

Marine Ecosystems

Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery in 2024



Roger Kirkwood and Simon Goldsworthy

**SARDI Publication No. F2010/000726-16
SARDI Research Report Series No. 1254**

**SARDI Aquatic and Livestock Sciences
PO Box 120 Henley Beach SA 5022**

June 2025

Report to PIRSA Fisheries and Aquaculture



**Government
of South Australia**

Department of Primary
Industries and Regions



Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery in 2024

Report to PIRSA Fisheries and Aquaculture

Roger Kirkwood and Simon Goldsworthy

**SARDI Publication No. F2010/000726-16
SARDI Research Report Series No. 1254**

June 2025

The South Australian Research and Development Institute respects Aboriginal people as the state's first people and nations. We recognise Aboriginal people as traditional owners and occupants of South Australian land and waters. We pay our respects to Aboriginal cultures and to Elders past, present and emerging.

This publication may be cited as:

Kirkwood, R. and Goldsworthy, S.D. (2025). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery in 2024. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2010/000726-16. SARDI Research Report Series No. 1254. 47pp.

DISCLAIMER

The authors warrant that they have taken all reasonable care in producing this report. The report has been through the SARDI internal review process and has been formally approved for release by the Research Director, Aquatic and Livestock Sciences. Although all reasonable efforts have been made to ensure quality, SARDI does not warrant that the information in this report is free from errors or omissions. SARDI 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. SARDI and its employees expressly disclaim all liability or responsibility to any person using the information or advice. Use of the information and data contained in this report is at the user's sole risk. If users rely on the information, they are responsible for ensuring by independent verification its accuracy, currency or completeness. The SARDI Report Series is an Administrative Report Series which has not been reviewed outside the department and is not considered peer-reviewed literature. Material presented in these Administrative Reports may later be published in formal peer-reviewed scientific literature.


© 2025 SARDI

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968 (Cth)*, no part may be reproduced by any process, electronic or otherwise, without the specific written permission of the copyright owner. Neither may information be stored electronically in any form whatsoever without such permission.

Author(s): Roger Kirkwood and Simon Goldsworthy

Reviewer(s): Jason Earl, Jason Tanner (SARDI) and Annabel Jones (PIRSA)

Approved by: Dr Stephen Mayfield
Program Leader - Fisheries

Signed: 

Date: 23 June 2025

Distribution: PIRSA Fisheries and Aquaculture, SARDI Aquatic and Livestock Sciences, Parliamentary Library, State Library and National Library

Circulation: OFFICIAL

ALL ENQUIRIES

South Australian Research and Development Institute - Aquatic and Livestock Sciences
2 Hamra Avenue West Beach SA 5024
PO Box 120 Henley Beach SA 5022
P: (08) 8207 5400
E: pirsa.sardiaquatics@sa.gov.au
W: <http://www.pir.sa.gov.au/research>

TABLE OF CONTENTS

LIST OF FIGURES	V
LIST OF TABLES.....	VI
ACKNOWLEDGEMENTS	VII
EXECUTIVE SUMMARY	1
1. INTRODUCTION	2
1.1. Background.....	2
1.2. Objectives.....	5
2. METHODS.....	6
3. RESULTS	10
3.1. Fishing effort.....	10
3.2. Observer coverage	10
3.3. Wildlife interaction forms (WIFs)	14
3.4. Dolphin interactions	14
3.5. Fishing behaviour	21
4. DISCUSSION	24
4.1. Observer coverage	24
4.2. Dolphin interactions	25
4.3. Fishing behaviour	26
4.4. Management considerations	26
4.5. Conclusions	30
REFERENCES	31
APPENDIX 1. CODE OF PRACTICE FLOWSHEET	40
APPENDIX 2. OBSERVER DATASHEET	41
APPENDIX 3. WILDLIFE INTERACTION FORM	42
APPENDIX 4. GAM RESULTS	43

LIST OF FIGURES

Figure 1. Spatial management zones for the SASF. For this report, the Outside Zone is split into West Coast and South-East regions (adapted from PIRSA 2000).....	6
Figure 2. Observer coverage of the SASF in 2024, by (a) month and (b) vessel.	12
Figure 3. Gridded density plots ($0.1^\circ \times 0.1^\circ$, equivalent to $\sim 11\text{km}^2$) showing the distribution of SASF net-sets with and without observers present: (a) in 2023 and (b) in 2024. Fishing Zones delineated by black lines, 40m and 100m depth contours in grey.....	13
Figure 4. Time series of (a) estimated number of dolphin encirclement events and (b) dolphins encircled based on rates recorded with and without an observer present, from 2005 to 2024. ...	16
Figure 5. Time series of (a) estimated number of dolphin mortality events, and (b) dolphin mortalities based on rates recorded with and without an observer present, from 2005 to 2024. ...	17
Figure 6. Time series of (a) estimated dolphin mortalities per year in the SASF based on rates recorded with and without an observer present, as 5-year running-means from 2009 to 2024. .	18
Figure 7. Gridded density plot ($0.1^\circ \times 0.1^\circ$, equivalent to $\sim 11\text{km}^2$) of the distribution of SASF net-sets in which dolphin mortalities were recorded, from 2005 to 2024.....	19
Figure 8. Comparison of indices of fishing behaviour with an observer (circles) and without an observer (squares), from 2005 to 2024: (a) net-sets per trip, (b) percentage net-sets with zero catch, (c) sardine catch per net-set (tonnes) including zero-catches and (d) sardine catch per net-set excluding zero-catch net-sets. Dashed line separates less comparable (pre-2011) and more comparable data (rationale provided in methods).....	22
Figure 9. IMOS sea-surface temperature data (blue = $\sim 14\text{-}15^\circ\text{C}$, dark-green = $\sim 17^\circ\text{C}$, red = $\sim 22^\circ\text{C}$) off South Australia, for mid-February to mid-May, 2023 and 2024 (IMOS Ocean Current data available at https://oceancurrent.aodn.org.au/).....	28
Figure 10. Water temperature profiles (30 to 100m depth) from July 2020 to Dec. 2024, measured at the IMOS National Reference Station west of Kangaroo Island (location given by star in top-left panel of Figure 10). White blocks are missing data (figure supplied by SARDI Oceanography).	29

LIST OF TABLES

Table 1. Summary of fishing effort (net-sets), observer coverage, and dolphin encirclement and mortality events, and number of dolphins involved (in brackets) recorded in the South Australian Sardine Fishery (SASF), by calendar year from 2005 to 2024.....	11
Table 2. Frequency by fishing zone of net-sets and observer coverage, in the SASF in 2024. .	13
Table 3. The frequency of delays to net-setting caused by sighting dolphins on the approach, based on observer data, from 2020 to 2024.....	15
Table 4. Frequency and rates of dolphin encirclement events with and without observers present, by fishing zone in 2024.	15
Table 5. Details of dolphin mortalities recorded in 2024.....	18
Table 6. Dolphin mortality events, frequency of occurrence (% net-sets) and numbers of dolphins that died, by fishing zone and observer presence, in all net-sets from 2020 to 2024.	19
Table 7. Probability (p) results from Wilcoxon-tests for similarity, comparing indices of fishing behaviour from net-sets with and without an observer present, annually from 2005 to 2024. The dashed line separates less comparable (pre-2011) and more comparable data (rationale provided in methods). All significant results ($p < 0.05$, in bold) indicate that when an observer was present there were either: more net-sets per trip, less sardine catch per net-set, or more catch per net-set in net-sets when dolphins were encircled.	21

ACKNOWLEDGEMENTS

Production of this report was funded by PIRSA Fisheries and Aquaculture through licence fees levied off commercial vessels in the South Australian Sardine Fishery (SASF). We thank licence holders and their representatives, skippers and crews of the SASF for providing observers with access to vessels and for providing logbook data and Wildlife Interaction Forms. Adam Kemp and observers from Seatec Marine Pty Ltd collected much of the data on which this report is based and did excellent work. A good relationship between skippers and observers is important for a fisheries monitoring program and has been evident in this fishery.

We thank Angelo Tsolos and his team in PIRSA Fisheries and Aquaculture for diligently extracting data from logbooks, observer returns, and Wildlife Interaction Forms, and Annie Sterns for administrative support.

Oceanographic data were sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). Dr Hugo Bastos de Oliveira (SARDI Oceanography) analysed the IMOS data from the Kangaroo Island National Reference Station and prepared Figure 11 of sea temperature profiles over time.

Dr Jason Earl and Dr Jason Tanner (SARDI), and Dr Annabel Jones (PIRSA) reviewed drafts of the report. The report was approved for release by Dr Stephen Mayfield (Program Leader, Fisheries, SARDI Aquatic & Livestock Sciences) and cleared for release by Dr Gretchen Grammer (Acting Research Director, Fisheries, SARDI Aquatic & Livestock Sciences).

EXECUTIVE SUMMARY

This report documents interactions between Common Dolphin (*Delphinus delphis*) and the South Australian Sardine Fishery (SASF) during 2024. A total of 928 net-sets were deployed, with 59% occurring between March and May. As in previous years, the majority of net-sets occurred in the Spencer Gulf Zone (67%), followed by the Outside Zone (22% comprising 14.5% on the west coast of Eyre Peninsula and 7.5% south-east of Kangaroo Island), and the Gulf St Vincent Zone (11%). Observer coverage exceeded the target level of 20%, achieving 21.3%, and was well distributed across months, vessels, and fishing zones.

During 2024, 52 dolphin encirclement events were recorded, involving a total of 142 dolphins, the lowest total recorded since 2007 (then 116 dolphins). Compared to 2023, the 2024 data represent a 41% reduction in encirclement events and a 34% reduction in dolphins encircled. The low level of dolphin encirclements in 2024 may have been influenced by atypical oceanographic conditions, including strong upwelling and persistent cold water along the continental shelf, which could have reduced dolphin presence in fishing grounds. Two dolphin mortality events involving single dolphins were recorded, and both occurred when no observer was present. As no mortalities were recorded in observed net-sets in 2024, the 5-year running mean for annual mortalities based on observer data dropped from 39 per year to 2023 (inflated by a high rate in 2019) to 11 per year up to 2024 (i.e., ~1 observed mortality per year).

In 2024, indices of fishing behaviour, including mean sardine catch retained per net-set, the proportion of net-sets with zero catch, and the number of net-sets per trip, showed no significant difference between observed and unobserved net-sets. This marked the highest level of consistency recorded in the fishery across observed and unobserved net-sets for these behavioural indices. These data indicated no apparent observer-effect in 2024.

Tabulated salient results from monitoring of SASF – dolphin interactions from 2020 to 2024.

Year	% net-sets observed	% net-sets with dolphins encircled		% net-sets with dolphin mortality		Mean sardine catch per net-set	
		With observer	Without observer	With observer	Without observer	With observer	Without observer
2020	6.9	10	11	0.0	0.3	27	38
2021	11.6	18	14	3.0	0.3	29	44
2022	11.3	10	11	2.0	0.2	27	46
2023	13.2	14	13	0.0	0.2	33	43
2024	21.6	4	6	0.0	0.3	47	48

Keywords: Purse-seine fishery, Observer, Logbook, *Sardinops sagax*, *Delphinus delphis*.

1. INTRODUCTION

1.1. Background

South Australian Sardine Fishery

The South Australian Sardine Fishery (SASF) is Australia's largest fishery in terms of landed tonnage. It operates out of Port Lincoln in South Australia. Annual sardine landings increased from seven tonnes (t) in 1991, to 3,809t in 1999, and 39,809t in 2005 (PIRSA 2014). Catch declined to 23,507t in 2006. Since then, annual catches have gradually increased, reaching 43,947t in 2022 (Grammer et al. 2024). The SASF is a purse-seine fishery that targets Australian Sardines (*Sardinops sagax*) in waters off South Australia, mostly in Spencer Gulf. Some product is used for human consumption and fishing bait, but most is used as a feed source for the 'ranching' of Southern Blue-fin Tuna (*Thunnus maccoyii*).

Since 2005, fishing effort in the SASF has averaged 960 net-sets by 10-15 vessels per year – with 11 vessels operating each year since 2022. Recent vessel lengths have ranged between 17-45m and had maximum capacities of ~30-200t sardines. A key feature of the fishery is that virtually all net-sets are at night, when sardines school near the surface. The majority of fishing trips are overnight and involve 1-3 net-sets. Multi-day trips may be required to access more distant fishing areas or if fishing success is reduced, for example by strong winds or appropriate fish schools not being located.

Common Dolphins in South Australia

Common Dolphins (*Delphinus delphis*) are widely distributed in tropical and temperate waters of the Atlantic, Pacific, and Indian Oceans (Perrin 2017). Density estimates in South Australian waters have ranged between 0.5 and 0.7 individuals per km² (Filby et al. 2010, Bilgmann et al. 2017, Parra et al. 2021, Goldsworthy et al. in review). There have been abundance estimates in two years in the core range of the SASF (Spencer Gulf, Investigator Strait, and shelf waters to 100m depth), providing estimates of approximately 25,000 in 2011 to 27,000 in 2021 (Parra et al. 2021, Goldsworthy et al. in review). Based on these estimates, between 50,000 and 100,000 Common Dolphins likely occur in South Australian waters.

There is evidence of genetic population structure of Common Dolphins in south-eastern Australia, with those in South Australian waters potentially belonging to a genetically linked population that extends from the Great Australian Bight to western Bass Strait (Bilgmann et al. 2008, 2014).

Recent genetics-based studies of inferred migration levels, however, suggest there could be a semi-isolated sub-population within Gulf St Vincent (e.g., Barceló et al. 2021, 2022). If that is the case, Common Dolphins in Gulf St Vincent may need to be considered as a separate group from those elsewhere in South Australia.

In Australia, all cetaceans (including Common Dolphins) are listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act, Chapter 5, Division 3: Whales and other cetaceans). Under this Act, it is an offence for a person to cause the death or injury of a cetacean (Section 229), unless that action has received Ministerial accreditation (Section 231). Where fisheries interact with cetaceans, the Minister may accredit relevant management plans, regimes or policies, if satisfied that “*the plan, regime or policy requires persons engaged in fishing under the plan, regime or policy to take all reasonable steps to ensure that cetaceans are not killed or injured as a result of fishing*” (Section 245).

Separately from the EPBC Act, within South Australian waters, legislation regarding interactions with cetaceans includes the *National Parks and Wildlife Regulation 2010 (Protected Animals – Marine Mammals)*, *National Parks and Wildlife Act 1972*, *Animal Welfare Act 1985* and *Fisheries Management Act 2007*. Regulations within these acts pertain to minimum approach distances, disturbance avoidance, vessel speed in the vicinity of cetaceans, avoidance of injury to individuals, compulsory reporting of interactions, and penalties for non-compliance.

Interactions

Interactions between Common Dolphins and the SASF occur when nets are set around schools of sardines. Dolphins may be feeding on the sardines but not seen by the fisher or dolphin’s approach after the nets are set (Hamer et al. 2008, Jaiteh et al. 2013, Kemper et al. 2023). Dolphins are present outside of nets feeding on sardines following more than 60% of observed net-sets, indicating they are attracted to the operations (e.g., see Kirkwood and Goldsworthy 2022). Since 2013, Common Dolphins have been encircled in 10% of SASF net-sets and dolphin mortalities have been recorded on 1% of net-sets (Kirkwood and Goldsworthy 2024a). Mortalities may result due to interactions with the net, stress, drowning, or due to separation from mothers or family groups (Forney et al. 2002, Edwards 2006, St Aubin et al. 2013, Kemper et al. 2023).

In 2006, a government-initiated observer program was introduced in response to high dolphin interaction rates recorded by an independent observer program in 2004-05, as well as concerns about under-reporting of interactions (Hamer et al. 2007, 2008, Ward et al. 2015a). Since then, the observer program has typically aimed to cover 10% of fishing effort – approximately 100 net-

sets, or about 10 net-sets per vessel per year. The South Australian Sardine Industry Association (SASIA) also developed a Code of Practice (CoP) which has been regularly updated to help reduce dolphin interactions (see summary of actions in Appendix 1). Over time, dolphin encirclement rates in observed and unobserved net-sets have gradually converged, and since 2012 have been similar, occurring in approximately 10% of net-sets (Kirkwood and Goldsworthy 2024a, 2024b). Dolphin mortality events have declined over time. In observed net-sets, the mortality rate declined from 2.2% of net-sets (2006-2012) to 1.1% (2013-2023). In net-sets without an observer present, the rate declined from 0.3% to 0.2% over the same periods (Kirkwood and Goldsworthy 2024b).

Annual reports by SARDI have provided assessments of the observer program, dolphin interactions and efficacy of the CoP (Hamer and Ward 2007, Hamer et al. 2009, Ward et al. 2010, 2011, 2012, 2013, 2015a, 2015b, Mackay and Goldsworthy 2016, 2017, Goldsworthy 2018, Goldsworthy et al. 2019, Kirkwood et al. 2020, Kirkwood and Goldsworthy 2021, 2022, 2024a, 2024b).

Under-reporting of bycatch mortalities in the absence of observers has been documented in many fisheries and attributed to a range of factors. These include the desire to avoid potential negative consequences associated with reporting, and the increased likelihood of detecting cryptic mortalities when an observer is present (Archer et al. 2001, Gilman et al. 2013, Heinemann 2017, Emery et al. 2019, Moore et al. 2021, Kennelly 2020). As a result, observer data are considered the most reliable source for estimating minimum bycatch mortality levels.

The accuracy of observer data in representing actual mortality levels across all net-sets depends on fishing behaviour remaining consistent regardless of observer presence – that is, absence of an *observer effect* (Johnson et al. 1999, Burns and Kerr 2008, Zollett et al. 2015, Luck et al. 2020). Observer effects may arise if fishers apply different fishing practices, or operate in different areas when an observer is present, due to the perception that such actions may increase the likelihood of bycatch, which is viewed negatively (Kelleher 2005, Faunce and Barbeaux 2011, Duarte and Cadrin 2024). Additionally, documentation may be more precise and consistent under observation than when unobserved. Harris (1998) suggests that the likelihood of observer effects increases when actions to avoid or the time required to process bycatch interactions, could reduce catch rates.

Quantifying observer effects can be challenging without a method for recording fisher behaviour in the absence of observers are not present, such as through an electronic monitoring system

(Bartholomew et al. 2018, Ward et al. 2023,). In the absence of such a system, assessments must rely on indirect indices of fishing behaviour that may reveal changes when an observer is present. In the SASF, the key indices used to compare fishing behaviour with and without observer presence include: 'net-sets per trip', 'percentage net-sets with zero catch', and 'catch per net-set'. Analyses of these indicators have shown persistent differences when an observer is present (e.g., Ward et al. 2013, Goldsworthy et al. 2019). While these patterns suggest behavioural changes, it remains unclear whether such changes lead to increased or decreased dolphin interactions and/or mortalities. In the absence of more definitive data, it is precautionary to consider dolphin mortality rates recorded by observers in the SASF as minimum estimates (see Benoît and Allard 2009, Kennelly 2020, Wakefield et al. 2018).

In March 2022, the federal Department of Climate Change, Energy, the Environment and Water (DCCEEW) placed a condition on the extension of the SASF's permit to interact with marine mammals, requiring that suitable systems be implemented to ensure that under-reporting was not occurring. In response to this provision, observer coverage in the SASF was increased to 20% in July 2023. Trials of on-board camera systems were also proposed to audit dolphin interaction reporting in the absence of an observers. However, these have been paused while trials of acoustic deterrent devices are undertaken.

1.2. Objectives

The aim of this report was to assess the SASF observer program, dolphin interaction rates, and the level of compliance with the CoP in 2024.

Key objectives of this assessment were to:

- 1) Examine patterns of observer coverage in 2024,
- 2) Assess dolphin interaction rates with the SASF in 2024,
- 3) Assess the effectiveness of the CoP in mitigating interactions in 2024,
- 4) Assess dolphin interactions and fishing patterns with and without observers present, and
- 5) Collate and present 2024 data against data from previous years.

2. METHODS

Three data sets for the 2024 calendar year were collated, cross-checked for accuracy, and then incorporated into long-term data records for the fishery:

- 1) South Australian Sardine Fishery Logbook Data (recorded since 1999 by commercial fishers) – logbook number, vessel, date, location, time of net-sets, and estimated catch.
- 2) SASF Observer Datasheets (recorded since 2005 by independent observers: see Appendix 2) – data to link with the logbook records, weather conditions, fishing procedures, CoP procedures, and dolphin interaction details, other wildlife (e.g., dolphins outside the net, other protected species seen, such as seals, white sharks and seabirds), and comments.
- 3) Wildlife Interaction Forms (WIFs) (recorded since 2007 by commercial fishers: see Appendix 3) – must document all interactions with protected species (e.g., dolphins, fur seals, sea lions, and white shark).

The fishing areas in place in 2024 were: Spencer Gulf, Gulf St Vincent, and the Outside Zone (PIRSA 2020, presented in Figure 1). In this report, two geographically separate areas of the Outside Zone were distinguished: west of the Eyre Peninsula, termed the West Coast, and south-east of Kangaroo Island, termed the South-East.

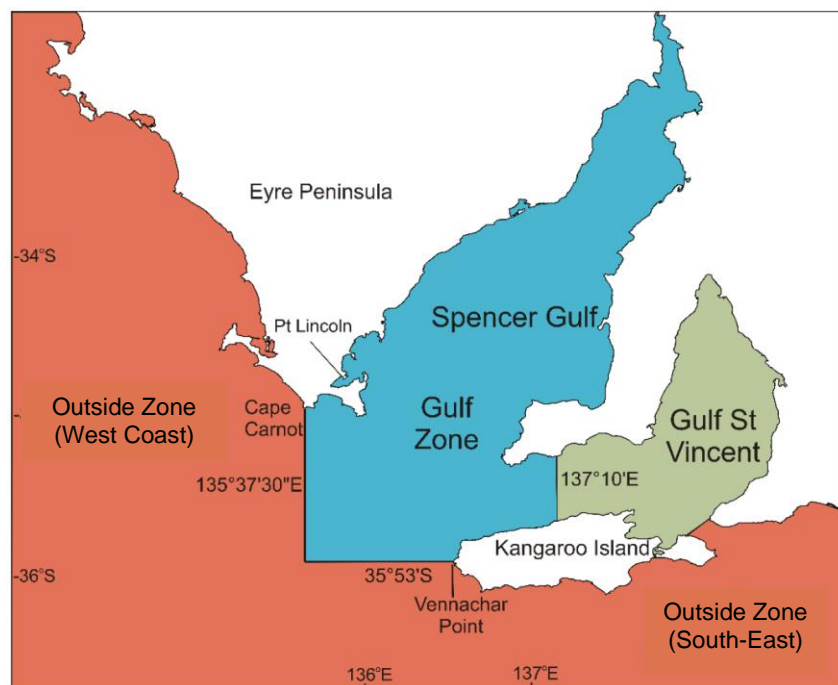


Figure 1. Spatial management zones for the SASF. For this report, the Outside Zone is split into West Coast and South-East regions (adapted from PIRSA 2000).

Before 2012, observer coverage was designated as a percentage of 'nights of fishing', then as a percentage of 'net-sets'. Observers boarded a vessel usually for trips of one (most common) up to four-nights. Observer effort aims to achieve the target percent coverage within each month, as well as in the year for each vessel and in each fishing area.

The allocation of observers to vessels was structured rather than randomised. For example, with coverage set at 10%, when a vessel approached 10 net-sets since its last observed net-set, an observer was allocated to that vessel and the observer boarded as soon as practicable. Allocation also considered that monthly coverage should be at the 10% rate. Therefore, at times, if a 'required vessel' was unavailable (e.g., out fishing or in maintenance), an observer could be assigned to the next available vessel, increasing its coverage for that month, which would be accounted for with fewer net-sets for that vessel in a later month. Achieving an even spatial coverage relied on there being no bias in the fishing area after placement of the observer, and negotiation with fishers to place an observer on a vessel that was heading to a particular zone.

In WIFs, fishers record all interactions with 'Threatened, Endangered and Protected Species' (TEPS: i.e., cetaceans, pinnipeds, seabirds, and white sharks). WIFs were introduced to meet state government obligations under the EPBC Act, that all contact between fishing gear and TEPS species, particularly injury and mortality events, be collated and reported-on annually.

Data preparation was performed in Microsoft Excel with further processing and statistical analysis in the R statistical framework (version 4.3.1, R Core Team 2025). Statistical differences were assessed using *F*-tests and *t*-tests for parametric data, and Wilcoxon-tests for non-parametric data, using the package dplyr (Wickham et al. 2019). Where appropriate, the data are summarised as means \pm standard errors.

Evaluations of dolphin encirclement and mortality rates were based on events recorded by observers and fishers, in WIFs. Estimates of annual numbers of encirclements and mortalities were derived from the recorded rates multiplied by the total number of net-sets. A 5-year running mean was applied to the annual mortality data to smooth out inter-annual variability and reveal multi-year trends. The evaluation of the application of the CoP was based on observer records of when fishers actively searched for dolphins, responses to dolphin sightings, and processes for releasing encircled dolphins.

To assess whether or not the observer data were representative for the entire fishery, that is, that there was no observer-effect, indices of fishing behaviour with and without an observer present were drawn from the data sets. The indices adopted were 1) the number of net-sets per trip, 2)

the number of net-sets with zero catch, 3) the catch per net-set, and 4) the catch per net-set excluding net-sets with zero-catch. Estimated sardine catches retained per net-set in which dolphin encirclements or mortalities occurred were also compared between net-sets with and without an observer present.

To further examine factors that could correlate with observer presence, sardine catch retained, dolphin encirclement event and dolphin mortality event, separate Generalised Additive Models (GAMs) were constructed using the *mgcv* package in R (Wood et al. 2016, Wood 2017). Restricted Maximum Likelihood (REML) models were applied as these do not assume gaussian distributions of data within variables. Variables included as factorial data were 'observer presence', 'encirclement event', 'mortality event', 'moon phase', 'time-of-day', 'fishing zone' and 'vessel'. Numerical variables included 'tonnage of sardines retained', 'water depth', 'search time' and 'number of dolphins encircled'. 'Vessel' was only included in GAMs investigating sardine catch, and were incorporated as a random factor because vessels in the fleet had different capacities.

Recent trends were investigated by constructing separate GAMs for the response variables in each year from 2021 to 2024. Annual GAMs for mortality events were not constructed, however, as their annual occurrence was too infrequent. Separate GAMs also investigated relationships in each response using all net-sets between 2013 to 2024.

Prior to running each GAM, evidence of cross-correlations of predictor variables were investigated to ensure their independence. Visual inspection using graphs (x-y, box and violin) and mosaic plots (*vcd* package), were followed by a combination of statistical techniques: Cramér's V (factor comparisons), Pearson's correlation coefficients (numeric comparisons) and Eta squared (η^2 , combined comparisons). In effect, predictor variables correlated poorly with each other (maximum correlation coefficient $r = 0.53$ for water depth and zone [>0.8 would indicate a strong correlation]), so none were excluded on that basis. However, predictors that had structural overlap with the response variable were excluded to avoid tautological relationships and overfitting (e.g., 'mortality events' are a subset of 'encirclement events' so were excluded from GAMs of encirclement events).

In each GAM, the *mgcv* package converts factorial variable into contrasts, whereby one level of the factor was treated as a reference level against which the other levels were tested. Selection of which level to present first was made prior to running the GAMs. For temporal data, a logical first period was selected, such as '0-3am' for 'time-of-day', and 'new-moon' for 'moon phase'. For

spatial data, the level with the most data was treated as the reference, such as 'Spencer Gulf' for 'fishing zone'. Due to the spatial separation of the West Coast and South-East within the Outer Zone, these areas were treated as separate zones in the GAMs.

Results of GAM models that including all predictors are presented, rather progressing through a step-wise selection process toward just the significant variables. This approach allowed for a comparison of each variable's relative contribution to the response, and how contributions evolved over time (i.e., through the night, across moon phases and between years).

Differences to previous analyses

In reviewing databases for the report on dolphin/SASF interactions in 2023 (Kirkwood and Goldsworthy 2024b), several adjustments to historical data sets were made and are adapted in this report. Briefly, the adjustments were:

- 1) Vessels did not routinely provide information for trips when no net was set. When this information was provided (departure date, landing date, search hours and zone visited) it was logged to a net-set, when no net-set had occurred. Database entries for trips with no net-sets were identified and excluded from counts of net-sets. Also, comparisons of 'net-sets per trip' with versus without an observer, excluded trips when no net was set. Thus, the comparisons were of the same metric, but the estimated values exceeded the true number of net-sets per trip.
- 2) Prior to 2010, some logbook entries for a trip gave a single net-set when observers recorded multiple net-sets (total catches on the trip were the same). Potentially, skippers were combining data from multiple net-sets into a single net-set. When no observer was present, data entered could have been for a single net-set or multiple net-sets. Therefore, comparisons between net-sets with versus without an observer present focused on the more reliable data post 2010.
- 3) One vessel routinely recorded dates either site of over-night fishing as departure and landing dates, such that all trips appeared to be single-day trips. Data for that vessel were excluded from comparisons of 'net-sets per trip', with versus without an observer.

3. RESULTS

3.1. Fishing effort

In 2024, a total of 928 net-sets were recorded in industry logbooks (Table 1). The temporal and spatial spread of net-sets was comparable with recent years, with 59% of net-sets occurring from March to May and 67% of net-sets being in the Spencer Gulf Zone. Eleven percent of net-sets were in Gulf St Vincent and 22% in the Outside Zone (14.5% West Coast, 7.5% South-East).

3.2. Observer coverage

In 2024, observers were present for 200 net-sets (21.3%; Table 1), with good coverage achieved in all months (range 20-33% of nets set per month; Figure 2a). Observer coverage on individual vessels ranged between 19% and 29% of net-sets (Figure 2b). Observer coverage by zone was: 21% in Spencer Gulf (129 of 619 net-sets), 32% in Gulf St Vincent (33 of 102 net-sets) and 18% in the Outside Zone (38 of 207 net-sets; comprising 23% in West Coast [31 of 136 of net-sets] and 10% in the South-East [7 of 71 of net-sets]; Figure 3, Table 2).

In 2024, observers reported that fishers always followed the industry CoP:

- 1) A search for dolphins was always conducted prior to net-setting.
- 2) When the crew saw dolphins, they immediately and clearly communicated this to the skipper.
- 3) If dolphins were sighted prior to setting, the set was always delayed and often relocated.
- 4) When dolphins were identified as encircled or entangled, the response to release them was always immediate (recognising that several minutes could be needed to complete a procedure before the front of the net could be released).
- 5) Release procedures were always in accordance with the CoP, that is, release the front of the net and if dolphins did not depart promptly, abort the set.

Table 1. Summary of fishing effort (net-sets), observer coverage, and dolphin encirclement and mortality events, and number of dolphins involved (in brackets) recorded in the South Australian Sardine Fishery (SASF), by calendar year from 2005 to 2024.

Year	Net-sets					Encirclements						Mortalities					
	Total	With obs.	No obs.	% obs.	% target	Events		With obs.		No obs.		Events		With obs.		No obs.	
2005	1297	87	1210	6.7	5	39	(115)	20	(92)	19	(23)	16	(24)	12	(20)	4	(4)
2006	856	82	774	9.6	10	38	(88)	10	(27)	28	(61)	4	(6)	0	(0)	4	(6)
2007	1011	97	914	9.6	10	54	(116)	18	(57)	36	(59)	7	(11)	6	(10)	1	(1)
2008	883	210	673	23.8	30	66	(183)	28	(93)	38	(90)	9	(12)	6	(8)	2	(3)
2009	989	212	777	21.4	30	58	(155)	17	(47)	41	(108)	5	(7)	4	(6)	1	(1)
2010	1022	253	769	24.8	30	64	(176)	26	(85)	38	(91)	4	(4)	1	(1)	3	(3)
2011	1079	74	1005	6.9	10	48	(148)	10	(37)	38	(111)	6	(6)	2	(2)	4	(4)
2012	1032	83	949	8.0	10	97	(283)	13	(48)	84	(235)	5	(6)	2	(2)	3	(4)
2013	762	71	691	9.3	10	92	(204)	6	(15)	86	(189)	3	(3)	0	(0)	3	(3)
2014	816	91	725	11.2	10	94	(245)	10	(35)	84	(210)	1	(1)	0	(0)	1	(1)
2015	847	93	754	11.0	10	73	(196)	8	(25)	65	(171)	4	(5)	2	(3)	2	(2)
2016	819	94	731	10.7	10	59	(176)	7	(27)	52	(149)	1	(1)	0	(0)	1	(1)
2017	1083	133	965	10.9	10	63	(213)	9	(35)	54	(178)	1	(1)	1	(1)	0	(0)
2018	901	103	797	11.5	10	89	(339)	12	(48)	77	(291)	0	(0)	0	(0)	0	(0)
2019	963	131	832	13.6	10	96	(379)	18	(81)	77	(296)	6	(16)	5	(15)	1	(1)
2020	1049	72	977	6.9*	20	118	(433)	7	(29)	111	(404)	3	(3)	0	(0)	3	(3)
2021	859	100	760	11.5	10	125	(409)	18	(64)	107	(345)	5	(5)	3	(3)	2	(2)
2022	997	113	884	11.3	10	112	(409)	11	(36)	101	(368)	4	(6)	2	(4)	2	(2)
2023	992	131	861	13.2	10-20	127	(423)	18	(63)	109	(360)	2	(2)	0	(0)	2	(2)
2024	928	200	728	21.3	20	52	(142)	7	(21)	45	(121)	2	(2)	0	(0)	2	(2)

* 2020 observer coverage affected by covid restrictions.

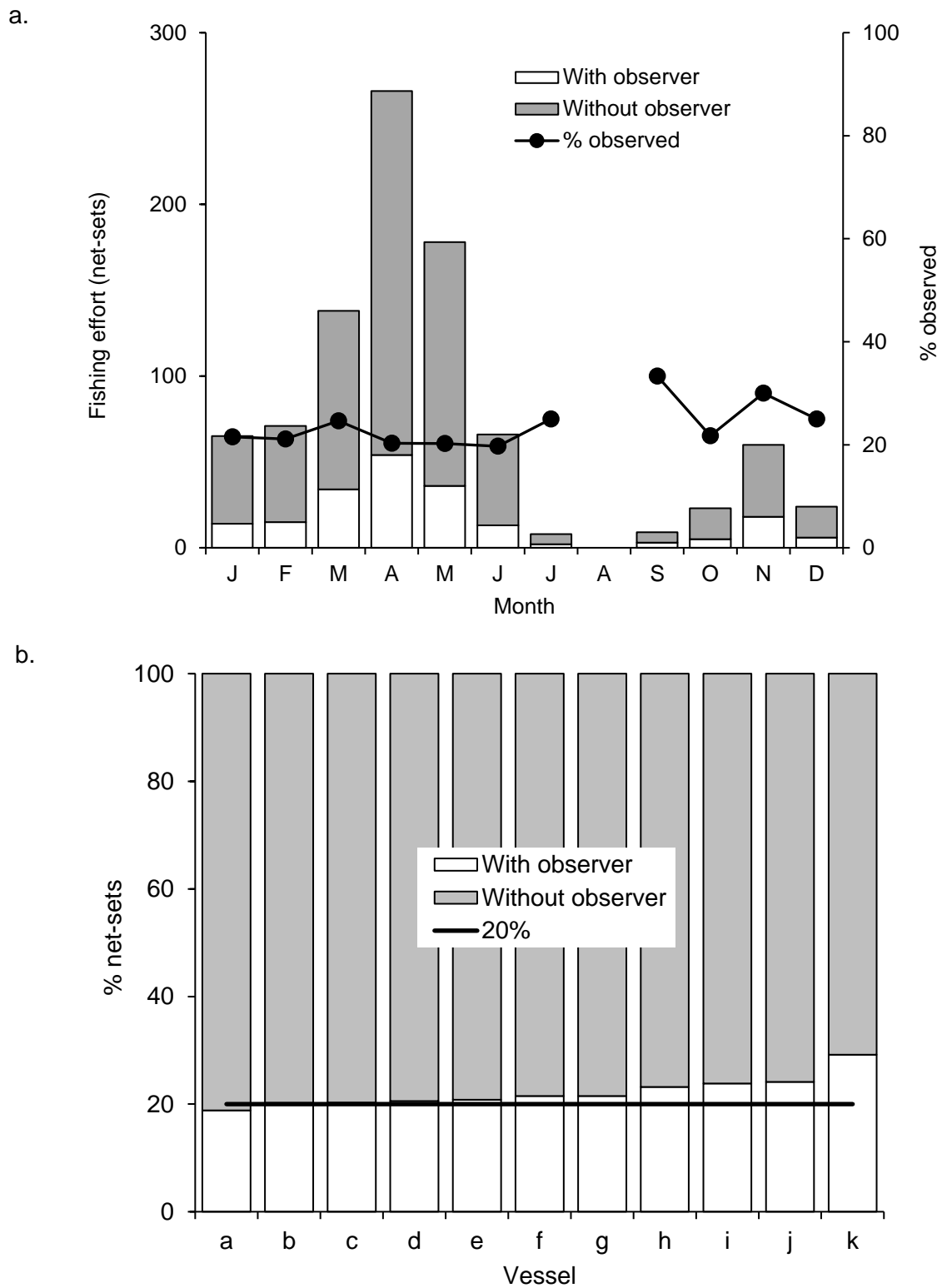


Figure 2. Observer coverage of the SASF in 2024, by (a) month and (b) vessel.

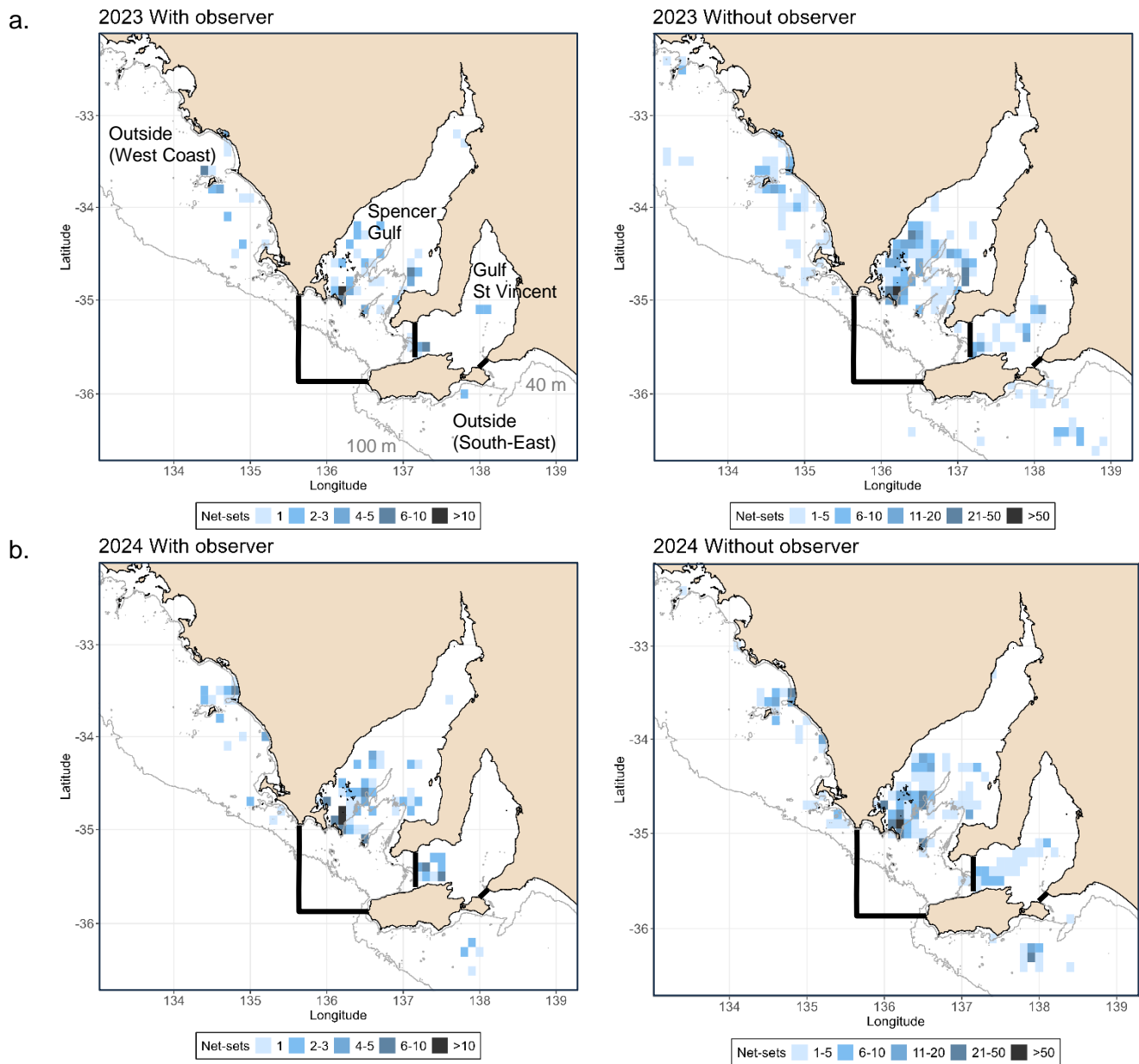


Figure 3. Gridded density plots (0.1° x 0.1°, equivalent to ~11km²) showing the distribution of SASF net-sets with and without observers present: (a) in 2023 and (b) in 2024. Fishing Zones delineated by black lines, 40m and 100m depth contours in grey.

Table 2. Frequency by fishing zone of net-sets and observer coverage, in the SASF in 2024.

Zones	Net-sets	%	Observer	%
Spencer Gulf	619	67	129	21
Gulf St Vincent	102	11	33	32
Outside (West Coast)	136	14.5	31	23
Outside (South-East)	71	7.5	7	10

3.3. Wildlife interaction forms (WIFs)

In 2024, WIFs were submitted by fishers for 75 TEPS interactions (compared to 167 interactions in 2023), 56 without an observer and 19 with an observer. Of the 56 WIFs submitted when no observer was onboard, 45 (109 in 2023) documented encirclements of Common Dolphins, and six (25 in 2023) reported delays to net-setting due to dolphin presence: the remaining five WIFs reported seal interactions.

The seven encirclements reported by observers had matching WIFs. Five times the reports were identical and on the remaining two the only difference was that the WIF recorded a delay prior to the set due to dolphin presence, while the observer report did not record a delay.

WIFs submitted by fishers when observers were not onboard documented similar rates of dolphin encirclement to observer reports and two mortality events, both when observers were not present.

3.4. Dolphin interactions

Dolphin presence

Observers recorded 205 occasions when a vessel was searching for sardines, on four of which no net-set was possible because either a suitable school of sardines was not located or there was poor weather or a mechanical malfunction (Table 3). Of the 201 occasions when a suitable school was located, the presence of dolphins delayed net-setting on 13 occasions (7%). On one occasion, net-setting was not possible due to on-going dolphin presence. The rate of dolphin-caused delays was lower than in previous years and continued a downward trend since 24% of net-sets were delayed by dolphins in 2020 (Table 3).

Common Dolphins were seen feeding on fish outside the net following 42% of observed net-sets, which was less frequent than in previous years (61% in 2020, 72% in 2021, 54% in 2022, and 60% in 2023). When present, the estimated number of dolphins ranged from one to 110 (median 15). Up to six seals were seen feeding on fish in-and-out of the net after 19% of observed net-sets (compared with 20% in 2023) These were identified as Australian Sea Lions (*Neophoca cinerea*) 26 times (67%), Long-nosed Fur Seals (*Arctocephalus forsteri*) five times (26%) and seal type was not provided six times. Following two net-sets, single Great White Sharks (*Carcharodon carcharias*) were observed, one was on the outside of the net, the second had entangled inside the net - it was cut free and released.

Table 3. The frequency of delays to net-setting caused by sighting dolphins on the approach, based on observer data, from 2020 to 2024.

Year	Searches for sardines	No set due to other reasons*	Net-set possible	Dolphins caused delay	% sets delayed by dolphins	No set due to dolphins	Net-sets
2020	81	9	72	17	24	0	72
2021	108	5	103	22	21	3	100
2022	118	4	114	16	14	1	113
2023	138	4	134	17	13	3	131
2024	205	4	201	13	7	1	200

* e.g., no suitable school located, poor weather, mechanical problem

Encirclements

In 2024, dolphins were encircled in 4% (7 of 200) of observed net-sets and 6% (45 of 728) of unobserved net-sets (Table 4). These represent a substantial reduction in the encirclement rates recorded in recent years. For example, across 2019-2023, encirclements occurred in 13% of net-sets when an observer was present and 12% when observers were not present. Estimates of total encirclement events in 2024 were 32, based on observed net-sets, and 57, based on net-sets without observers (Figure 4), with an actual total of 52 encirclement events recorded.

Table 4. Frequency and rates of dolphin encirclement events with and without observers present, by fishing zone in 2024.

Zone	With observer			Without observer		
	Sets	Encirclement events	%	Sets	Encirclement events	%
Spencer Gulf	129	6	5	490	36	7
Gulf St Vincent	33	1	3	69	5	7
Outside (West Coast)	31	0	0	105	0	0
Outside (South-East)	7	0	0	64	4	6
Total	200	7	4	728	45	6

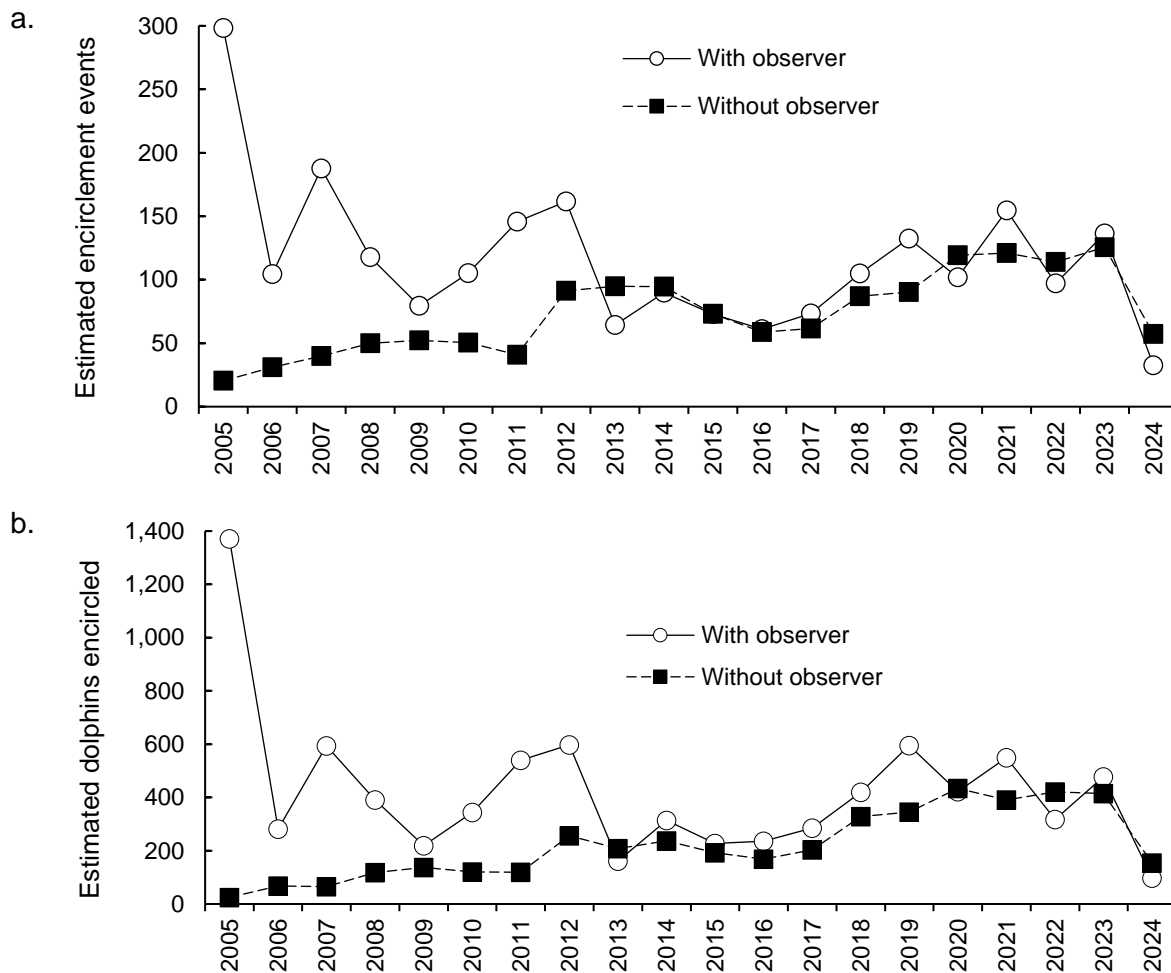


Figure 4. Time series of (a) estimated number of dolphin encirclement events and (b) dolphins encircled based on rates recorded with and without an observer present, from 2005 to 2024.

In 2024, averages of three dolphins per encirclement were recorded in net-sets both with and without an observer present. Estimates of total encirclements in 2024 were 97 dolphins based on the rate with an observer, and 154 dolphins based on the rate without an observer present (Figure 4). These numbers were much lower than in 2023, when estimates were for 477 encircled dolphins, based on the rate with an observer, and 415 based on the rate without an observer.

In 2024, dolphins were encircled in 6-7% of net-sets in Spencer Gulf, Gulf St Vincent and the South-East region of the Outside Zone, but there were no encirclements in the 136 net-sets in the West Coast region of the Outside Zone. The rate of encirclements has been consistently lower in the West Coast than elsewhere. In 2023, there were encirclements in 7% of net-sets on the West Coast compared with encirclements in 10-15% of net-sets elsewhere. Since 2013, 18% of net-

sets in the fishery have been made on the West Coast and these have accounted for only 6% of encirclements. By comparison, since 2013 in Spencer Gulf, 70% of the fishery’s net-sets have been made and these have accounted for 81% of all encirclements. Elsewhere since 2013, in Gulf St Vincent there have been 5% of net-sets and 6% of encirclements, and in the South-East region of the Outside Zone there have been 7% of net sets and 7% of encirclements.

Mortalities

In 2024, (as occurred in 2023) observers did not record a dolphin mortality. This was the eighth year of the 20-year observer program during which observers did not record dolphin mortalities (Figure 5). When observers were not present in 2024, two dolphin mortality events were recorded, each involving a single dolphin (Table 5).

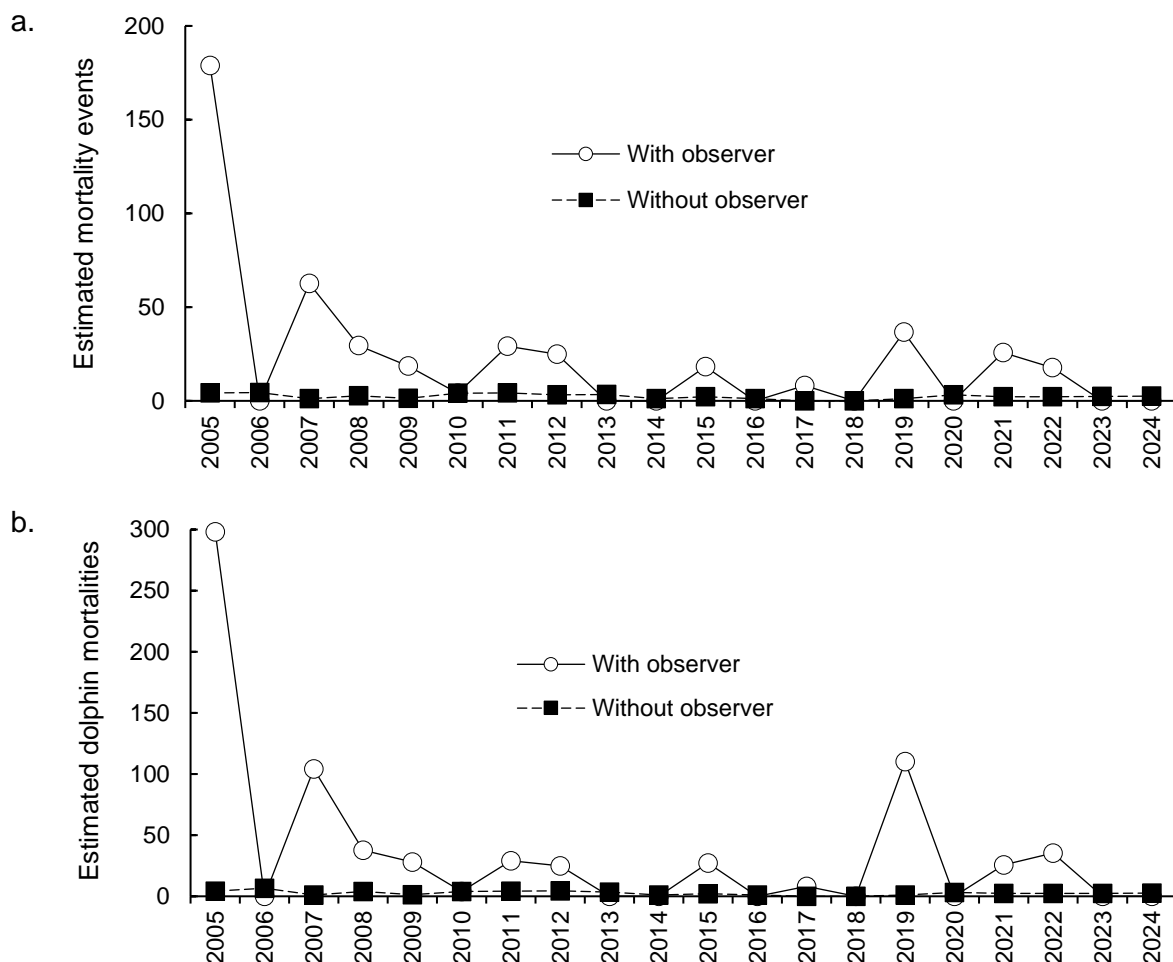


Figure 5. Time series of (a) estimated number of dolphin mortality events, and (b) dolphin mortalities based on rates recorded with and without an observer present, from 2005 to 2024.

Table 5. Details of dolphin mortalities recorded in 2024.

Date	Time seen	Observer present	Zone	After a delay due to a dolphin sighting	No. dolphin deaths	Comment
13-Apr	3:15	no	GSV	yes	1	Entangled on outside
16/17-Dec	0:30	no	SG	no	1	First seen after pumping

The annual 5-year running-mean of dolphin mortalities, estimated from observer data, declined from 39 ± 20 in 2023 to 11 ± 8 in 2024 (Figure 6). This substantial reduction reflects both the absence of recorded mortalities in observed net-sets during 2024 and the removal of the 2019 mortality spike (when an estimated 110 mortalities occurred) from the 5-year calculation (Figure 5b). For net-sets without observers, the 5-year running-mean remained unchanged at two dolphin mortalities per year through to 2024 (Figure 6).

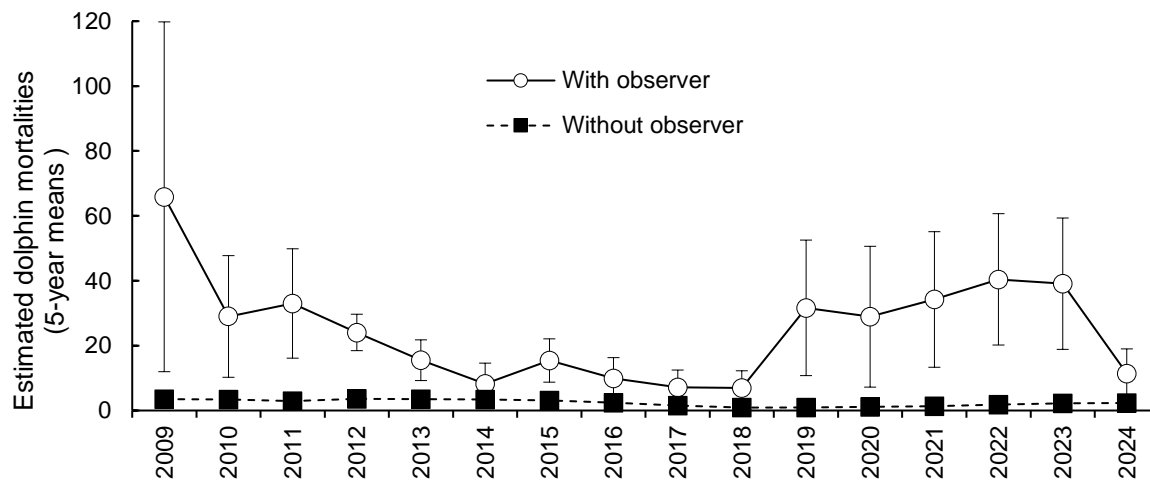


Figure 6. Time series of (a) estimated dolphin mortalities per year in the SASF based on rates recorded with and without an observer present, as 5-year running-means from 2009 to 2024.

During the five years from 2020 to 2024 in the SASF, a total of 16 mortality events were recorded involving 18 dolphins (Table 6). Of these, 12 mortality events (75%, involving 14 dolphins) were in the Spencer Gulf Zone, 3 events (3 dolphins) in Gulf St Vincent, 1 event (1 dolphin) in the South-East region of the Outside Zone, and no events in the West Coast region of the Outside Zone (Table 6). Since 2005, 90% of the recorded mortality events have been in Spencer Gulf (Figure 7).

Table 6. Dolphin mortality events, frequency of occurrence (% net-sets) and numbers of dolphins that died, by fishing zone and observer presence, in all net-sets from 2020 to 2024.

Fishing zone	With observer			Without observer		
	Events	% sets	Dolphins	Events	% sets	Dolphins
Spencer Gulf	4	1.0	6	8	0.3	8
Gulf St Vincent	1	1.3	1	2	0.4	2
Outside: West Coast	0	0	0	0	0	0
Outside: South-East	0	0	0	1	0.2	1
Total	5	0.8	7	11	0.3	11

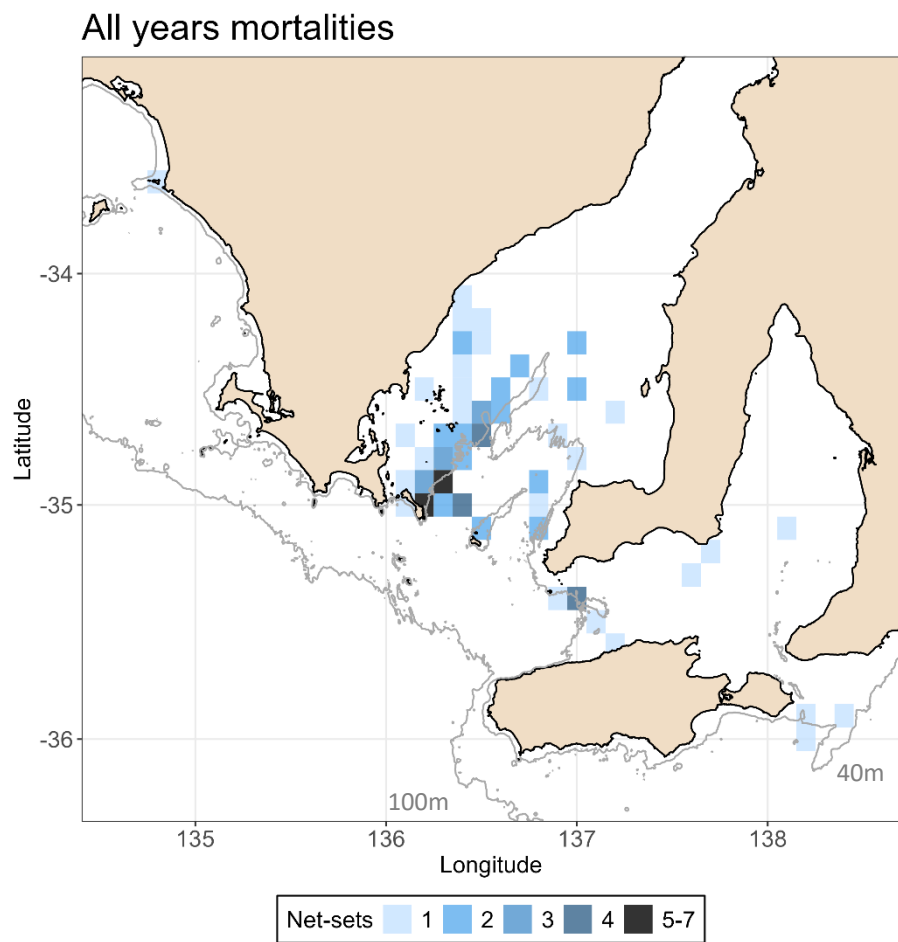


Figure 7. Gridded density plot (0.1° x 0.1°, equivalent to ~11km²) of the distribution of SASF net-sets in which dolphin mortalities were recorded, from 2005 to 2024.

Generalised Additive Model (GAM) analyses

Observer presence

In 2024, presence of observers did not correlate significantly with the tonnage of sardine retained per net-set ($p = 0.39$) the frequency of encirclement events ($p = 0.36$), dolphins per encirclement ($p = 0.95$) or the frequency of mortality events ($p = 0.99$; Appendix 4.1). The only significant correlations with observer presence were related to fishing zone (Appendix 4.1). Compared to Spencer Gulf, observer presence was significantly higher in Gulf St Vincent ($z = 2.41$, $p = 0.02$) and lower in the South-East region of the Outside Zone ($z = -2.57$, $p = 0.01$).

Catch per net-set

As for the GAM on observer presence, in 2024, there was no correlation between the amount of retained catch per net-set and observer presence ($t = -0.28$, $p = 0.78$). The most significant correlations were for smaller catches in periods of the night just after sunset (18:00 to 21:00, $t = -2.01$, $p = 0.05$) and just before sunrise (6:00 to 9:00, $t = -2.28$, $p = 0.02$; Appendix 4.2). Over the years from 2020 to 2024, there has been considerable variability in factors that correlated with retained catch size. Across all net-sets from 2013 to 2024, the strongest correlations with sardine catch have indicated smaller catches in the presence of an observer ($t = -10.5$, $p < 0.001$), and in periods of the night just after sunset ($t = -5.47$, $p < 0.001$) and just before sunrise ($t = -10.1$, $p < 0.001$).

Encirclement events

As with the GAM on observer presence, in 2024, encirclement events were more frequent in net-sets between 3am and 6am ($z = 2.87$, $p = 0.004$); this period of the day had correlated with more encirclement events in 2022, but not in 2021 or 2023 (Appendix 4.3). Also in 2024, the amount of deviance in the data that was explained by the model was much higher than in analyses on previous encirclement events in previous years. In the GAM applied to net-sets spanning the period from 2013 to 2024, the strongest correlation was for fewer encirclements in the West Coast region of the Outside Zone.

Mortality events

In the GAM that investigated mortality events between 2013 to 2024, there was a highly significant positive correlation with observer presence ($z = 4.64$, $p < 0.001$; Appendix 4.4).

3.5. Fishing behaviour

Since 2013, the presence of an observer has typically been associated with higher numbers of net-sets per trip, a greater percentage of net-sets yielding zero sardine catch, and lower tonnages of sardines catch per net-set, even when zero-catch net-sets are excluded (Table 7, Figure 8). However, this pattern did not persist in 2024, when no significant differences were observed in any of the fishing behaviour indices. For the one vessel that recorded net-sets per night rather than per trip, there was no significant difference in net-sets per night with and without an observer from 2015 to 2024 ($df = 9$, $t = 0.19$, $p = 0.42$). Additionally, in net-sets where dolphins were encircled, the mean retained sardine catch rarely differed significantly between net-sets with without an observer presence (Table 7).

Table 7. Probability (p) results from Wilcoxon-tests for similarity, comparing indices of fishing behaviour from net-sets with and without an observer present, annually from 2005 to 2024. The dashed line separates less comparable (pre-2011) and more comparable data (rationale provided in methods). All significant results ($p < 0.05$, in bold) indicate that when an observer was present there were either: more net-sets per trip, less sardine catch per net-set, or more catch per net-set in net-sets when dolphins were encircled.

Year	Net-sets/trip	Catch/net-set including zero catch sets	Catch/net-set excluding zero catch sets	Catch/net-set with a dolphin encirclement
2005	0.006	<0.001	0.613	0.121
2006	0.187	<0.001	0.086	0.046
2007	<0.001	0.004	0.515	0.009
2008	<0.001	0.003	0.646	0.189
2009	0.003	0.002	0.040	0.535
2010	0.009	<0.001	0.032	0.126
2011	0.105	0.386	0.643	0.622
2012	0.085	0.263	0.532	0.375
2013	<0.001	0.007	0.048	0.219
2014	0.043	0.004	0.060	0.102
2015	0.037	<0.001	0.003	0.645
2016	0.024	0.010	0.029	0.249
2017	0.087	<0.001	0.001	0.282
2018	0.002	<0.001	<0.001	0.008
2019	0.128	0.017	0.288	0.861
2020	0.398	0.003	0.002	0.149
2021	0.160	<0.001	0.019	0.135
2022	<0.000	<0.001	<0.001	0.195
2023	0.085	<0.001	<0.001	0.878
2024	0.899	0.387	0.180	0.800

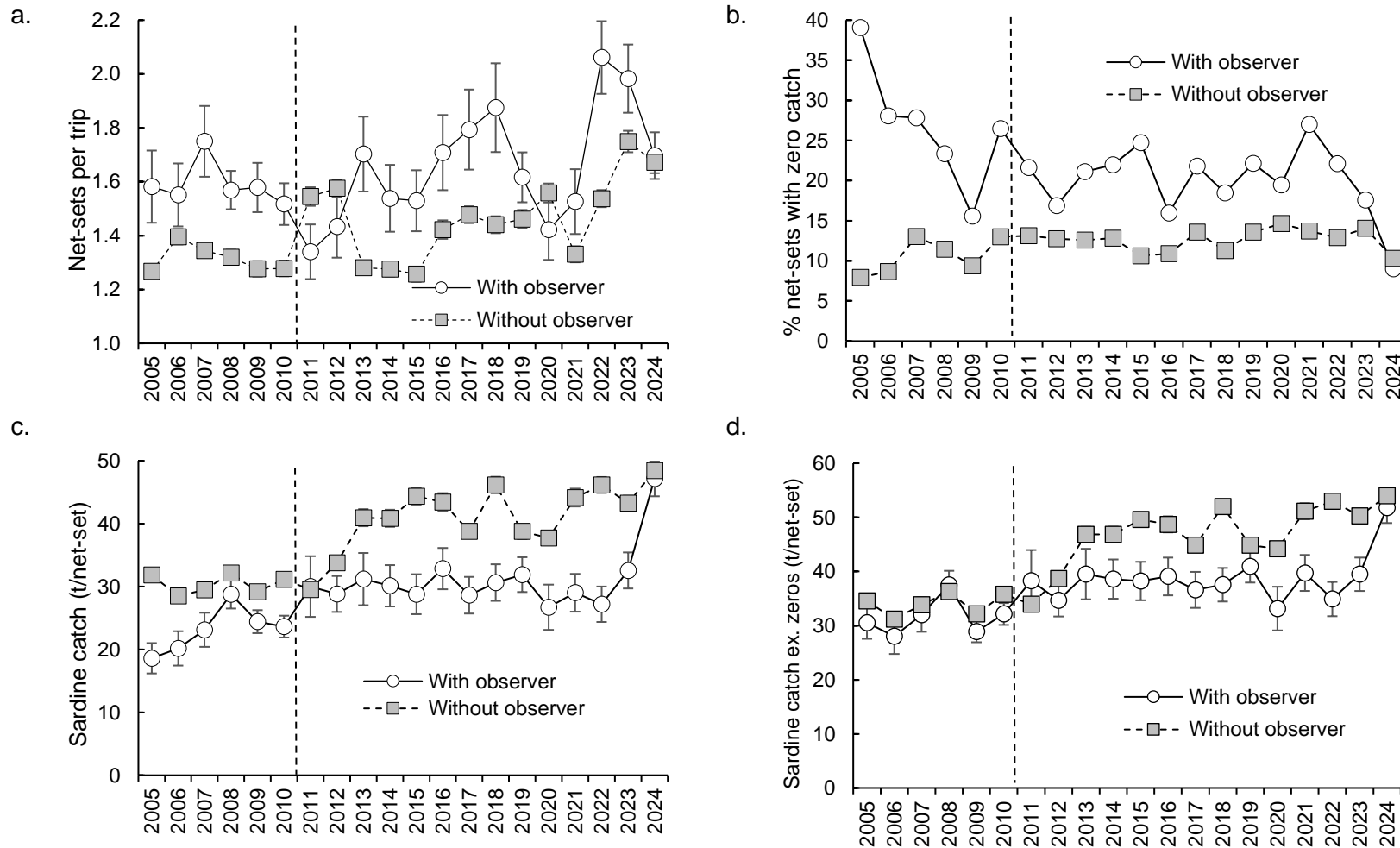


Figure 8. Comparison of indices of fishing behaviour with an observer (circles) and without an observer (squares), from 2005 to 2024: (a) net-sets per trip, (b) percentage net-sets with zero catch, (c) sardine catch per net-set (tonnes) including zero-catches and (d) sardine catch per net-set excluding zero-catch net-sets. Dashed line separates less comparable (pre-2011) and more comparable data (rationale provided in methods).

In 2024, the sardine catch per net-set did not differ significantly with versus without an observer (paired Wilcoxon-test, $p = 0.97$). Across vessels, catch per net-set ranged between 22% more to 26% less when an observer was present. In the previous two years, there had been significantly less catch per net-set when an observer was present. In 2023, catch per net-set was 25% less when an observer was present (paired Wilcoxon-test, $p = 0.005$), with vessel-level differences ranging from 6% more to 59% less catch. In 2022, catch per net-set was 39% less with an observer (paired Wilcoxon-test, $p < 0.001$), ranging across vessels between 21% to 73% less catch when an observer was present.

4. DISCUSSION

The 928 SASF net-sets in 2024 was about 7% less than the net-sets in 2022 and 2023 (997 and 992, respectively), although they approximated the mean number of net-sets per year for the previous 10-years (933 ± 31). More than 60% of net-sets were in Spencer Gulf, as has occurred in all years of the fishery. In 2024, rates of dolphin interactions, including dolphin presence delaying net-setting, dolphin encirclements, mortalities and presence following net-sets, were among the lowest levels recorded for the fishery since 2004. Also, for the first time since observer monitoring began, all indices of fishing behaviour indicated no significant differences between observed and non-observed net-sets.

4.1. Observer coverage

The 21.3% of net-sets observed in 2024 exceeded the target level of 20%. The coverage was well balanced across months, vessels and zones, fulfilling the spatial and temporal requirements of the observer program (PIRSA 2020). Within zones, however, there were several gaps in spatial coverage. Within the Outside Zone, there was just 10% observer coverage in the region south-east of Kangaroo Island (23% coverage in the West Coast region). In 2023, there was also low observer coverage in the South-East region of the Outside Zone (4% when the target level was 10% and 17% was achieved in the West Coast region). Also in 2024, all observed net-sets in the Gulf St Vincent Zone were in Investigator Strait, with no coverage in Gulf St Vincent proper. In 2023, the majority of observed net-sets in Gulf St Vincent also had been in Investigator Strait. As noted in the 2023 report, considering the potential that Common Dolphins within Gulf St Vincent are semi-isolated from populations elsewhere in South Australia (Barceló et al. 2021, 2022), ensuring robust observer coverage of fishery-dolphin interactions in this Gulf is important.

Code of Practice (CoP) assessment

In 2024, observers reported that in their presence, fishers always adhered to the CoP. Fishers checked for dolphins prior to net-setting and throughout fishing operations, delayed net-sets if dolphins were sighted, immediately reacted to free encircled or entangled dolphins, and released dolphins by opening the front of the net and aborting the set if dolphins did not release immediately.

4.2. Dolphin interactions

Dolphin presence

Both the rate at which dolphin sightings caused delays to net-setting (6.5% of approaches to a sardine school) and the frequency at which dolphins were recorded on the outside of nets following net setting (42% of sets) were low in 2024. Between 2020 and 2023, delays in net-setting due to dolphin presence decreased from 24 to 13% of sets, while the presence of dolphins outside the net after net-setting remained high and fluctuated, between 54 and 72%, suggesting the decline was not due to any reduction in dolphin numbers. The continued trend of decreasing dolphin-caused delays to net-setting may reflect adaptations of fishers to reduce interactions. Different oceanographic conditions in 2024 compared with other recent years may also have altered dolphin distribution and local abundance, influencing the low frequency of delays due to dolphin presence and reduced presence after net-sets in 2024. This is discussed further below under management considerations.

Encirclements

The rate of dolphin encirclement in 2024 was low compared with previous years. Estimates based on observer data (32 encirclement events involving 97 dolphins) represents the lowest annual levels recorded for the SASF. This may reflect both reduced dolphin presence in the fishing area in 2024 and continued improvements in dolphin avoidance practices by the fleet.

Historically, the likelihood of dolphin encirclement has been highest in Spencer Gulf and lowest in the West Coast region of the Outside Zone. However, dolphin abundance surveys suggest that Common Dolphins densities are similar in both regions, 0.5 to 0.7 dolphins/km² in Spencer Gulf (Parra et al. 2021, Goldsworthy et al. in review) and 0.7 dolphins/km² on the West Coast (Bilgmann et al. 2018). The different interaction rates between these regions may relate more to variation in fishing activity than dolphin density. Spencer Gulf has consistently accounted for the majority of net-sets, resulting in greater exposure of dolphins to purse-seine operations and associated feeding opportunities.

Mortalities

Dolphin mortality levels recorded in 2024 were consistent with recent levels recorded in the fishery. The two mortalities recorded in net-sets without an observer present matched the long-term rate for unobserved net-sets. No dolphin mortalities were recorded in observed net-sets, marking the eighth year, in 20-years of monitoring, in which observers recorded zero mortalities.

However, the absence of mortalities in 2024 is particularly notable, as observer coverage exceeded 20% of net-sets, compared with about 10% coverage in previous years when no mortalities were observed.

Under-reporting of dolphin mortalities in unobserved net-sets has previously been evident in the fishery (e.g., Goldsworthy 2020). In both 2023 and 2024, two dolphin mortality events were recorded, each involving a single dolphin, and both in the absence of observers. Therefore, no evidence of under-reporting of mortalities was apparent in the annual data for those years. However, the 5-year running-mean based on observer data still indicated an annual mortality rate of 11 dolphins up to 2024. Given that 80% of net-sets were not independently observed in 2024, it cannot be definitively concluded that under-reporting did not occur. Several additional years of consistent data, similar to that from 2023 and 2024 would strengthen the assumption that under-reporting of dolphin mortalities is no longer a significant concern in the fishery.

4.3. Fishing behaviour

In years from 2005 to 2023, overarching trends have revealed that with an observer present, there have been more net-sets per night, more net-sets with zero sardine catch, lower sardine catch rates per net-set (even when excluding zero-catches), and a higher likelihood of retaining a larger sardine catch in the event of a mortality incident. These indices of fishing behaviour were not significantly different in data collected with and without an observer present in 2024. Also, there was no significant difference for any vessel in catch per net-set, with versus without an observer present. Thus, no apparent observer-effect was detected for 2024.

Progressive adaptations in fisher behaviour may have influenced the steady reduction in the frequency of delays to net-setting caused by dolphin sightings. In 2020, 24% of net-sets were delayed due to dolphin presence. In 2023 this was 13% of net-sets, and in 2024 it was 7%. Recognition of where and when dolphins may be more/less likely to interact, and methods to avoid interactions, likely have been refined over time.

4.4. Management considerations

Observer effect and under-reporting

The 2024 annual data showed no evidence of a significant observer effect or under-reporting of dolphin mortalities. Several factors may have contributed to these outcomes, including

progressive adaptation within the fishery and the increase in observer coverage from 10% to 20%, with 2024 being the first full year since 20% observer coverage was implemented in July 2023. Progressive adaptation has been evident since 2005, with a gradual reduction in dolphin interaction rates and increasing alignment between data recorded in observed and unobserved net-sets.

Dolphin interactions

In 2024, Common Dolphin sightings and interaction rates in the SASF were lower than in previous years. A possible factor to influence this may have been a lower abundance of Common Dolphins in the SASF regions. There is minimal information on Common Dolphin distribution and movement in the region. Common Dolphin surveys conducted in 2011 and 2021 in the core fishing area of the SASF during the main fishing period, revealed similar distribution and abundance patterns (Goldsworthy et al. in review, Parra et al. 2021), but based on recorded variabilities in Common Dolphin distributions elsewhere (e.g., southern Africa: Cockcroft and Peddemors 1990; New Zealand: Stockin et al. 2008; and the north Atlantic: Murphy et al. 2013), there could be more variability in distribution in South Australia than was detected in these two survey years.

Potential drivers of interannual variations in Common Dolphin distributions in South Australian coastal waters include temporal changes in prey availability, water temperature and currents (Bilgmann et al. 2014, Peters et al. 2020, Zanardo et al. 2016). Off the south-east coast of southern Africa, seasonal migrations of Common Dolphins are driven by changes in availability of their main prey (the Southern African Sardine, *Sardinops ocellatus*; Cockcroft and Peddemors 1990). In South Australia, the Australian Sardines may be an important prey of Common Dolphins and interannual changes in distribution and availability of this fish may alter dolphin distributions.

One major oceanographic difference between the years of 2020-23 and 2024 was that in February 2024, a strong upwelling event occurred off the South Australian coast, and colder than average waters persisted on the continental shelf through autumn (Figure 9, from IMOS Ocean Current data available at <https://oceancurrent.aodn.org.au/>). In 2023, upwelling occurred but was weaker than in 2024 (Figure 9). Common Dolphins are widely distributed from tropical to cool temperate waters, so they can tolerate a broad temperature range (Jefferson et al. 2007). However, Common Dolphins do avoid water temperatures below 15°C (Jefferson et al. 2009, Murphy et al. 2013). The colder oceanographic conditions in SA shelf waters in 2024 may have reduced dolphin abundance in the fishing area of the SASF.

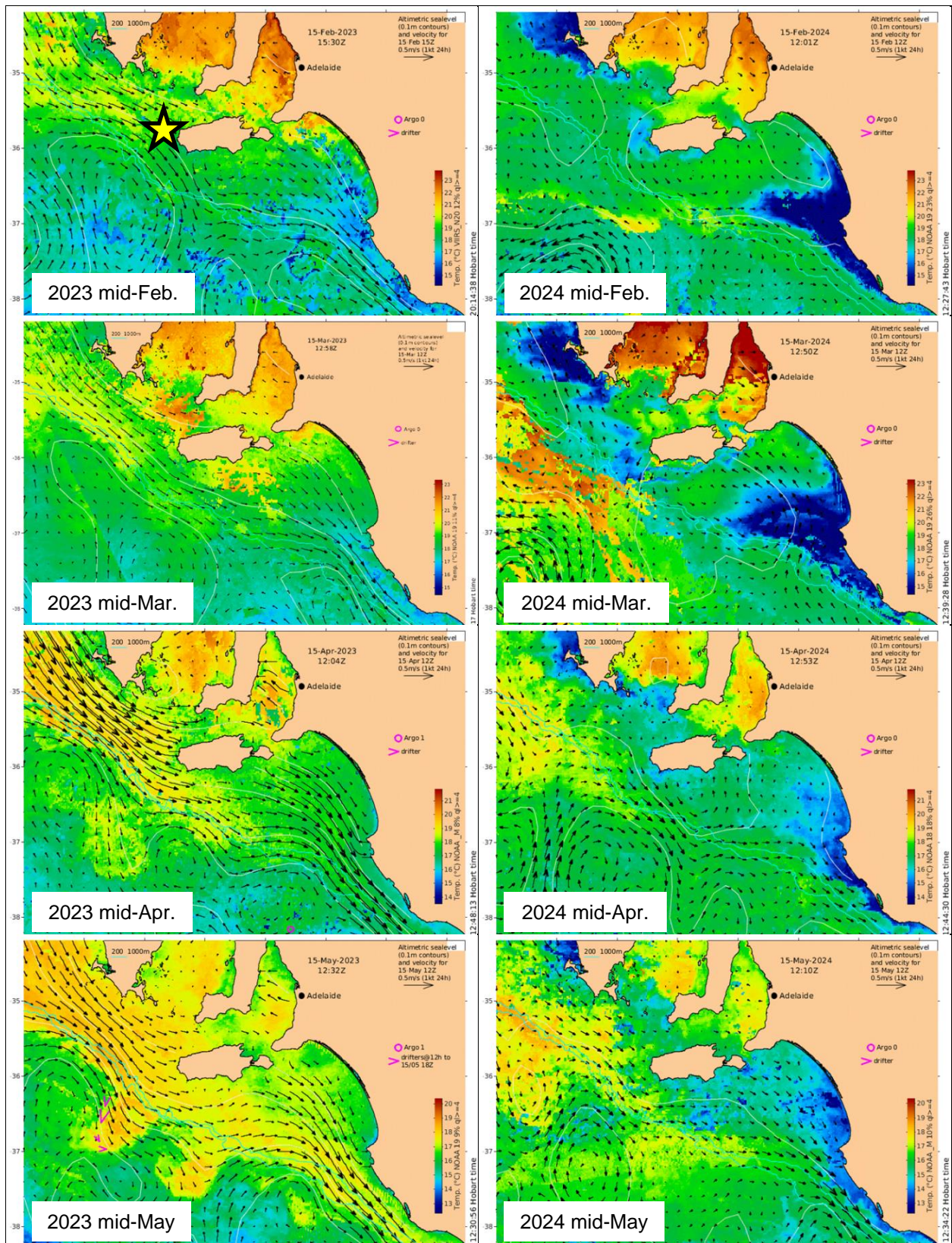


Figure 9. IMOS sea-surface temperature data (blue = ~14-15°C, dark-green = ~17°C, red = ~22°C) off South Australia, for mid-February to mid-May, 2023 and 2024 (IMOS Ocean Current data available at <https://oceancurrent.aodn.org.au/>).

During January to March off SA, upwelling routinely brings cold (<15°C) bathyal waters onto the continental shelf (Lewis 1981). The upwelling is initiated by easterly winds blowing surface shelf-waters adjacent to west-facing coastlines, offshore (Schahinger 1987, McClatchie et al. 2006). The volume of the colder water drawn onto the shelf and its expression on the surface varies between years, depending on the strength and persistence of the easterly winds (Shute et al. 2022). In 2024, the volume, surface expression and persistence on the shelf of the cold water, was greater than usual (Figure 9). It was also colder. In the summers of 2021 to 2023, the surface waters at the IMOS National Reference Station west of Kangaroo Island dropped to 14.5°C, whereas in 2024, they reached 11.5°C (Figure 10).

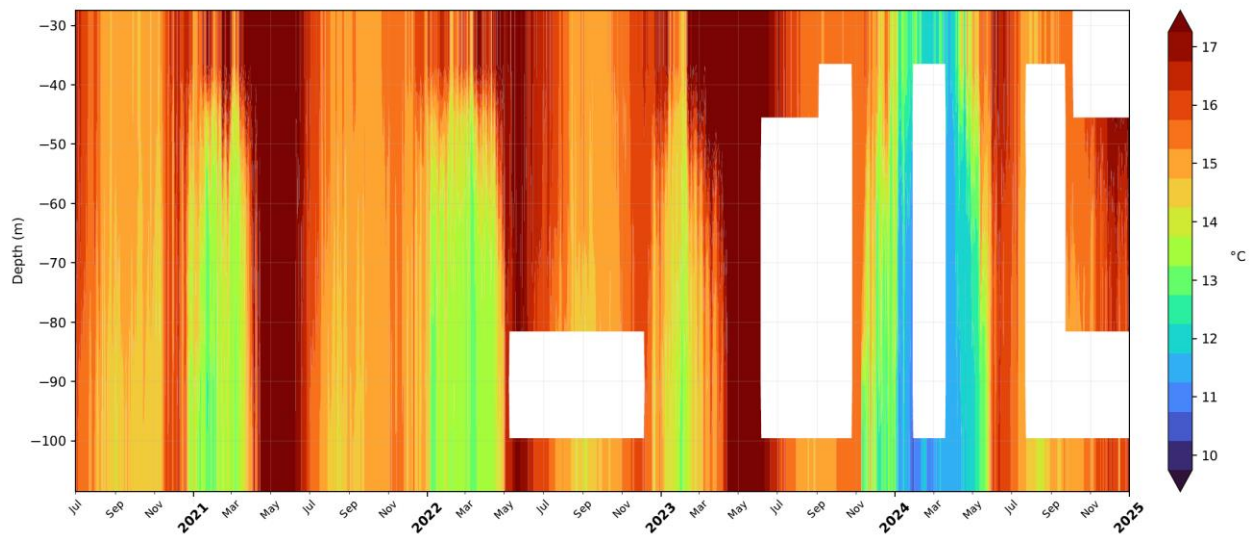


Figure 10. Water temperature profiles (30 to 100m depth) from July 2020 to Dec. 2024, measured at the IMOS National Reference Station west of Kangaroo Island (location given by star in top-left panel of Figure 10). White blocks are missing data (figure supplied by SARDI Oceanography).

Upwelling of water bodies with temperatures below 13°C became evident at the IMOS reference station in November 2023, and persisted on the shelf into May 2024 (Figures 11). To avoid these cold temperatures, Common Dolphins may have moved higher up the gulfs or offshore. Further research on the distribution and abundance of Common Dolphins in SA could help to identify links with oceanographic conditions and explain some of the variability in dolphin interaction rates with the SASF.

Dolphin Deterrent Devices

In late 2024, the SASF received permits to use acoustic Dolphin Deterrent Devices (DDD) to test if they reduced Common Dolphin interactions during net-setting operations. The device adopted, the DDD-03H (STM Industrial Electronics, Italy), has been shown to be effective in reducing Common Dolphin interactions in a night-time purse-seine fishery in the Algarve Region, Spain (Marçalo et al. 2025). Although many wild fisheries, including the SASF, have previously trialled acoustic deterrent devices, results have been variable (Ward et al. 2023, Voß et al. 2024). Short-term reductions in interaction rates have been achieved; however, evidence of long-term deterrence has been challenging to demonstrate. After a period of deterrence around fishing operations, marine mammal numbers may increase, possibly due to the attraction to enhanced feeding opportunities gradually outweighing the deterrent effect (e.g., Würsig and Gailey 2002, Schaker and Blumstein 2013).

Compared with previous acoustic deterrents, DDD-03H's aim to reduce the opportunity for dolphin adaptation by producing acoustics in randomly assigned frequency spectra (5-250kHz, including up-sweeps which are known to have a high chance of deterring marine mammals, Kastelein et al. 2014), sound level ranges (pulse 130-165 dB re 1 μ Pa at 1m), durations (55-9000 milliseconds [ms] plus click trains of 100ms), and periods (on average every 40s). The careful deployment of DDD-03H's in the SASF may further reduce dolphin interaction rates; however, their effectiveness in this fishery has not yet been evaluated.

4.5. Conclusions

Analyses of observer and logbook data collected for the SASF in 2024 indicated no evidence of a significant observer effect or under-reporting of dolphin mortalities. These findings likely reflect progressive changes and adaptations within the fishery aimed at minimising dolphin interactions.

The reduced rate of dolphin interactions observed in 2024 may also have been influenced by lower Common Dolphin abundance in fishing areas, potentially associated with strong upwelling events and the prolonged presence of cold water on the continental shelf from late summer into autumn.

Continued monitoring will be important to better understand the relationship between oceanographic conditions, Common Dolphin distribution, and their interactions with SASF operations.

REFERENCES

- Archer, F., Gerrodette, T., Dizon, A., Abella, K. and Southern, S. (2001). Unobserved kill of nursing dolphin calves in a tuna purse-seine fishery. *Marine Mammal Science* 17: 540-554.
- Barceló, A., Sandoval-Castillo, J., Brauer, C.J., Bilgmann, K., Parra, G.J., Beheregaray, L.B. and Möller, L.M. (2022). Seascape genomics of common dolphins (*Delphinus delphis*) reveals adaptive diversity linked to regional and local oceanography. *BMC Ecology and Evolution* 22(1): 88.
- Barceló, A., Sandoval-Castillo, J., Stockin, K.A., Bilgmann, K., Attard, C.R M., Zanardo, N., Parra, G.J., Hupman, K., Reeves, I.M., Betty, E.L., Tezanos-Pinto, G., Beheregaray, L B. and Möller, L.M. (2021). A matter of scale: population genomic structure and connectivity of fisheries at-risk common dolphins (*Delphinus delphis*) from Australasia. *Frontiers in Marine Science* 8: 616673.
- Bartholomew, D.C., Mangel, J.C., Alfaro-Shigueto, J., Pingo, S., Jimenez, A. and Godley, B.J. (2018). Remote electronic monitoring as a potential alternative to on-board observers in small-scale fisheries. *Biological Conservation* 219: 35-45.
- Benoît, H.P. and Allard, J. (2009). Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards? *Canadian Journal of Fisheries and Aquatic Sciences* 66(12): 2025-2039.
- Bilgmann, K., Möller, L.M., Harcourt, R.G., Gales, R. and Beheregaray, L.B. (2008). Common dolphins subject to fisheries impacts in Southern Australia are genetically differentiated: implications for conservation. *Animal Conservation* 11: 518-528.
- Bilgmann, K., Parra, G.J., Zanardo, N., Beheregaray, L.B. and Möller, L.M (2014). Multiple management units of short-beaked common dolphins subject to fisheries bycatch off southern and south-eastern Australia. *Marine Ecology Progress Series* 500: 265-279.
- Bilgmann, K., Parra, G.J. and Möller, L.M. (2017). Occurrence, distribution and abundance of cetaceans off the western Eyre Peninsula in the Great Australian Bight. *Deep Sea Research Part II* 157-158: 135-145.
- Burns, R.J. and Kerr, G.N. (2008). Observer effect on fisher bycatch reports in the New Zealand ling (*Genypterus blacodes*) bottom longlining fishery. *New Zealand Journal of Marine and Freshwater Research* 42(1): 23-32.

Cockcroft, V.G. and Peddemors, V.M. (1990). Seasonal distribution and density of common dolphins *Delphinus delphis* off the south-east coast of southern Africa. *South African Journal of Marine Science* 9(1): 371-377.

Duarte, D. and Cadrin, S.X. (2024). Review of methodologies for detecting an observer effect in commercial fisheries data. *Fisheries Research* 274: 107000.

Edwards, E.F. (2006). Duration of unassisted swimming activity for spotted dolphin (*Stenella attenuata*) calves: implications for mother-calf separation during tuna purse-seine sets. *Fisheries Bulletin* 104: 125-135.

Emery, T.J., Noriega, R., Williams, A.J. and Larcombe, J. (2019). Changes in logbook reporting by commercial fishers following the implementation of electronic monitoring in Australian Commonwealth fisheries. *Marine Policy* 104: 135-145.

Faunce, C.H. and Barbeaux, S.J. (2011). The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer. *ICES Journal of Marine Science* 68(8): 1757-1763.

Forney, K.A., St Aubin, D.J. and Chivers, S.J. (2002). Chase encirclement stress studies on dolphins involved in eastern tropical Pacific Ocean purse-seine operations during 2001. *NOAA Administrative Report LJ-02-32*. 26 pp.

Filby, N.E., Bossley, M., Sanderson, K.J., Martinez, E. and Stockin, K.A. (2010). Distribution and population demographics of common dolphins (*Delphinus delphis*) in the Gulf St. Vincent, South Australia. *Aquatic Mammals* 36: 33-45.

Gilman, E., Suuronen, P., Hall, M. and Kennelly, S. (2013). Causes and methods to estimate cryptic sources of fishing mortality. *Journal of Fish Biology* 83(4): 766-803.

Goldsworthy, S.D. (2018). Effectiveness of the industry Code of Practice in mitigating Interactions between short-beaked common dolphins and the South Australian Sardine Fishery: 2017-18 Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. F2010/000726-9. *SARDI Research Report Series* No. 1000. 36 pp.

Goldsworthy, S.D., Ferguson, G.J. and Ward, T.M. (2019). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2018-19. Report to PIRSA Fisheries and Aquaculture. South Australian Research and

Development Institute (Aquatic Sciences), Adelaide. F2010/000726-10. *SARDI Research Report Series* No. 1041. 36 pp.

Goldsworthy, S.D., Kirkwood, R., Kemper, C., Bilgmann, K. and Bailleul, F. (in review). Abundance, population modelling, and potential biological removal estimates for Common Dolphins in Spencer Gulf: implications for the South Australian Sardine Fishery, Adelaide. *Final Report to FRDC* 2019-063.

Grammer, G. L. and Ivey, A. R. (2023). Spawning biomass of Sardine, *Sardinops sagax*, in waters off South Australia in 2023. Report to PIRSA Fisheries and Aquaculture (PDF 3.6 MB). South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2007/000566-13. *SARDI Research Report Series* No. 1194. 32 pp.

Grammer, G.L., Bailleul, F. and Ivey, A. (2024). Stock assessment of Australian Sardine (*Sardinops sagax*) off South Australia 2023. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000765-9. *SARDI Research Report Series* No. 1208. 105 pp.

Hamer, D.J. and Ward, T.M. (2007). Operational interactions between the South Australian Sardine Fishery and common dolphins in 2006/07: assessing the effectiveness of the industry Code of Practice. SARDI Aquatic Science Publication No. F2007/00198-1. *SARDI Research Report Series* No. 252. 30 pp.

Hamer, D.J., Ward, T.M., Goldsworthy, S.D., McGarvey, R. and Rogers, P.J. (2007). Measurement, management and mitigation of operational interactions between common dolphins and the South Australian Sardine Fishery. SARDI Aquatic Science Publication No. F2006/00212. *SARDI Research Report Series* No. 174. 38 pp.

Hamer, D.J., Ward, T.M. and McGarvey, R. (2008). Measurement, management and mitigation of operational interactions between the South Australian Sardine Fishery and short-beaked common dolphins (*Delphinus delphis*). *Biological Conservation* 141: 2865-2878.

Hamer, D.J., Ivey, A. and Ward, T.M. (2009). Operational Interactions of the South Australian Sardine Fishery with the common dolphin: November 2004 to March 2009. SARDI Aquatic Science Publication No F2007/001098-2. *SARDI Research Report Series* No. 354. 32 pp.

Harris, L.W.E. (1998). The quantification of perceptual and behavioural variation in commercial fishing logbooks. Master's Thesis, University of Manitoba, Department of Zoology. 76 pp.

Available from: <https://mspace.lib.umanitoba.ca/server/api/core/bitstreams/7b740f60-25f7-4405-b389-fc94527a0c81/content>

Heinemann, D. (2017). Cryptic mortality correction factors, In: National Marine Fisheries Service. Proceedings of the First National Protected Species Assessment Workshop. *NOAA Technical Memorandum NMFS-F/SPO-172*. pp 60-63.

Jaiteh, V.F., Allen, S.J., Meeuwig, J.J. and Loneragan, N.R. (2013). Subsurface behavior of bottlenose dolphins (*Tursiops truncatus*) interacting with fish trawl nets in northwestern Australia: Implications for bycatch mitigation. *Marine Mammal Science* 29(3): E266-E281.

Jefferson, T.A., Webber, M.A. and Pitman, R.L. (2007). *Marine mammals of the world: a comprehensive guide to their identification*. 2nd Edition. Academic Press/Elsevier, San Diego.

Jefferson, T.A., Fertl, D., Bolaños-Jiménez, J. and Zerbin, A.N. (2009). Distribution of common dolphins (*Delphinus* spp.) in the western Atlantic Ocean: a critical re-examination. *Marine Biology* 156(6): 1109-1124.

Johnson, D.R., Yeung, C. and Brown, C.A. (1999). Estimates of marine mammal and marine turtle bycatch by the US Atlantic pelagic longline fleet in 1992-1997. *NOAA Technical Memorandum NMFS-SEFSC-418*. 70 pp.

Kastelein, R.A., Schop, J., Gransier, R., Steen, N. and Jennings, N. (2014). Effect of series of 1 to 2 kHz and 6 to 7 kHz up-sweeps and down-sweeps on the behavior of a harbor porpoise (*Phocoena phocoena*). *Aquatic Mammals* 40(3): p.232-242.

Kelleher, K. (2005). Discards in the world's marine fisheries: an update. *FAO Fisheries Technical Paper* 470. Rome. 131 pp.

Kennelly, S. (2020). Australia's First National Bycatch Report. *FRDC Project Report* ISBN: 978-0-6488217-0-0. 128 pp.

Kemper, C., Tomo, I., Bovari, G., Hamer, D., Gibbs, S. and Fellowes, T.S. (2023). Characterising injuries and pathologies of common dolphin *Delphinus delphis* mortalities in the South Australian Sardine Fishery. *Diseases of Aquatic Organisms* 156: 99-114.

Kirkwood, R. and Goldsworthy, S.D. (2021). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2020-21. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute

(Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-12. *SARDI Research Report Series* No. 1116. 31 pp.

Kirkwood, R. and Goldsworthy, S.D. (2022). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2021-22. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-13. *SARDI Research Report Series* No. 1154. 34 pp.

Kirkwood, R. and Goldsworthy, S.D. (2024a). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2022. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2010/000726-14. *SARDI Research Report Series* No. 1209. 58 pp.

Kirkwood, R. and Goldsworthy, S.D. (2024b). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2023. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2010/000726-15. *SARDI Research Report Series* No. 1220. 48 pp.

Kirkwood, R.J., Goldsworthy, S.D. and Ward, T.M. (2020). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2019-20. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-11. *SARDI Research Report Series* No. 1077. 34 pp.

Lewis, R.K. (1981). Seasonal upwelling along the south-eastern coastline of South Australia. *Marine and Freshwater Research* 32: 843–854.

Luck, C., Jessopp, M., Tully, O., Cosgrove, R., Rogan, E. and Cronin, M. (2020). Estimating protected species bycatch from limited observer coverage: A case study of seal bycatch in static net fisheries. *Global Ecology and Conservation* 24: p.e01213.

McClatchie, S., Middleton, J.F., Ward, T.M. (2006). Water mass analysis and alongshore variation in upwelling intensity in the eastern Great Australian Bight. *Journal of Geophysical Research: Oceans* 111(C8).

Mackay, A.I. and Goldsworthy, S.D. (2016). Mitigating operational interactions with short-beaked common dolphin (*Delphinus delphis*): application of the South Australian Sardine Fishery industry Code of Practice 2015-16. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. F2010/000726-7. *SARDI Research Report Series* No. 934. 39 pp.

Mackay, A.I. and Goldsworthy, S.D. (2017). Mitigating operational interactions with short-beaked common dolphin (*Delphinus delphis*): application of the South Australian Sardine Fishery industry Code of Practice 2016-17. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. F2010/000726-8. *SARDI Research Report Series* No. 970. 44 pp.

Marçalo, A., Carvalho, F., Frade, M., Bentes, L., Monteiro, P., Pontes, J., Alexandre, S., Oliveira, F., Kingston, A., Erzini, K. and Gonçalves, J.M. (2025). Reducing cetacean interactions with bottom set-nets and purse seining using acoustic deterrent devices in southern Iberia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 35(2): p.e70061.

Moore, J.E., Heinemann, D., Francis, T.B., Hammond, P.S., Long, K.J., Punt, A.E., Reeves, R.R., Sepúlveda, M., Sigurðsson, G.M., Siple, M.C. and Víkingsson, G.A. (2021). Estimating bycatch mortality for marine mammals: concepts and best practices. *Frontiers in Marine Science* 8: p.752356.

Murphy, S., Pinn, E.H. and Jepson, P.D. (2013). The short-beaked common dolphin (*Delphinus delphis*) in the North-East Atlantic: distribution, ecology, management and conservation status. *Oceanography and Marine Biology: An annual review*, 51: 193-280.

Perrin, W. (2017). Common Dolphins. In: *Encyclopedia of Marine Mammals: Third Edition* (eds B Würsig, J.G.M. Thewissen and K.M. Kovacs) Academic Press, Elsevier. pp 205-209.

Parra, G.J., Bilgmann, K., Peters, K.J. and Möller, L.M. (2021). Abundance and potential biological removal of common dolphins subject to fishery impacts in South Australian waters. *Frontiers in Marine Science* 8:1237.

PIRSA (2014). Paper number 68: Management plan for the South Australian Commercial Marine Scalefish Fishery, Part B– management arrangements for the taking of sardines South Australian Fisheries Management Series. 88 pp.

PIRSA (2020). Sardine Fishery Operator User Guide. Government of South Australia. 21 pp.

R Core Team (2025). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.Rproject.org/> .

SASIA (2021). Code of practice for mitigating the interactions of the South Australian Sardine Fishery with wildlife. South Australian Sardine Industry Association (SASIA). Port Lincoln. 16 pp.

Schahinger, R.B. (1987). Structure of coastal upwelling events observed off the south-east coast of South Australia during February 1983–April 1984. *Australian Journal of Marine and Freshwater Research* 38(4): 439-459.

Schakner, Z.A. and Blumstein, D.T. (2013). Behavioral biology of marine mammal deterrents: a review and prospectus. *Biological Conservation* 167: 380-389.

Shute, A., Kämpf, J., Doubell, M., Rodriguez, A.R., Möller, L., Baring, R. and Newman, M. (2022). Variability of surface and subsurface phytoplankton blooms in a seasonal coastal upwelling system. *Continental Shelf Research* 246. p.104832.

St Aubin, D.J., Forney, K.A., Chivers, S.J., Scott, M.D., Danil, K., Romano, T.A., Wells, R.S. and Gulland, F.M. (2013). Haematological, serum, and plasma chemical constituents in pantropical spotted dolphins (*Stenella attenuata*) following chase, encirclement, and tagging. *Marine Mammal Science* 29(1): 14-35.

Stockin, K.A., Pierce, G.J., Binedell, V., Wiseman, N. and Orams, M.B. (2008). Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Aquatic Mammals* 34(2): 200-211.

Torres-Villegas, J.R., Ochoa-Báez, R.I., Pérez Gómez-Álvarez, L. and García-Melgar, G. (1995). Comparison of seasonal variability in the reproduction of Pacific sardine (*Sardinops sagax*) from Baja California Sur, Mexico, in the years 1982-1992. *Scientia Marina* 59(3-4): 255-264.

Voß, J., Rose, A., Kosarev, V., Vilela, R., Diederichs, A. (2024). Response of harbor porpoises to pingers and acoustic harassment devices. In: Popper, A.N., Sisneros, J.A., Hawkins, A.D., Thomsen, F. (eds) *The effects of noise on aquatic life*. Springer, Cham. https://doi.org/10.1007/978-3-031-50256-9_178.

Ward, T.M., Attwood-Henderson, I. and Kirkwood, R. (2023). Monitoring and mitigating interactions between small pelagic fisheries and dolphins: literature review and analysis of fishery data. Fisheries Research and Development Corporation Project No. 2020-049, *Final Report to FRDC* 46 pp.

Ward, T.M., Ivey, A.R. and Burch, P. (2010). Effectiveness of an Industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-1. *SARDI Research Report Series* No. 439. 38 pp.

Ward, T.M., Ivey, A., Hamer, D.J. and Burch, P. (2011). Effectiveness of an industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-2. *SARDI Research Report Series* No. 583. 32 pp.

Ward, T.M., Ivey, A.R. and Burch, P. (2012). Effectiveness of an Industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-3. *SARDI Research Report Series* No. 666. 27 pp.

Ward, T.M., Ivey, A.R. and Burch, P. (2013). Effectiveness of an Industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-4. *SARDI Research Report Series* No. 743. 32 pp.

Ward, T.M., Ivey, A. and Carroll, J. (2015a). Effectiveness of an industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-5. *SARDI Research Report Series* No. 821. 35 pp.

Ward, T.M., Ivey, A. and Carroll, J. (2015b). Effectiveness of an industry Code of Practice in mitigating the operational interactions of the South Australian Sardine Fishery with the short-beaked common dolphin (*Delphinus delphis*). Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000726-6. *SARDI Research Report Series* No. 876. 35 pp.

Ward, T.M., Ivey, A. and Carroll, J. (2018). Code of practice for reducing accidental mortality of dolphins in purse-seine fisheries. *Marine Policy* 87: 203-211.

Wakefield, C.B., Hesp, S.A., Blight, S., Molony, B.W., Newman, S.J. and Hall, N.G. (2018). Uncertainty associated with total bycatch estimates for rarely-encountered species varies substantially with observer coverage levels: Informing minimum requirements for statutory logbook validation. *Marine Policy* 95: 273-282.

Wickham, H., François, R., Henry, L., Müller, K. and Wickham, M.H. (2019). Package 'dplyr'. A grammar of data manipulation. R package version 8.

Wood, S.N., Pya, N. and Säfken, B. (2016). Smoothing parameter and model selection for general smooth models. *Journal of the American Statistical Association* 111(516): 1548-1563.

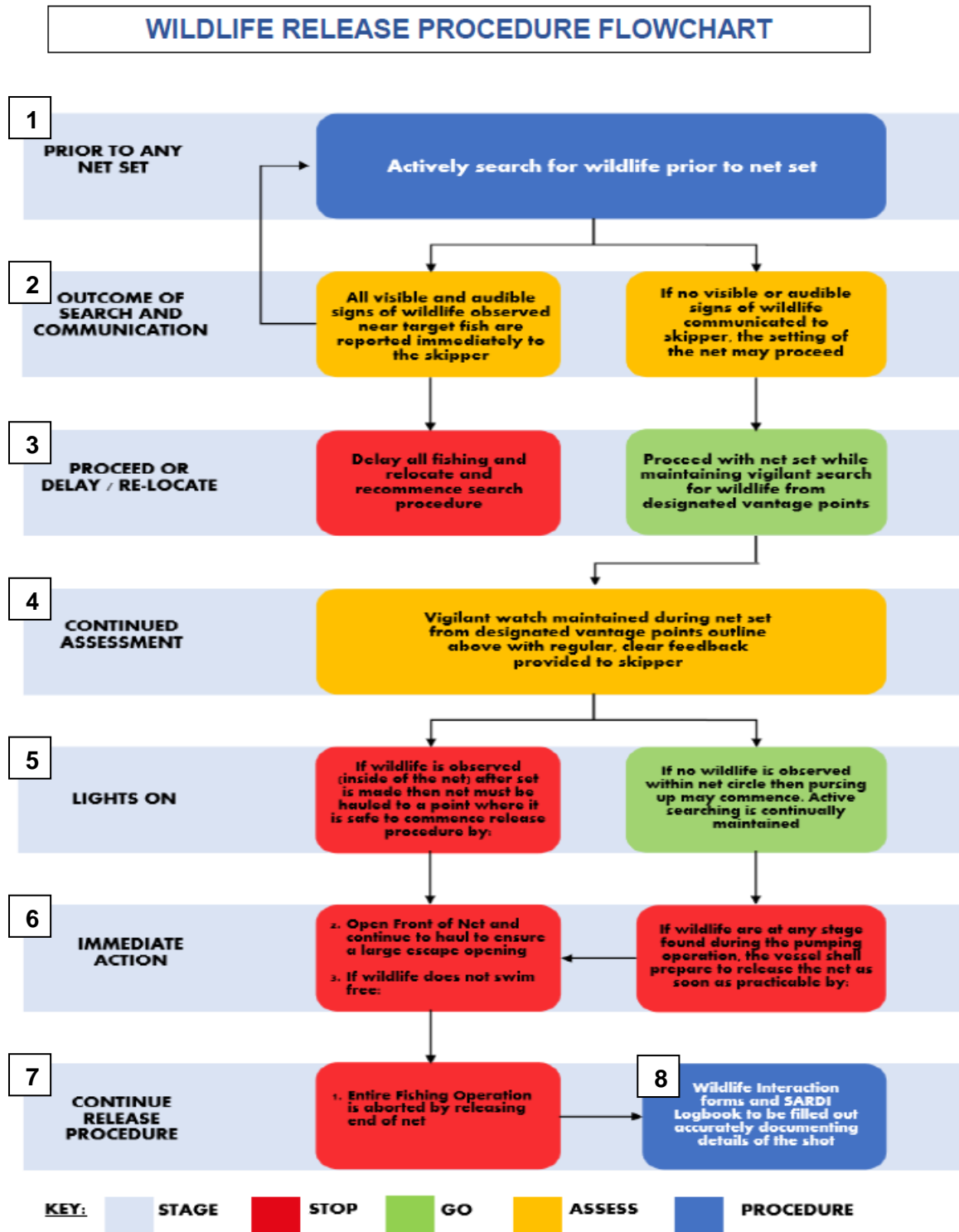
Wood, S.N. (2017). *Generalized additive models: an introduction with R, 2nd edition*. CRC press, Bristol, UK.

Würsig, B. and Gailey, G.A. (2002). Marine mammals and aquaculture: conflicts and potential resolutions. In Stickney, R.R. and McVey, J.P. (eds) *Responsible marine aquaculture*. Cabi Publishing, Wallingford UK. pp 45-59.

Zollett, E.A., Trumble, R.J., Swasey, J.H. and Stebbins, S.B. (2015). Guiding principles for development of effective commercial fishery monitoring programs. *Fisheries* 40(1): 20-25.

APPENDIX 1. CODE OF PRACTICE FLOWSHEET

Operational steps to mitigate interactions with Common Dolphins in the South Australian Sardine Fishery (SASF), Code of Practice (CoP) (SASIA 2021).



** This procedure is a requirement of the Code of Practice and must be displayed at all times in the wheelhouse and galley

APPENDIX 2. OBSERVER DATASHEET

SASF TEPS OBSERVER DATASHEET

SARDI Logbook No.		Observer name and signature	
Trip Start Date			
Trip End Date		Time of each fishing stage	Time (24:00 hr)
Skipper name		1. Start net-set	
Vessel name and Licence no.		2. Begin pursing	
Shot date		3. Begin hauling	
Shot no.		4. End hauling	
Wind (knots)		5. Begin pumping	
Swell height (m)		6. Finish net-set	

Code of Practice Assessment	Y/N	No. of times	Comments (details of application of CoP)
Active search from designated vantage points			
Dolphins present – delay			
Dolphins present – relocate			
Active search after setting			
Immediate action to encirclement			

Dolphin encirclement details

Species							
Time first observed (24:00hr)							
Time release commenced (24:00hr)							
Stage first observed	Setting <input type="checkbox"/>	Pursing <input type="checkbox"/>	Hauling <input type="checkbox"/>	Pumping <input type="checkbox"/>			
Stage release commenced	Setting <input type="checkbox"/>	Pursing <input type="checkbox"/>	Hauling <input type="checkbox"/>	Pumping <input type="checkbox"/>			
Release method used	Open front of net <input type="checkbox"/>	Abort shot <input type="checkbox"/>	Herd with skiff <input type="checkbox"/>	Cut out of net <input type="checkbox"/>	Other (describe):		
Initial condition of dolphins	Nature of encirclement			Condition of released dolphins			
No. alive	No. free in net		No. alive				
No. injured	No. entangled inside net		No. injured				
No. dead	No. entangled outside net		No. dead				
Comments							
<p align="center">IF NO FISH CAUGHT THIS SHOT PLEASE ✓ BOXES</p>							
No Fish Seen	Shot Missed School	Too Rough	Break Down	Net Damage	Dolphins	Fish Not Schooling	Other

Wildlife interactions	Species	No. of individuals	Behaviour / nature of interaction
Dolphins (outside net)			
Seals			
Sharks			
Other			

APPENDIX 3. WILDLIFE INTERACTION FORM

SOUTH AUSTRALIAN SARDINE FISHERY WILDLIFE INTERACTION FORM

Date of interaction Observer On Board (tick) Yes No Licence Number Corresponding Logbook No.

Shot No.	Time (24:00 HR)	Location		Common species name (see species list and identification guide)	Number of Animals	Nature of interaction			Status			Fate		Band or tag #	
		Latitude	Longitude			Caught	Entangled	Impact/collision	Other	Alive	Dead	Injured	Released / discarded		Retained

CODE OF PRACTICE ASSESSMENT – FILL IN WHEN A DOLPHIN IS SIGHTED DURING SEARCHING AND/OR ENCIRCLEMENT OCCURS

Actively search prior to setting: No <input type="checkbox"/> Yes <input type="checkbox"/>	Dolphins present – delay and/or Dolphins present – relocate No <input type="checkbox"/> Yes <input type="checkbox"/>	No. of times: _____	Actively search after setting: No <input type="checkbox"/> Yes <input type="checkbox"/>
Time (24:00HR) first observed	Stage first observed	Setting <input type="checkbox"/> Pursuing <input type="checkbox"/> Hauling <input type="checkbox"/> Pumping <input type="checkbox"/>	Time (24:00HR) release commenced
Release method used	Open front of net <input type="checkbox"/> Abort shot <input type="checkbox"/>	Setting <input type="checkbox"/> Pursuing <input type="checkbox"/> Hauling <input type="checkbox"/> Pumping <input type="checkbox"/>	Other (describe):
Initial condition of dolphins		Condition of released dolphins	
No. alive	No. free in net	No. alive	
No. injured	No. entangled inside net	No. injured	
No. dead	No. entangled outside net	No. dead	
Comments:			

I certify this form to be complete and accurate (Signature of Licence Holder/Master)

APPENDIX 4. GAM RESULTS

Variable	Data type	Description
vessel	random factor	Only used in GAMs for catch (random factor due to range of vessel capacities)
moon phase	factor	8 phases: new moon (1new), waxing to first quarter (2wax), first quarter (3firstq), waxing to full (4wax), full moon (5full), waning to last quarter (6wan), last quarter (7lastq), waning to new moon (8wan)
time-of-day	factor	8 x 3-hour blocks: 0–3am, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24
zone	factor	Spencer Gulf (1sg), Gulf St Vincent (2gsv), South-East (3se), West Coast (4wc)
water depth	numeric	Bathymetry (in metres) at the location recorded in logbooks for the net-set, using 2009 bathymetry metadata available from Geoscience Australia, aligned with locations using the <i>raster</i> package in R. Not all locations in logbooks were in fishing zones. To reduce bias from potentially incorrectly entered locations and still maximise data retention, positions interpreted to be on land (i.e., positive metres) or too shallow for a net-set (~0–10m depth), bathymetries above 10m were changed to 10m depth. Similarly, few net-sets in the fishery have been in depths >100 m, so net-sets determined to be below 150m were changed to 150m depth.
observer	factor	absent, present
encirclement event	factor	en_event: no, yes
dolphins encircled	numeric	en_dolphins
mortality event	factor	m_event: no, yes
estimated catch	numeric	est_catch, tonnes of sardines retained
search hours	numeric	Hours between when sonar was switch on to commence searching for sardine schools and when a net was set, recorded in logbooks – although not consistently by all fishers. Only used in Observer GAM for 2013-2024 data.

Appendix 4.1 GAMs for observer presence

~ moon_phase + time_of_day + zone + depth + en_event + encircle + m_event + estcatch
(+ search_hrs in ≥ 2013 GAM)

Significance codes: *** = <0.001 (i.e., 1^{-3}), ** = <0.01 , * = <0.05 , . = <0.1

Year/s	≥ 2013 (n = 10945)		2021 (n = 858)		2022 (n = 997)		2023 (n = 992)		2024 (n = 928)	
Coefficients	z	p	z	p	z	p	z	p	z	p
(Intercept)	-20.9	$<2^{-16}$ ***	-7.0	3.3^{-12} ***	-6.2	4.8^{-10} ***	-6.2	6.6^{-10} ***	-8.0	9.1^{-16} ***
<i>Moon:1new</i>										
2wax	-1.26	0.21	1.95	0.05	0.78	0.43	-0.72	0.47	-0.05	0.96
3firstq	1.88	0.06	1.85	0.06	0.25	0.80	0.31	0.76	1.01	0.31
4wax	-0.70	0.48	1.91	0.06	1.72	0.08	-1.19	0.24	1.91	0.06
5full	0.66	0.51	2.3	0.02 *	1.29	0.20	-0.67	0.50	0.33	0.74
6wan	-1.39	0.16	1.69	0.09	-0.51	0.61	-1.82	0.07	-0.29	0.77
7lastq	1.55	0.12	1.91	0.06	1.99	0.05 *	-1.56	0.12	1.20	0.23
8wan	-0.23	0.82	2.17	0.03 *	-0.65	0.52	0.28	0.78	-0.50	0.62
<i>Time:0 - 3h</i>										
3 - 6	0.34	0.74	0.63	0.53	-0.68	0.5	0.06	0.95	0.94	0.35
6 - 9	2.71	0.01 **	1.27	0.20	-1.07	0.28	-1.58	0.11	0.28	0.78
9 - 12	1.52	0.13	-0.01	1.00	-0.13	0.90			1.72	0.09
12 - 15	0.75	0.46	0.00	1.00	1.45	0.15	-4.0^{-3}	1.00	1.19	0.23
15 - 18	1.89	0.06	2.58	0.01 **	1.48	0.14	1.63	0.10	0.79	0.43
18 - 21	0.87	0.38	0.59	0.55	-0.95	0.34	0.64	0.52	1.83	0.07
21 - 24	0.16	0.87	1.15	0.25	-0.31	0.76	0.27	0.79	1.62	0.11
<i>Zone:1sg</i>										
2gsv	1.43	0.15	2.23	0.03 *	-2.00	0.05 *	1.34	0.18	2.41	0.02 *
3se	-3.30	9.8^{-4} ***	-0.99	0.32	0.41	0.68	-1.74	0.08	-2.57	0.01 *
4wc	-0.95	0.34	-0.06	0.95	-0.58	0.56	1.07	0.29	-0.74	0.46
depth	-3.09	0.002 **	-0.53	0.59	-2.56	0.01 *	-0.14	0.89	-1.13	0.26
en_event	-3.94	8.1^{-5} ***	-1.32	0.19	-0.96	0.34	-0.67	0.50	-0.92	0.36
en_dolphins	1.96	0.05 *	0.65	0.52	-0.97	0.33	0.25	0.81	0.06	0.95
m_event	5.45	5.2^{-8} ***	2.86	4.3^{-3} **	2.59	0.01 **	-0.01	1.00	-0.01	0.99
est_catch	-9.65	$<2^{-16}$ ***	-3.67	2.5^{-4} ***	-5.58	2.4^{-8} ***	-2.92	3.4^{-3} **	-0.85	0.39
search_hrs	-6.04	1.5^{-9} ***								
% Deviance explained	2.79		7.24		12.1		4.75		3.58	
REML*	3962		280		318		365		473	

* REML = Restricted Maximum Likelihood (a measure of variance)

Appendix 4.2 GAMs for sardine catch (vessel as a random factor)

~ s(vessel, bs = "re") + season + moon_phase + time_of_day + zone + depth + observer

Significance codes: *** = <0.001 (i.e., 10^{-3}), ** = <0.01, * = < 0.05, . =<0.1

Year/s	≥2013 (n = 11013)			2021 (n = 858)			2022 (n = 997)			2023 (n = 992)			2024 (n = 928)		
Coefficients	<i>t</i>	<i>p</i>		<i>t</i>	<i>p</i>		<i>t</i>	<i>p</i>		<i>t</i>	<i>p</i>		<i>t</i>	<i>p</i>	
(Intercept)	8.46	4.5⁻¹⁶	***	5.26	1.9⁻⁷	***	5.60	2.7⁻⁸	***	5.70	1.6⁻⁸	***	6.02	2.6⁻¹⁶	***
<i>Season:1sum</i>															
2aut	2.76	0.01	**	1.83	0.07	.	1.30	0.19		0.32	0.75		1.65	0.10	.
3win	1.37	0.17	.	1.59	0.11		0.05	0.96		-1.40	0.16		0.27	0.79	
4spr	-2.04	0.04	*	-0.48	0.63		-0.57	0.57		-0.27	0.79		-0.79	0.43	
<i>Moon:1new</i>															
2wax	0.05	0.96		0.72	0.47		0.58	0.56		0.48	0.63		-0.90	0.37	
3firstq	-0.09	0.93		0.46	0.65		-0.08	0.94		-0.32	0.75		0.09	0.93	
4wax	0.43	0.66		0.22	0.83		-0.81	0.42		-0.25	0.80		-0.69	0.49	
5full	1.88	0.06	.	2.36	0.02	*	0.37	0.71		0.31	0.76		0.90	0.37	
6wan	2.39	0.02	*	2.35	0.02	*	-0.43	0.67		2.21	0.03	*	0.50	0.62	
7lastq	1.18	0.24		2.55	0.01	*	0.36	0.72		0.17	0.86		-0.52	0.61	
8wan	0.76	0.45		1.33	0.18		-1.02	0.31		-0.54	0.59		0.75	0.46	
<i>Time:0 – 3am</i>															
3 - 6	-4.62	3.9⁻⁶	***	-1.91	0.06	.	-2.33	0.02	*	-0.48	0.63		-1.77	0.08	.
6 - 9	-10.1	<2⁻¹⁶	***	-3.09	2.1⁻³	**	-2.72	0.01	**	-0.82	0.41		-2.28	0.02	*
9 - 12	-2.10	0.04	*	-0.50	0.62		-0.34	0.74					-0.79	0.43	
12 - 15	-0.56	0.58		2.10	0.04	*	0.52	0.60		0.69	0.49		-1.07	0.28	
15 - 18	3.05	2.3⁻³	**	1.14	0.25		1.06	0.29		1.14	0.26		0.37	0.71	
18 - 21	-5.47	4.7⁻⁸	***	-1.25	0.21		-1.50	0.13		-0.10	0.92		-2.01	0.05	*
21 - 24	0.95	0.34		1.11	0.27		1.67	0.10	.	0.29	0.77		-0.73	0.47	
<i>Zone:1sg</i>															
2gsv	-2.19	0.03	**	-2.47	0.01	*	0.52	0.60		-1.15	0.25		-1.08	0.28	
3se	-2.01	0.04	*	0.93	0.36		-0.29	0.78		-0.92	0.36		-0.06	0.95	
4wc	-2.65	0.01	**	-2.97	3.1⁻³	**	0.90	0.37		-3.50	4.9⁻⁴	***	1.20	0.23	
depth	2.32	0.02	*	1.35	0.18		1.35	0.18		0.59	0.56		2.30	0.02	*
observer	-10.5	<2⁻¹⁶	***	-4.19	3.1⁻⁵	***	-5.92	4.4⁻⁹	***	-2.51	0.01	*	-0.28	0.78	
% Deviance explained	26.1			34.6			31.5			24.2			30.9		
REML	53543			4140			4809			4780			4498		

Appendix 4.3 GAMs for encirclement events

~ season + moon_phase + time_of_day + zone + depth + observer

Significance codes: *** = <0.001 (i.e., 10^{-3}), ** = <0.01, * = < 0.05, . =<0.1

Year/s	≥2013 (n = 11013)			2021 (n = 858)			2022 (n = 997)			2023 (n = 992)			2024 (n = 928)		
Coefficients	z		p	z		p	z		p	z		p	z		p
(Intercept)	-21.9	<2⁻¹⁶	***	-5.16	2.5⁻⁷	***	-7.01	2.4⁻¹²	***	-5.56	2.8⁻⁸	***	-6.84	8.2⁻¹²	***
<i>Season:1sum</i>															
2aut	0.74	0.46		0.17	0.86		2.52	0.01	*	0.40	0.69		1.53	0.13	
3win	-0.81	0.42		-0.58	0.56		1.52	0.13		-0.39	0.7		-0.25	0.81	
4spr	-2.60	0.01	**	-1.92	0.06	.	0.26	0.79		-1.13	0.26		-0.01	1.00	
<i>Moon:1new</i>															
2wax	-0.09	0.93		-0.26	0.79		-1.01	0.32		-0.18	0.86		1.46	0.14	
3firstq	0.14	0.89		1.24	0.22		-1.69	0.09	.	0.47	0.64		1.09	0.27	
4wax	-1.09	0.28		-1.44	0.15		-0.34	0.73		0.04	0.97		0.28	0.78	
5full	-0.40	0.69		-0.97	0.33		-2.32	0.02	*	-0.28	0.78		0.61	0.54	
6wan	-1.21	0.22		-2.02	0.04	*	-1.19	0.23		-0.70	0.49		1.17	0.24	
7lastq	0.43	0.66		-0.31	0.76		-0.95	0.34		-0.07	0.94		1.02	0.31	
8wan	0.16	0.88		0.41	0.68		-1.16	0.25		0.56	0.58		0.84	0.40	
<i>Time:0 - 3am</i>															
3 - 6	0.85	0.39		0.41	0.68		3.68	2.4⁻⁴	***	-0.87	0.38		2.87	4.2⁻³	**
6 - 9	1.46	0.14		2.52	0.01	*	0.45	0.65		0.32	0.75		0.15	0.88	
9 - 12	-0.24	0.81		-0.01	0.99		-0.01	0.99					0.00	1.00	
12 - 15	-0.03	0.98		-0.01	0.99		-0.01	1.00		-0.01	0.99		0.00	1.00	
15 - 18	0.66	0.51		-0.76	0.45		0.40	0.69		0.30	0.76		0.44	0.66	
18 - 21	3.23	1.2⁻³	***	0.35	0.73		1.85	0.06	.	-0.11	0.91		0.53	0.60	
21 - 24	3.58	3.5⁻⁴	***	1.87	0.06	.	0.68	0.50		0.54	0.59		1.49	0.14	
<i>Zone:1sg</i>															
2gsv	0.96	0.34		2.95	3.2⁻³	**	0.41	0.68		-1.16	0.25		-0.91	0.36	
3se	-1.03	0.30		0.87	0.39		-1.10	0.27		-0.37	0.71		-1.36	0.17	
4wc	-8.90	<2⁻¹⁶	***	-0.80	0.43		-3.81	1.4⁻⁴	***	-1.05	0.29		-0.01	0.99	
depth	-0.03	0.98		1.85	0.07	.	-1.70	0.09	.	0.32	0.75		-1.27	0.21	
observer	-0.16	0.87		0.80	0.43		-0.47	0.64		0.48	0.63		-1.41	0.16	
% Deviance explained	2.75			7.86			8.90			2.23			29.9		
REML	3501			316			308			371			144		

Appendix 4.4 GAM for mortality events

~ season + moon_phase + time_of_day + zone + depth + observer

Significance codes: *** = <0.001 (i.e., 1^{-3}), ** = <0.01, * = < 0.05, . =<0.1

Years	2013-24 (n = 11013)		
Coefficients	z	p	
(Intercept)	-8.48	2.0⁻¹⁶	***
<i>Season:1sum</i>			
2aut	-0.28	0.78	
3win	-1.10	0.27	
4spr	0.37	0.71	
<i>Moon:1new</i>			
2wax	-0.72	0.47	
3firstq	-0.07	0.95	
4wax	-0.59	0.55	
5full	-1.27	0.21	
6wan	-0.56	0.57	
7lastq	-1.24	0.22	
8wan	0.38	0.71	
<i>Time:0 - 3am</i>			
3 - 6	-1.25	0.21	
6 - 9	-0.01	0.99	
9 - 12	0.00	1.00	
12 - 15	0.00	1.00	
15 - 18	-0.01	1.00	
18 - 21	-1.23	0.22	
21 - 24	-1.74	0.08	.
<i>Zone:1sg</i>			
2gsv	0.85	0.40	
3se	0.64	0.52	
4wc	-1.68	0.09	.
depth	-0.31	0.76	
observer	4.64	3.5⁻⁶	***
% Deviance explained	11.3		
REML	155		