterns of insect
580 establishment risk revealed from two centuries of alien species discoveries. Sci
581 Adv 7(44):eabj1012. https://doi.org/10.1126/sciadv.abj1012
582 Malacrida AR, Gomulski LM, Bonizzoni M, Bertin S, Gasperi G, Guglielmino CR (2007)
583 Globalization and fruit fly invasion and expansion: the medfly paradigm. Genetica 131(1):1–
584 9. https://doi.org/10.1007/s10709-006-9117-2

585 Matsumoto H (2007) International air network structures and air traffic density of world cities.
586 Transportation Research Part E: Logistics and Transportation Review 43(3):269–282.
587 McInnis DO, Hendrichs J, Shelly T et al (2017) Can polyphagous invasive tephritid pest
588 populations escape detection for years under favorable climatic and host conditions? Am
589 Entomol 63(2):89-99. https://doi.org/10.1093/ae/tmx038
590 Mumford JD (2002) Economic issues related to quarantine in international trade. Eur Rev Agric
591 Econ 29(3):329–348.
592 Norrbom AL, Carroll LE, Thompson FC, White IM, Freidberg A (1999) Systematic database of
593 names. In: Thompson FC (ed) Fruit fly expert identification system and systematic
594 information database. Myia (1998) 9, vii + 524 pp & Diptera Data Dissemination Disk (CD-
595 ROM) (1998) 1, pp 65–251.
596 Paini DR, Sheppard AW, Cook DC, De Barro PJ, Worner SP, Thomas MB (2016) Global threat
597 to agriculture from invasive species. Proc Natl Acad Sci USA 113(27):7575–7579.
598 https://doi.org/10.1073/pnas.1602205113
599 Papadopoulos NT, Plant RE, Carey JR (2013) From trickle to flood: the large-scale, cryptic
600 invasion of California by tropical fruit flies. Proc Royal Soc B 280(1768):20131466.
601 https://doi.org/10.1098/rspb.2013.1466
602 Papadopoulos NT (2014) Fruit fly invasion: historical, biological, economic aspects and
603 management. In: Shelly T et al. (eds), Trapping and the detection, control, and regulation of
604 Tephritid fruit flies, Springer Netherlands, pp 219–252.
605 Permkam S, Hancock DL (1995) Australian Trypetinae (Diptera: Tephritidae). Invertebr Syst
606 9(6):1047–1209.

607 Peterson E, Grant J, Roberts D, Karov V (2013) Evaluating the trade restrictiveness of
608 phytosanitary measures on U.S. fresh fruit and vegetable imports. Am J Agric Econ
609 95(4):842–858. https://doi.org/10.1093/ajae/aat015
610 Phillips C (2013) Living without Fruit Flies: Biosecuring horticulture and its markets.
611 Environ Plan 45(7):1679–1694. https://doi.org/10.1068%2Fa45274
612 Ponti L, Cossu QA, Gutierrez AP (2009) Climate warming effects on the ***Olea europaea***-
613 ***Bactrocera oleae*** system in Mediterranean islands: Sardinia as an example. Glob Change Biol
614 15(12):2874–2884. https://doi.org/10.1111/j.1365-2486.2009.01938.x
615 Qin Y, Paini DR, Wang C, Fang Y, Li Z (2015) Global establishment risk of economically
616 important fruit fly species (Tephritidae). PLoS ONE 10(1):1–8.
617 https://doi.org/10.1371/journal.pone.0116424
618 Quilici S, Donner P (2012) Analysis of Exotic Fruit Fly Trapping Networks. EPPO Bulletin,
619 42(1):102–108.
620 Rindos D (1987) The origins of agriculture: an evolutionary perspective. Academic Press. San
621 Diego.
622 Santini A, Liebhold AM, Migliorini D, Woodward S (2018) Tracing the role of human
623 civilization in the globalization of plant pathogens. The ISME Journal 12(3):647–652.
624 https://doi.org/10.1038/s41396-017-0013-9
625 Satoh I, Yamabe M, Satoh S, Ohki A (1985) Study on the frequency of finding of the fruit flies
626 infesting the fruits imported as air baggage. Research Bulletin of the Plant Protection Service,
627 Japan (21):71-73.
628 Sauer J (1993) Historical geography of crop plants: a select roster. CRC Press. Boca Raton.

629 Shimizu Y, Kohama T, Uesato T, Matsuyama T, Yamagishi M. (2007) Invasion of solanum fruit
630 fly ***Bactrocera latifrons*** (Diptera: Tephritidae) to Yonaguni Island, Okinawa prefecture,
631 Japan. Appl Entomol Zool 42(2):269–275. http://dx.doi.org/10.1303/aez.2007.269
632 Siebert JB, Cooper T (1995) If Medfly Infestation Triggered a Trade Ban: Embargo on
633 California Produce Would Cause Revenue, Job Loss. Calif Agric 49(4):7–12.
634 Simberloff D (2009) The role of propagule pressure in biological invasions. Annu Rev Ecol Evol
635 40, 81–102. https://doi.org/10.1146/annurev.ecolsys.110308.120304
636 Smith RM, Baker RHA, Collins DW et al (2018) Recent trends in non–native, invertebrate, plant
637 pest establishments in Great Britain, Accounting for time lags in reporting. Agric For Entomol
638 20(4):496–504. https://doi.org/10.1111/afe.12282
639 Stephens AEA, Kriticos DJ, Leriche A (2007) The current and future potential geographical
640 distribution of the oriental fruit fly, ***Bactrocera dorsalis*** (Diptera: Tephritidae). Bull Entomol
641 Res 97(4):369–378. https://doi.org/10.1017/S0007485307005044
642 Suckling DM, Kean JM, Stringer LD et al (2016) Eradication of Tephritid fruit fly pest
643 populations: outcomes and prospects. Pest Mana Sci 72(3):456–465.
644 https://doi.org/10.1002/ps.3905
645 Turner CE (1996) Tephritidae in the biological control of weeds. In: McPheron A, Steck GJ
646 (eds) Fruit fly pests: a world assessment of their biology and management, St. Lucie Press,
647 Delray, Florida, pp 157–164.
648 Vargas RI, Walsh WA, Kanehisa D, Stark JD, Nishida T (2000) Comparative demography of
649 three Hawaiian fruit flies (Diptera: Tephritidae) at alternating temperatures. Ann Entomol Soc
650 Am 93(1):75–81. http://dx.doi.org/10.1603/0013-8746(2000)093[0075:CDOTHF]2.0.CO;2

651 Vera MT, Rodriguez R, Segura DF, Cladera JL, Sutherst RW (2002) Potential geographical
652 distribution of the Mediterranean fruit fly, ***Ceratitis capitata*** (Diptera: Tephritidae), with
653 emphasis on Argentina and Australia. Environ Entomol 31(6):1009–1022.
654 https://doi.org/10.1603/0046-225X-31.6.1009
655 Ward NL, Masters GJ (2007) Linking climate change and species invasion: An illustration using
656 insect herbivores. Glob Change Biol 13(8):1605–1615. https://doi.org/10.1111/j.1365-
657 2486.2007.01399.x
658 Ward SF, Fei S, Liebhold AM (2019) Spatial patterns of discovery points and invasion hotspots
659 of non-native forest pests. Glob Ecol Biogeogr 28(12):1749–1762.
660 https://doi.org/10.1111/geb.12988
661 White IM, Clement SL (1987) Systematic notes on ***Urophora*** (Diptera, Tephritidae) species
662 associated with ***Centaurea solstitialis*** (Astreraceae, Cardueae) and other Palaearctic weeds
663 adventive in North America. Proc Entomol Soc Wash 89(3):571–580.
664 White IM, Elson–Harris MM (1992) Fruit flies of economic significance: their identification and
665 bionomics. CAB International. Wallingford.
666 Wu J, Fan L., & Guangqin L. (2009). Atlas of economic fruit flies (Diptera: Tephritidae).
667 Guangdong Scientific and Technological Press. Guangzhou.
668 Zhao Z, Hui C, Plant RE, Su M, Papadopoulos NT, Carpenter TE, Li Z, Carey JR (2019) The
669 failure of success: cyclic recurrences of a globally invasive pest. Ecol Appl 29(8):p.e01991.
670 https://doi.org/10.1002/eap.1991
671

STATEMENTS & DECLARATIONS

Funding

This work was supported by grant EVA4.0, No. CZ.02.1.01/0.0/0.0/16_019/0000803 financed by OP RDE and by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1639145.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Data collection was performed by Jiří Trombik, Allen L. Norrbom and Andrew M. Liebhold. The data analysis was done by Sam Ward and Jiří Trombik. The manuscript was written and edited by all authors. All authors read and approved the final manuscript.

Data Availability

The datasets generated during the current study are available in Supplementary material and can be acquired in digital form from the corresponding author on reasonable request.

Ethics approval

The study did not include research involving human or animal subjects, therefore no ethical approval was required.

Consent to participate

The study did not include research involving human subjects, therefore no consent to participate was needed.

Consent to publish

Manuscript does not contain any individual person’s data in any form, therefore no consent to publish was needed.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- TephritidaeSMJPSfinal.pdf

Doc 24

NATIONAL FRUIT FLY STRATEGY 2020-25

Acknowledgements

The National Fruit Fly Council is funded by Commonwealth and state governments, and by Hort Innovation through the Hort Frontiers Fruit Fly Fund.

Copyright statement

Copyright in this publication is owned by Plant Health Australia, except when content has been provided by other contributors, in which case copyright may be owned by another person. With the exception of any material protected by a trade mark, and except where otherwise indicated, these publications are licensed under a Creative Commons Attribution 3.0 Australia licence. Any use of the publication, other than as authorised under this licence or copyright law, is prohibited.

Attribution

You are free to copy, communicate and adapt the material in this publication, so long as you attribute the Plant Health Australia, and the authors in the following manner:

National Fruit Fly Council (2020) *National Fruit Fly Strategy*, Plant Health Australia
© Plant Health Australia 2020

ISBN 978-0-6482456-1-2

Plant Health Australia
ABN 97 092 607 997
Level 1, 1 Phipps Close
Deakin ACT 2600

Phone 02 6215 7700
Email fruitfly@phau.com.au
preventfruitfly.com.au

Contents

Chair's message 3

Overview 4

The 2020–25 National Fruit Fly Strategy 7

Implementation of the 2020–25 National Fruit Fly Strategy 8

The strategic framework 11

- Vision 11
- Goal 11
- Strategic objectives 11
  - Maintain Australia's freedom from exotic fruit fly 11
  - Minimise the incidence and spread of fruit fly 11
  - Implement national systems that support market access 11
  - Facilitate a cooperative and committed national approach to fruit fly management 11

Priority areas 12

- Market access 13
- Management of established fruit fly 14
- Prevention, preparedness and response 15
- Research 17
- Surveillance 19
- Diagnostics 21
- Communication and engagement 23
- Cooperation 24

Image: Department of Agriculture, Water and the Environment

Image: Rod Turner

Image: Ingrid Roth

Image: Ross Abberfield

Chair's message

When fruit fly is mentioned in horticultural circles, it evokes a wide variety of responses. For some it is just another pest they have to manage, for others it is a relatively new pest that they are adjusting to, and for some it is an absent pest but acknowledged as an important and significant risk to industries. From each of these viewpoints the overriding goal is to ensure that fruit fly does not prevent access to markets. Achieving this requires us to carefully balance differing needs within Australia so that a cohesive, sustainable and robust national fruit fly system can be maintained.

This strategy provides a framework for stakeholders to work within as we manage and enhance the national fruit fly system. Importantly it provides a blueprint for national cooperation as we seek to both prevent and minimise the impacts of fruit fly, as well as to maintain and advance access to domestic and international markets. The issue of sustainable funding is a key challenge going forward and will need serious consideration by governments and industry as they contemplate future-proofing our fruit fly system.

The National Fruit Fly Council is tasked with overseeing the implementation of the strategy however our strength lies in the contribution that every individual and every organisation makes to combating fruit fly in Australia. To this end, I commend the use of this strategic framework in your own planning and execution of fruit fly management, and ongoing engagement with other stakeholders who work in this space.

Lloyd Klumpp

Chair – National Fruit Fly Council
General Manager, Biosecurity Tasmania
Department of Primary Industries, Parks, Water and Environment

Overview

Fruit flies (Family Tephritidae) are major economic pests globally, damaging a wide range of fruit and vegetable crops. They are a key barrier to market access for fruit fly affected industries, which make up about half of Australia's $13 billion horticulture sector.

There are two economically significant fruit fly species present in Australia – Queensland fruit fly (*Bactrocera tryoni*) (Qfly) and Mediterranean fruit fly (*Ceratitis capitata*) (Medfly) – as well as a few minor pest species and a range of non-pest native fruit fly species. A distribution map for Qfly and Medfly in Australia is shown in Figure 1.

As well as managing these established fruit flies, Australia also focuses on ensuring exotic species, including Oriental fruit fly (*Bactrocera dorsalis*) and spotted wing drosophila (*Drosophila suzukii*), do not enter Australia.

Effective management of fruit flies is essential to gaining and maintaining access to premium markets for Australia's horticultural products and relies on cooperation at all levels of government, and between industry bodies, research institutions, regional groups, growers, and community and home gardeners. Given the size of Australia, a one size fits all approach to management will not be effective. Instead, national coordination is required which considers the differing statuses of fruit fly in growing regions, and the diversity of affected crops.

National coordination of fruit fly management is aligned with the broad strategic framework for plant biosecurity, spearheaded by the Intergovernmental Agreement on Biosecurity which cascades into a range of plant specific national strategic plans. These strategies include the National Plant Biosecurity Strategy, National Plant Biosecurity Diagnostic Strategy and the National Plant Biosecurity Surveillance Strategy, and are shown in Figure 2.

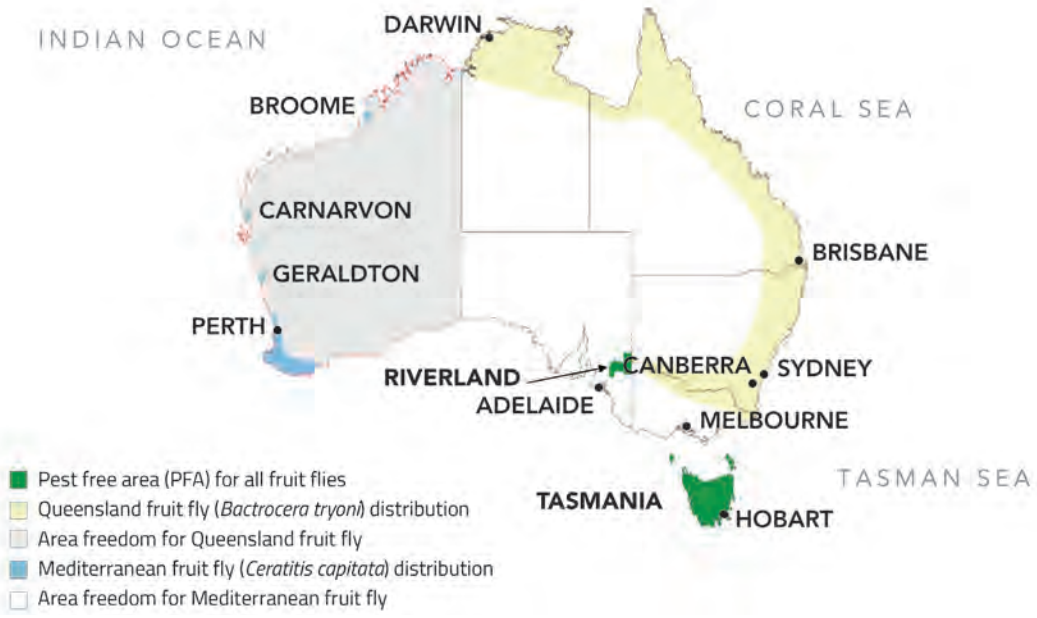


Figure 1. Queensland and Mediterranean fruit fly distribution in Australia.
Image courtesy of Australian Government Department of Agriculture, Water and the Environment

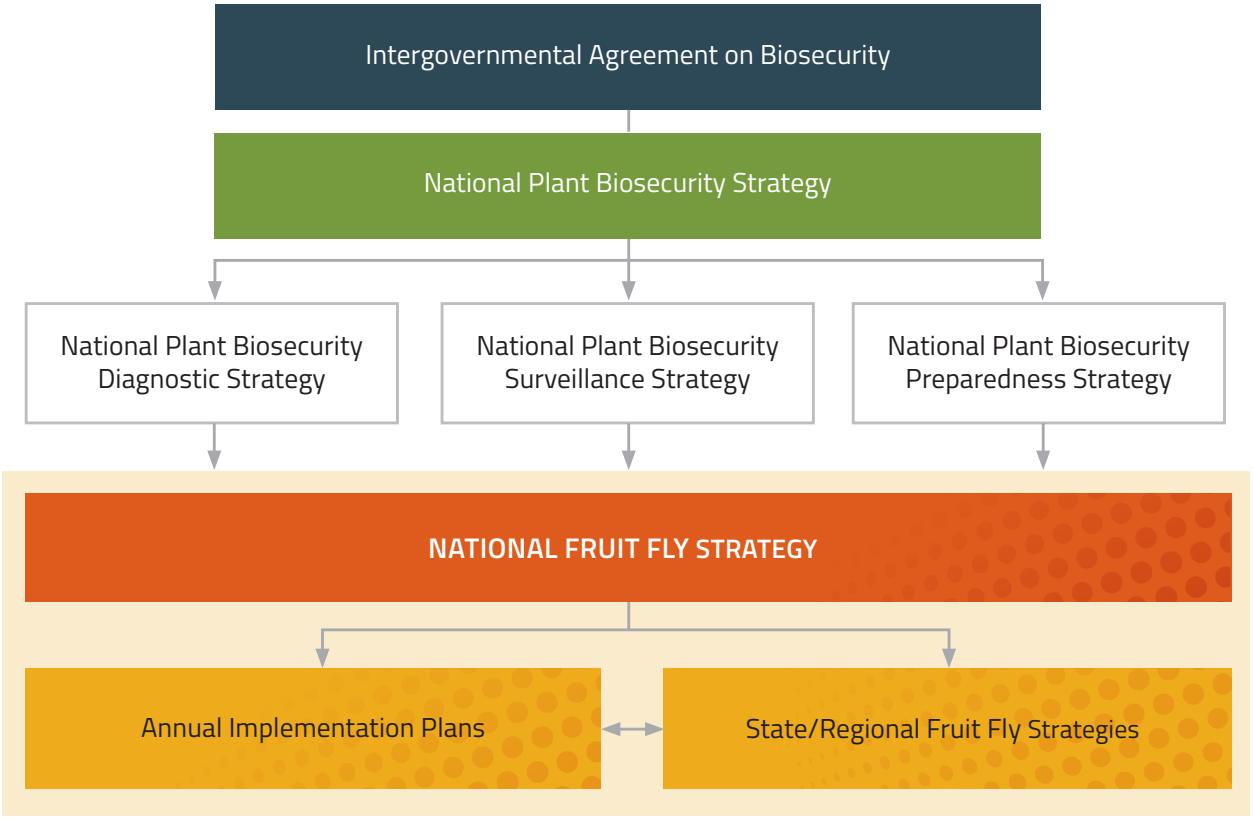


Figure 2. The National Fruit Fly Strategy sits within a broader strategic framework for plant biosecurity which is underpinned by the Intergovernmental Agreement on Biosecurity. This framework provides decision-makers with a blueprint for delivering nationally consistent and coordinated fruit fly activities in Australia.

The 2020–25 National Fruit Fly Strategy

In 2008 the draft National Fruit Fly Strategy was released and for the first time brought together a national approach to fruit fly management in one document. The original objectives of the 2008 strategy remain relevant today: reducing the risk of exotic fruit fly incursion, effective and efficient management of established fruit fly species, and a robust national system to manage risk and underpin market access.

Considerable progress has been made against these objectives since 2008, such as:

- the Emergency Plant Pest Response Deed being used to manage responses to pest incursions and national cost-sharing for the Exotic Fruit Fly in Torres Strait Response Program
- increased volume, integrity and sharing of surveillance data through platforms such as AUSPestCheck™
- development of a new Qfly Sterile Insect Technique (SIT) production facility in South Australia and Hort Innovation funding to conduct a research program to improve the technology
- release of a revised Australian Handbook for the Identification of Fruit Flies and establishment of the Fruit Fly ID Australia website **fruitflyidentification.org.au**
- establishment of the Australian Research Council funded Centre for Fruit Fly Biosecurity Innovation
- support for emerging market access options such as irradiation and systems approaches
- improved access to information on international and domestic market access requirements through the Manual of Importing Country Requirements (MICOR) database and the Australian Interstate Quarantine website **interstatequarantine.org.au**.

At the same time there have been clear challenges to the fruit fly system. This includes ongoing deregistration of chemicals used for in-field and post-harvest treatments, increased demands from trading partners for evidence to support area freedom claims, changing fruit fly distribution patterns, changes to regulation of fruit fly controls in New South Wales and Victoria, and recent outbreaks in pest free areas.

In response to these challenges the Australian Government announced a $16.9 million Smart Fruit Fly Management measure in 2018 for initiatives to improve national harmonisation and coordination. A key component is a fruit fly research and development program that is co-funded by states and territory governments, providing a total of $13 million to address current gaps in research related to market access.

Industry and governments also continue to invest in fruit fly programs, such as the Exotic Fruit Fly in Torres Strait Response Plan, and in other research and development activities, such as Hort Innovation funded area wide management and post-harvest disinfestation research.

A renewed national approach to fruit fly management will help progress:

- the maintenance of resource capability and capacity to manage fruit fly
- an increase in the availability and development of management tools
- the maintenance of existing markets and development of new markets.

The revision of the National Fruit Fly Strategy has been the result of a collaborative effort by Australia's horticultural industries, state and territory governments, the Australian Government, Hort Innovation and various research institutions. Plant Health Australia (PHA) has facilitated and supported its development.

Implementation of the 2020–25 National Fruit Fly Strategy

The purpose of the strategy is to provide a national framework for governments, industry and research funders to advance fruit fly management in Australia. Importantly it is hoped the strategy can help to strengthen coordination of regional or commodity-specific fruit fly plans and their contribution to the national system.

The National Fruit Fly Council is tasked with overseeing the implementation of the National Fruit Fly Strategy 2020–25, while recognising the importance of aligning strategic priorities and coordinating stakeholder input in building a strong national fruit fly system. The National Fruit Fly Council provides strategic advice and leadership on fruit fly policy and RD&E issues to stakeholders including the National Biosecurity Committee, Plant Health Committee, Hort Innovation, industry and the broader community.

While no new funding has been provided for the strategy, annual implementation plans will be used to identify and monitor key activities. These plans will acknowledge the considerable and ongoing contribution by many different stakeholders to fruit fly management in Australia. Regular reporting on progress will also provide an opportunity for the Council to consider potential gaps to be addressed in the national system. Importantly this will be accompanied by an exploration of options to create sustainable funding into the future.

Members of the National Fruit Fly Council outside the Sterile Insect Technology Facility in Port Augusta

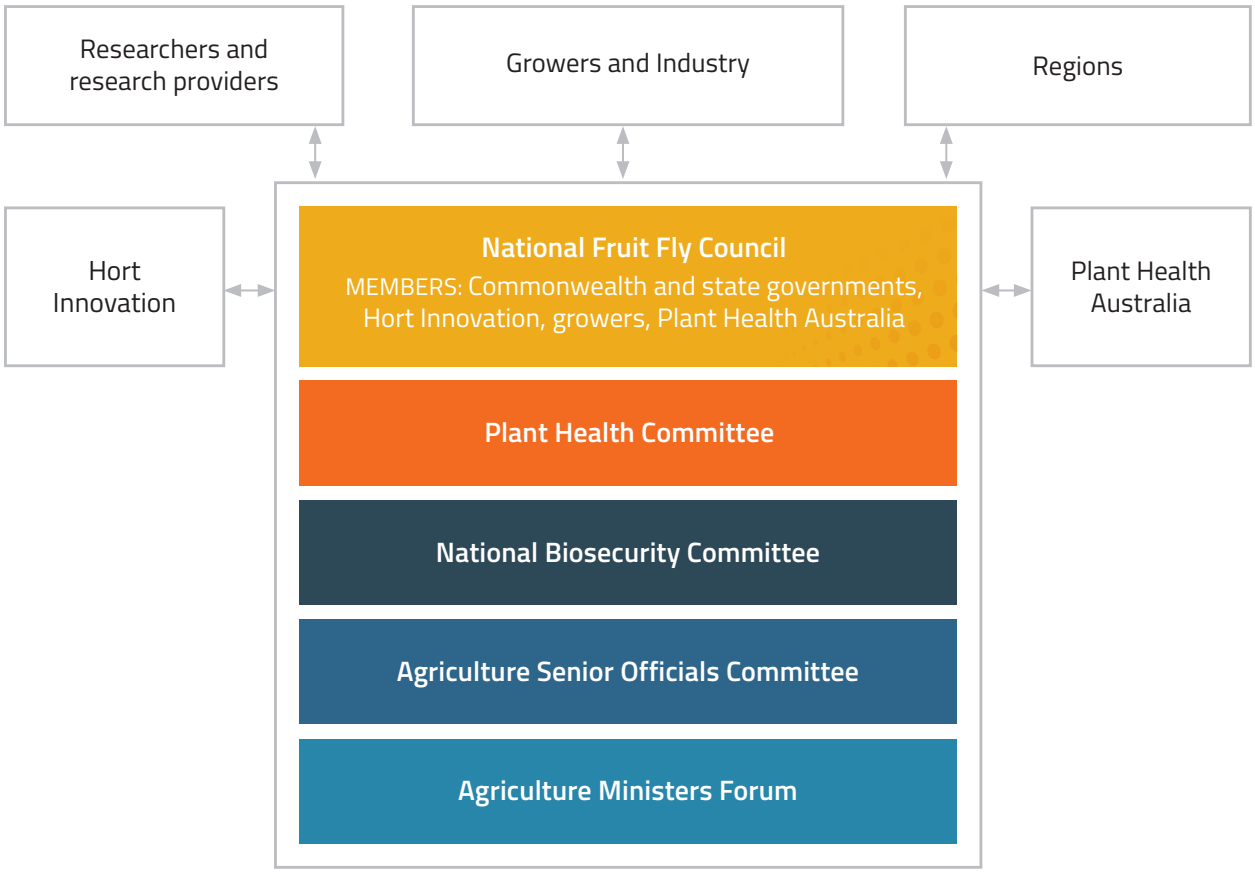


Figure 3. The National Fruit Fly Council is Australia's peak advisory body for fruit fly in Australia. It promotes leadership and coordination of national fruit fly issues through its relationships and communication with stakeholders across the biosecurity spectrum.

Image: APAL flickr

The strategic framework

Vision

Australia has a robust fruit fly management system that supports growth in horticultural production, market access and trade.

Goal

Australia will have a contemporary, viable, cost-effective and coordinated national approach to fruit fly management, with stakeholders committed to the national strategy.

Strategic objectives

MAINTAIN AUSTRALIA'S FREEDOM FROM EXOTIC FRUIT FLY

Maintaining freedom from exotic fruit flies is important to the sustainability of Australia's horticultural industries.

Key Performance Indicator: *Incursion(s) of exotic fruit fly in Australia are detected early and eradicated.*

MINIMISE THE INCIDENCE AND SPREAD OF FRUIT FLY

Improving the management and suppression of established fruit fly species and preventing their further spread will help support productivity, reduce management costs, and enable trade and market access opportunities through low pest prevalence and pest free areas.

Key Performance Indicator: *Domestic and international recognition of fruit fly pest free areas is retained or increased.*

IMPLEMENT NATIONAL SYSTEMS THAT SUPPORT MARKET ACCESS

Being able to provide markets (domestic and international) confidence in our fruit fly system will ensure Australian growers can capitalise on our reputation for high quality produce.

Key Performance Indicator: *No critical non-conformance in the national fruit fly assurance system.*

FACILITATE A COOPERATIVE AND COMMITTED NATIONAL APPROACH TO FRUIT FLY MANAGEMENT

Cooperation of governments, industries and communities, who operate in different fruit fly management areas, is vital to the success of the fruit fly system.

Key Performance Indicator: *Consistency between the strategy and strategic fruit fly objectives of governments, industries and communities.*

Priority areas

Eight different, yet interdependent, priority areas have been identified for the strategy.

1

Market access

Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures, is legally enforceable and technically justified.

2

Management of established fruit fly

Build and promote efficient and effective methods to manage established fruit fly species, to reduce the impact on production and facilitate access to sensitive markets.

3

Prevention, preparedness and response

Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

4

Research

Maintain and enhance fruit fly research capability, capacity and resources, pursuing research and extension that focuses on nationally agreed priorities.

5

Surveillance

Ensure a nationally consistent surveillance framework that provides clarity around fruit fly distribution, prevalence and control.

6

Diagnostics

Maintain and enhance rapid diagnostic capability and capacity, to support responses to incursions or outbreaks and to confirm area freedom.

7

Communication and Engagement

Adopt systems and mechanisms for the efficient and effective communication, training, extension and uptake of fruit fly information across a broad range of audiences.

8

Cooperation

Maintain and enhance engagement processes that serve to coordinate, progress and improve fruit fly management systems.

Market access

1 Develop a framework of policy, legislation and operations that enables market access with the least trade restrictive measures, is legally enforceable and technically justified.

Australia has strong domestic and international biosecurity systems that are vital for supporting market access for fruit fly affected industries. These systems need to reflect internationally accepted standards and protocols, uphold risk management principles, and be transparent and scientifically robust in order to maintain confidence among domestic and international trading partners. To achieve this, it is important that fruit fly policy, legislation and operations meet market access needs and are continuously improved.

This priority area will be achieved through activities that include:

1. Championing approaches that underpin market access, such as alignment with international standards and adherence to phytosanitary regimes along the supply chain.
2. Focusing research and development to deliver market access goals that are technically justified.
3. Negotiating international market access protocols that recognise the range of Australia's differing fruit fly statuses and provide different, workable and economical options to producers.
4. Monitoring the integrity of the fruit fly system to provide national assurance of the effectiveness of management measures.
5. Harmonising and refining interstate measures, regulations and certification systems, consistent with Australia's international trade requirements.

Mangoes being packed
Image: Matt Weinert, QDAF

Management of established fruit fly

2 Build and promote efficient and effective methods to manage established fruit fly species, to reduce the impact on production and to facilitate access to sensitive markets.

Better understanding of established fruit flies helps to improve the effectiveness of control methods and tools. It is important that growers have a range of management and disinfestation options to control fruit fly and maintain or gain access to markets. These options must be economical and be underpinned by evidence and confidence in supporting assurance systems.

This priority area will be achieved through activities that include:

1. Improving understanding of the physiological, behavioural and ecological processes relating to a wide range of fruit fly species, particularly for Qfly and Medfly.
2. Establishing in-field control measures that reduce abundance of fruit fly and improve crop protection, whether based on existing chemicals, new chemicals, or alternative strategies such as SIT.
3. Supporting initiatives that seek to improve area wide management of fruit fly.
4. Assessing the feasibility, practicality and cost-effectiveness of eradicating Medfly from Australia.
5. Implementing changes to current or future fruit fly control measures to help manage the impact of climate change on the potential distribution and abundance of fruit fly species in Australia.

Mediterranean fruit fly, *Ceratitis capitata*

Prevention, preparedness and response

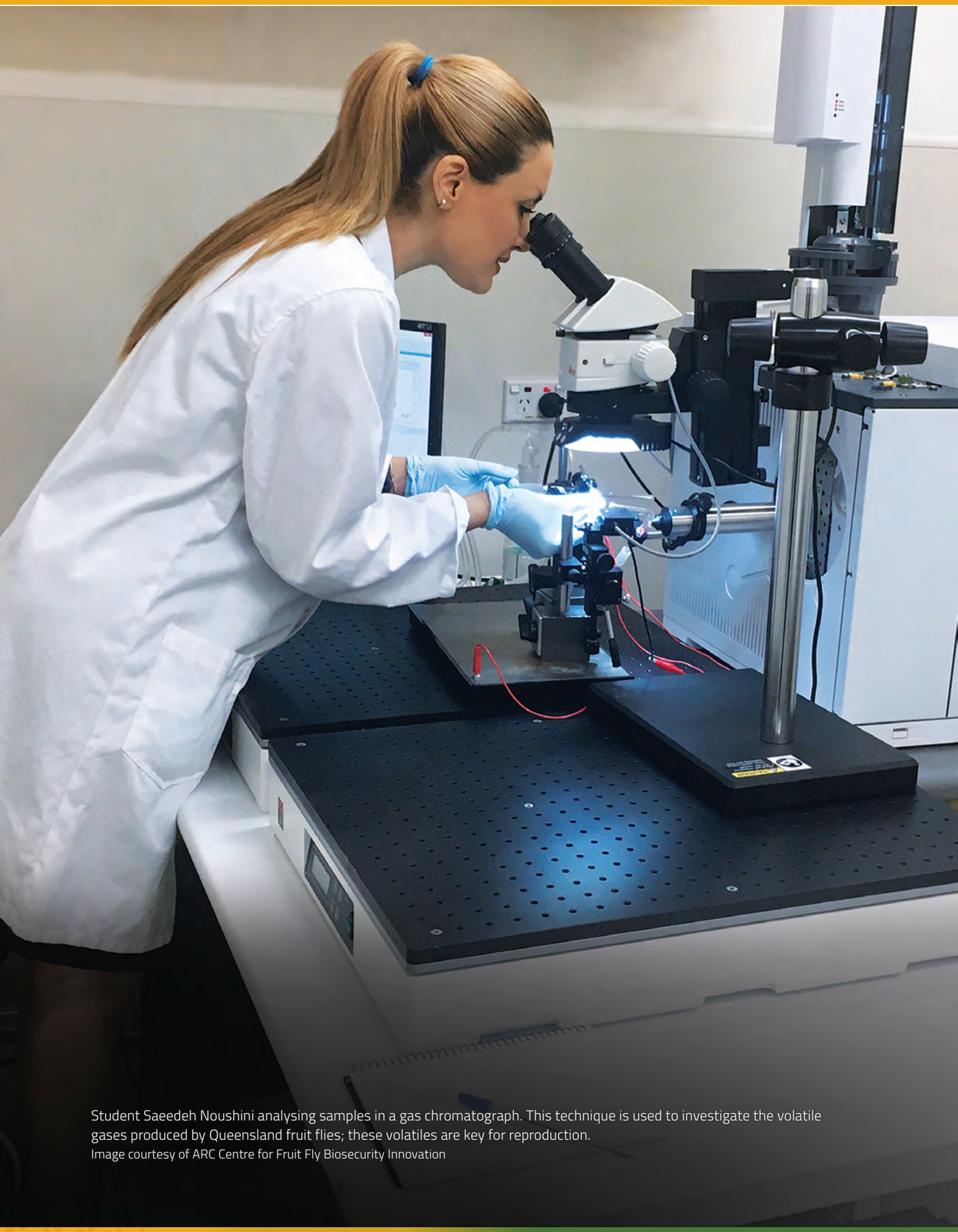
3 Continue to support the development and resourcing of prevention, preparedness and response measures for incursions or outbreaks.

Australia works hard to maintain freedom from exotic fruit flies and to minimise the spread of established fruit flies into pest free areas. Understanding fruit fly characteristics and risk pathways can help in the design of detection and control measures to manage incursions and prevent fruit fly spread. Governments, industries and communities also have a role to play in taking steps to prepare for potential risks, including planning for fruit fly eradication and for business continuity. There are high returns on investment for prevention and preparedness activities and these remain a priority for Australia's fruit fly management system.

This priority area will be achieved through activities that include:

1. Maintaining and monitoring market access requirements and pre-border and border mechanisms that serve to prevent the entry of exotic fruit flies.
2. Supporting efforts to reduce the overall occurrence of, and prevent the spread of, established fruit flies into pest free areas in Australia.
3. Promoting intelligence collection and analysis to help inform fruit fly management, prevention and preparedness activities.
4. Supporting contingency planning as a vehicle for linking industry preparedness with national fruit fly management and response strategies.
5. Promoting the responsibilities of communities and industries, along the whole supply chain, in preventing fruit fly spread and preparing for fruit fly incursions or outbreaks.
6. Ensuring enough capacity and capability is available to deliver timely, effective and coordinated controls for emergency responses to exotic incursions and outbreaks of established fruit flies in pest free areas.

A NAQS ranger checks a trap for exotic fruit flies. Early detection through the Response Plan for Exotic Fruit Fly in Torres Strait is vital to the prevention of incursions in mainland Australia.
Image: Department of Agriculture, Water and the Environment



Student Saeedeh Noushini analysing samples in a gas chromatograph. This technique is used to investigate the volatile gases produced by Queensland fruit flies; these volatiles are key for reproduction.
Image courtesy of ARC Centre for Fruit Fly Biosecurity Innovation

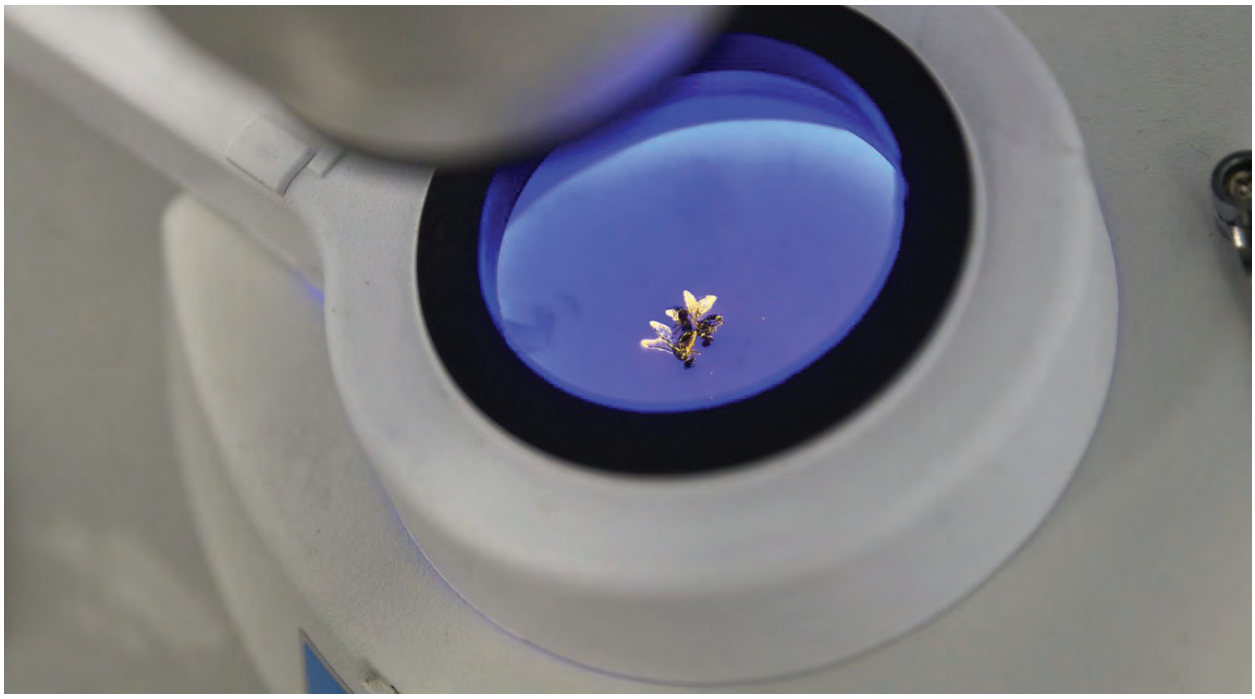
Research

4 Maintain and enhance fruit fly research capability, capacity and resources, pursuing research and extension that focus on nationally agreed priorities.

Research, development and extension activities underpin all elements of fruit fly management, including operations, legislation, regulation, market access, biosecurity and improvements in management practices. Research provides technically justifiable approaches and innovative solutions to enable market access and sustainable production. It is essential that capability and capacity is maintained, and that research, development and extension is prioritised, coordinated and strengthened through national and international research linkages.

This priority area will be achieved through activities that include:

1. Promoting long-term, coordinated investment in research that aligns with national strategic priorities.
2. Fostering strong partnerships between regulators, research funders, researchers, industry and end-users to identify and support both immediate and anticipated research needs.
3. Encouraging exchanges, linkages and cooperation among different research sectors to minimise research duplication and maximise the benefits of a collaboration.
4. Fostering scientific and technical skills, expertise and knowledge available for research and development.
5. Sharing research and development outputs with end-users and integrating learnings into government and industry practices.



Queensland fruit fly under a UV light showing the fluorescent dye used to help differentiate trapped farmed (sterile) flies from wild flies in the field.

Image: Primary Industries and Regions South Australia

Irymple Girl Guides delivering fruit fly traps as part of a mass trap distribution program within the Sunraysia region of Victoria
Image courtesy of Narelle Beattie, Regional Coordinator, Greater Sunraysia Pest Free Area

Surveillance

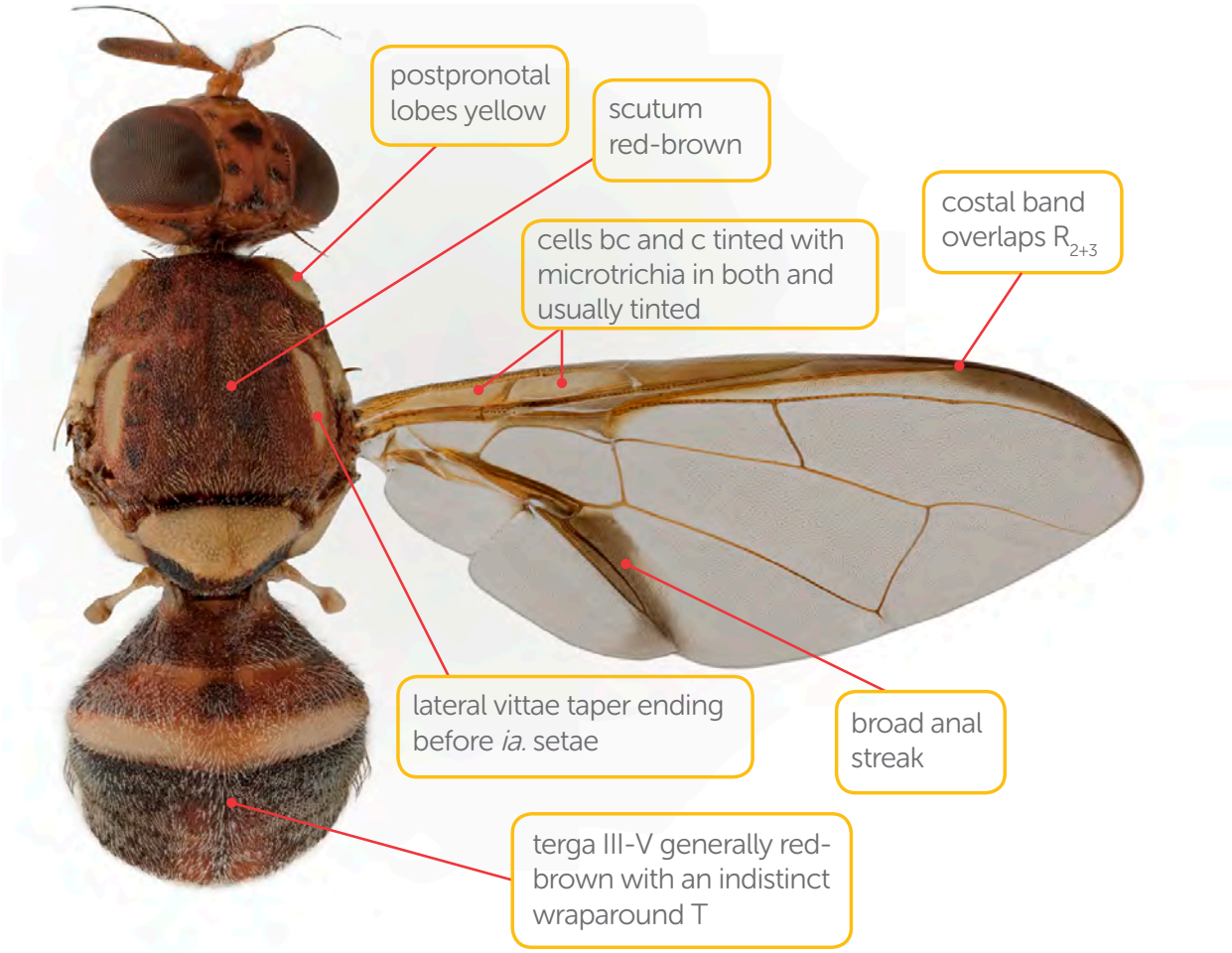
5 Ensure a nationally consistent surveillance framework that provides clarity around fruit fly distribution, prevalence and control.

Surveillance systems provide early detection of fruit flies, deliver information for risk analyses and demonstrate the fruit fly status of an area. They are an integral part of fruit fly management and essential for rapid responses and access to markets. While surveillance must be done in accordance with agreed standards and protocols, it is also increasingly important that it is efficient, effective and able to harness information from both specific (programs to formally demonstrate pest presence or absence) and general (drawn from various government or non-government) sources.

This priority area will be achieved through activities that include:

1. Facilitating a national approach to fruit fly surveillance systems that is based on science, risk analysis, international standards and world's best practice.
2. Regularly reviewing and improving methodologies to maximise the ability to detect exotic species whilst ensuring surveillance systems are managed in a cost-effective manner.
3. Minimising the risk of establishment of exotic fruit flies through contingency planning for eradication.
4. Formalising commitment to the national exotic fruit fly detection system through long-term funding agreements.
5. Developing and promoting the use of sampling and survey data collection methods that are technically justified, and enable information to be collated, analysed and reported.
6. Identifying ways to capture data from the general surveillance network to improve detection capacity.

This is a Lynfield dry trap, which is used by NSW DPI for capturing males of various fruit fly species, including Queensland fruit fly.



Abdominal variation

Lateral thorax

Head

Fore, mid, hind legs

Features of Queensland fruit fly (*Bactrocera tryoni*) morphology used by diagnosticians to identify the pest.
Image reproduced from the Australian Handbook for the Identification of Fruit Fly

Diagnostics

6 Maintain and enhance rapid diagnostic capability and capacity to support responses to incursions or outbreaks and to confirm area freedom.

Accurate and rapid fruit fly identification underpins responsiveness to potential incursions or outbreaks and increases the chance of successful eradication. Tools and materials that enhance the ease and throughput of identification of species complexes are of particular value. Confidence in diagnostic capability across a range of established and exotic fruit fly species is fundamental to providing national assurance of area freedom.

This priority area will be achieved through activities that include:

1. Facilitating a national approach to diagnostic capacity and capability through networks, training, formally recognised protocols and reference materials.
2. Continuing to develop diagnostic platforms and tools that streamline and facilitate identification of fruit flies.
3. Resolving taxonomically problematic species complexes.
4. Developing diagnostic methods to understand genetic relationships and geographic origins of invasive populations to enable identification of high-risk pathways.
5. Promoting the value of diagnostic services to stakeholders, to gain a higher level of investment in essential infrastructure, expertise, and research.

A fruit fly identification workshop was held to ensure that the scientific capacity and capability exists within Australia to identify exotic species of fruit fly, should they make it to Australia.
Image: Plant Health Australia

Stakeholders at the National Fruit Fly Symposium held in Melbourne in 2018.
Image: Plant Health Australia

Communication and engagement

7 Adopt systems and mechanisms for the efficient and effective communication, training, extension and uptake of fruit fly information by a broad range of audiences.

A cohesive fruit fly management system relies on effective sharing and adoption of relevant information. It improves the quality of decision-making and ensures stakeholders at all levels are better equipped to manage fruit fly challenges. Reliable and up-to-date information is also instrumental in maintaining or enhancing industry competitiveness. Improved communication and engagement across fruit fly management systems will help increase the uptake of innovation and creation of shared outcomes. It is also important that information reaches all those who contribute to or benefit from fruit fly management systems, including consumers, wholesalers, retailers, exporters, importers, transport operators and treatment providers.

This priority area will be achieved through activities that include:

1. Developing a communication and engagement strategy for the National Fruit Fly Strategy 2020–25, including roles and responsibilities of stakeholders.
2. Raising awareness of the various processes and components of the national fruit fly system that serve to maintain and gain market access.
3. Promoting the roles and responsibilities of all stakeholders in upholding the integrity of the national fruit fly system.
4. Utilising existing systems to exchange up-to-date information on fruit fly management issues between governments, industries, regions and communities.
5. Encouraging adoption of area wide management approaches, including through applying relevant social research outcomes.

A Mediterranean fruit fly display at the Carnarvon Library in Western Australia, providing information for the community on fruit fly biology, behaviour and homemade control solutions.
Image: WA Department of Primary Industries and Regional Development.

Cooperation

8 Maintain and enhance engagement processes that serve to coordinate, progress and improve fruit fly management systems.

A coordinated national system requires cooperation across disciplines and geographic boundaries towards achieving agreed common goals. Industry, government, researcher and community forums all play a role in raising awareness of fruit fly issues, determining priorities, directing and providing resources and monitoring progress. Collectively these forums represent the national system and are fundamental sources of information and influence which must be connected to one another and be able to serve the national interest.

This priority area will be achieved through activities that include:

1. Strengthening the partnership between the National Fruit Fly Council and regulatory and research decision-makers, including Plant Health Committee, Hort Innovation, peak industry groups and other relevant stakeholders.
2. Improving the two-way flow of information and engagement between governments, industries, researchers and communities to better identify and address fruit fly challenges and opportunities.
3. Building sustainable funding models to support fruit fly management activities that are critical to the national system.
4. Collaborating with stakeholders to prioritise activities and monitor progress against the strategy.
5. Adequately resourcing and empowering the National Fruit Fly Council to monitor and drive implementation of the strategy.

Meeting of local, regional, state and national fruit fly representatives at the Goulburn Murray Valley Fruit Fly Governance Group meeting in Cobram, Victoria, to discuss opportunities to further enhance the coordinated management of the pest.
Image: Plant Health Australia

Image: Ian Bally

Phone 02 6215 7700
Email fruitfly@phau.com.au
preventfruitfly.com.au

PHA 20-005

Government of South Australia
Primary Industries and Regions SA

Minute to
Minister for Primary Industries and Regional Development

MINISTER'S OFFICE
28 DEC 2018
RECEIVED

Ref: A3892389

For	**Approval**
Critical Date	Urgent
Subject	**Zero tolerance approach to fruit fly quarantine restrictions**

Synopsis

Advice is provided on the request from your office to implement a zero tolerance approach in relation to the Yamba Quarantine Station to further protect the fruit fly exclusion zone in the Riverland.

Recommendations

That you:

1. Note the information provided in this briefing.
   NOTED / NOT APPROVED

2. Approve implementation of a zero tolerance approach continuing at random road blocks and in the first instance at the Yamba permanent quarantine station.
   APPROVED / NOT APPROVED

3. Note that implementation at the Yamba station will begin on Friday 4th January, 2019.
   APPROVED / NOT APPROVED

4. Approve removal of signage that conflicts with the zero tolerance approach and that temporary electronic signs are put in place.
   APPROVED / NOT APPROVED

5. Approve communication material that conflicts with the zero tolerance approach being retrieved/revised where possible, new material issued and national media is also targeted to raise awareness of this new policy approach.
   APPROVED / NOT APPROVED

Hon Tim Whetstone MP
Minister for Primary Industries and Regional Development
28 / 12 / 2018

Background

- The South Australian Government implements an annual program to protect South Australia for infestation of fruit fly.
- The Random Roadblock Program operates between September and April each year to supplement controls applied at the four permanent Quarantine Stations at Ceduna, Oodla Wirra, Pinnaroo and Yamba. The main focus has been to educate the travelling public about the danger of fruit fly and prevent host material entering into the Riverland.
- Travellers have historically been directed to declare any fruit or vegetables on arrival at the Quarantine Station or random roadblock. The fruit is confiscated and inspected before being bagged and sent for deep burial.
- The results of the random roadblocks indicate that non-compliance with the prohibition on the entry of host material into the Riverland by the traveling public has plateaued, with between 15% to 20% of travellers being detected with prohibited fruit. Of these the vast majority are detected with much fewer than 10 pieces of fruit.
- Following an outbreak of Q-fly in Loxton in early December, 2018 heightened detection and enforcement activities are underway to protect the fruit fly Pest Free Area in the Riverland.

Discussion

- There are currently a number of sanctions imposed for non-compliance with legislation administered by Biosecurity SA. These include Advisory Letters, Formal Written Warnings, Expiation Notices and Prosecution. All of the above measures are recorded against the alleged offender and provide a sound rationale for any future decisions regarding repeat offenders.
- Your office has advised that given the circumstances of the current Q-fly outbreak, you wish to move to a zero tolerance approach with expiation notices issued for all non-compliant fruit detected. This policy is intended to reinforce the importance of this quarantine measure, change behaviours and any complacency within the community and provide better protection of South Australia's horticulture industry.
- This approach was implemented last weekend at a random roadblock through Bordertown with more than 230 drivers recommended for expiation.
- To enable this policy to be implemented more fully, including at the Yamba permanent quarantine station, the following activities are underway:

Short term	**Status**
Any signage that conflicts with the policy to be removed	To be completed by 28 Dec 2018
Temporary electronic signage erected that, based on DPTI advice, will read: **FRUIT AND VEG PROHIBITED** **FINES APPLY**	To be transported to site and intended to be in place by 28 Dec 2018
Media release and supporting social media relating to Bordertown Random Roadblocks and zero tolerance at Yamba It is recommended that national media is also targeted to raise awareness of this new approach	Scheduled for 28 Dec 2018
All PIRSA website information updated	28 Dec 2018 - 4 Jan 2019

Medium term	
Disposal bins and pull off zones built on the approach to stations and arrangements put in place to ensure bins are emptied regularly	DPTI advises 6 – 8 weeks for approval Construction/road access to be built Expected total timeframe approximately 3 - 4 months
Communication material that conflicts with new policy approach retrieved/revised where possible	Commenced – Further details will be provided by the Communications Unit, 28 Dec 2018 – 4 January 019
New permanent signage to be erected where required	DPTI approval being obtained Installation expected to be 6-8 weeks
New and existing officers recruited and trained to implement the approach and process expiation notices	Ongoing

- It is recommended that implementation of this policy at permanent quarantine stations begin in the first instance at the Yamba roadblock with a start date of 4 January 2019.
- To enable you to inform Cabinet of this change in approach a Cabinet note is being prepared and will be provided for your consideration in early January.

.....

ACTING CHIEF EXECUTIVE
Primary Industries and Regions SA
28 / 12 / 2018

CONTACT	Jo Collins and Will Zacharin
POSITION	Executive Director Agriculture, Food and Wine and Executive Director Biosecurity
DIVISION	Agriculture, Food and Wine / Biosecurity
MOBILE	Clause 6(1) / Clause 6(1)
PREPARED BY	Elena Anear

Government
of South Australia

Cr Neil Martinson
Mayor
Renmark Paringa Council
PO Box 730
RENMARK SA 5341

Dear Mayor, NEIL,

Thank you for the cooperation of the Renmark Paringa Council in providing a works crew at short notice on 28 December 2018 to remove roadside signs on the approach to the Yamba Quarantine Station as part of the Marshall Liberal Government's efforts to protect the Riverland from Queensland Fruit Fly.

My department is currently working with industry to eradicate fruit fly from the Loxton Outbreak Area and we are taking all steps to prevent further fruit fly incursions into the region.

While it is prohibited to bring fruit, vegetables and grape host material into South Australia, motorists entering the state via the Sturt Highway have historically been directed to declare any fruit or vegetables on arrival at the Yamba Quarantine Station where the fruit is confiscated and inspected. Over the last weekend, 285 vehicles were found with more than 500 kilograms of fruit entering the Yamba Quarantine Station. This is an unacceptably high level of fruit being brought into our state.

Similarly, the results of random roadblocks have consistently demonstrated a high level of non-compliance with the prohibition on bringing host material into the Riverland, with between 15 to 20 per cent of travellers being detected with prohibited fruit.

Following the fruit fly outbreak at Loxton, the Government is implementing a 'zero tolerance' approach to motorists caught with illegal fruit at random roadblocks and at the Yamba Quarantine Station. Fines of $375 will apply to motorists found with illegal fruit, with court penalties of up to $100,000 for serious breaches. This new approach is intended to protect our region from fruit fly by driving an improved compliance culture.

Protecting the Riverland from fruit fly is a shared responsibility for the whole community and I appreciate the support of the Renmark Paringa Council in achieving this objective.

Yours sincerely

Hon Tim Whetstone MP
MINISTER FOR PRIMARY INDUSTRIES AND REGIONAL DEVELOPMENT

28 / 12 / 2018

Minister for Primary Industries and Regional Development

Level 10, 1 King William Street Adelaide SA 5000 | GPO Box 1671 Adelaide SA 5001 DX 667
Tel 08 8226 2931| Fax 08 8226 0844| Minister.Whetstone@sa.gov.au