Marine Ecosystems

Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery in 2023

Roger Kirkwood and Simon Goldsworthy

SARDI Publication No. F2010/000726-15
SARDI Research Report Series No. 1220

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

July 2024

Report to PIRSA Fisheries and Aquaculture

Government of South Australia
Department of Primary Industries and Regions

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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This publication may be cited as:
Kirkwood, R. and Goldsworthy, S.D. (2024). Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery in 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. 48pp.

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Date:	17 July 2024
Distribution:	PIRSA Fisheries & Aquaculture, SARDI Aquatic and Livestock Sciences, Parliamentary Library, State Library and National Library
Circulation:	OFFICIAL

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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. 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.

Dr George Giatas and Dr Shannen Smith (SARDI), and Hamish Telfer (PIRSA) reviewed a draft of the report. The report was approved for release by Dr Stephen Mayfield (SARDI Fisheries Program Science Leader) and cleared for release by Dr Mike Steer (Research Director, SARDI Aquatic & Livestock Sciences).

EXECUTIVE SUMMARY

This report documents common dolphin (*Delphinus delphis*) interactions with the South Australian Sardine Fishery (SASF) in 2023. It details patterns of observer coverage, compares observed and fisher-reported rates of interactions and indices of fishing behaviour, and assesses the effectiveness of the industry Code of Practice (CoP) at mitigating interactions. In 2023 in the SASF, 992 net-sets were conducted, with most activity occurring from March to May (67% of net-sets). Most net-sets were in the Spencer Gulf Zone (66%), followed by the Outside Zone (22%; 17% on the West-coast of Eyre Peninsula and 5% south-east of Kangaroo Island) then Gulf St Vincent Zone (12%). Observer coverage surpassed target levels of 10% (12% achieved) for the first half of the year and 20% (25% achieved) for the second half. Coverage was well distributed across months, vessels, and zones, with observers reporting consistent and effective application of the industry CoP.

In 2023, 127 dolphin encirclement events involving 423 dolphins were recorded. The observed encirclement rate (14% of net-sets) was similar to that recorded in the absence of observers (13% of net-sets), as well as rates recorded annually since 2013 (11% ± 1%, range 7-18%). Two mortality events involving single dolphins were recorded in 2023, both in the absence of observers. Based on net-sets without an observer present, two dolphin mortalities were estimated to have occurred in the fishery in 2023, equal to the annual rate based on unobserved net-sets since 2013. Based on net-sets with an observer present, the absence of a mortality in 2023 reduced the annual rate since 2013, based on observed net-sets, from 21 to 19 dolphins.

In 2023, differences in indices of fishing behaviour between when observers were present and when they were absent (i.e., when present, the mean sardine catch retained per net-set was lower, rates of net-sets with zero catch were higher, and there were more net-sets per trip) indicated an observer-effect in the fishery, which has been evident in most years. In 2023, however, this effect was less notable compared to previous years. The increase in observer coverage to 20% in 2023 may help mitigate the observer-effect, though conclusive evidence for this would require monitoring at this rate over multiple years. Implementing camera systems (electronic monitoring) to audit logbook reporting in the absence of observers could expedite the resolution of observer-effects and under-reporting of mortalities.

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 tonnage landed. Annual sardine landings increased from 7 t in 1991, to 3,809 t in 1999, and 39,809 t in 2005 (PIRSA 2014). Since then, annual catches have ranged between 27,000 and 40,100 t (Grammer et al. 2021). It 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*). A key feature of the fishery is that all net-sets are at night, when sardines school near the surface. Since 2005, the fishing effort has been approximately 960 net-sets per year.

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 km^2 (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 100 m 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 estimates, common dolphins off South Australia may number between 50,000 and 100,000.

There is evidence of genetic population structure of common dolphins in south-eastern Australia, with those offshore in South Australia 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 the case, common dolphins in Gulf St Vincent may need to be considered as a separate group to those elsewhere in South Australia.

In Australia, all cetaceans (including common dolphins) are listed under the Commonwealth *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999* (the EPBC Act) as

protected species (Chapter 5, Division 3 – Whales and other cetaceans). Under this Act, a person commits an offence if an action they take results in the death or injury of a cetacean, unless that action is authorised by a permit (Section 229). Australian fisheries can apply for permits that allow operations that "take all reasonable steps to ensure that cetaceans are not killed or injured as a result of fishing" (Section 245 [f]). The EPBC Act also requires a person to report details of any injury or death of cetaceans to the Minister's Secretary within 7-days of it occurring (Section 232). Pursuant to the EPBC Act, Australian fisheries that are permitted to interact with protected species must undergo periodic environmental assessments and address recommendations from the Minister before an exemption is extended. Separately, 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 levels of penalties for non-compliance.

Interactions

Interactions between common dolphins and the SASF occur when nets are set around schools of sardines. Dolphins can be in the vicinity but unseen and inadvertently become encircled or entangled on the outside of the net (Hamer et al. 2008, Kemper et al. 2023). Dolphins also may approach a fishing operation if they perceive that it provides productive feeding opportunities (Jaiteh et al. 2013). Dolphins have been encircled on approximately 10% of net-sets and dolphin mortalities have been recorded on approximately 1% of net-sets (Kirkwood and Goldsworthy 2024). Also, dolphins are present outside of nets feeding on sardines following more than 60% of observed net-sets (e.g., see Kirkwood and Goldsworthy 2022). Mortalities may result due to interactions with the net, stress, drowning, or at a later time, for example, due to separation of dependent young from their mothers or family groups (Forney et al. 2002, Edwards 2006, St Aubin et al. 2013, Kemper et al. 2023).

Data on dolphin interactions recorded in fisheries logbooks between 1999 and 2004 indicated an average of six encirclement events each year and a single mortality of one dolphin in April 2002 (Hamer et al. 2007). Based on interactions recorded during an observer program in 2004-05, it was estimated there were more than 2000 dolphins encircled and 484 dolphin mortalities in the 2004-05 financial year (Hamer and Ward 2007, Hamer et al. 2008, Ward et al. 2015a). The high rate and apparent under-reporting of interactions stimulated the state government to initiate an

observer program. This program has been running continuously since 2006, mostly aiming to cover 10% of fishing effort (approximately 100 net-sets per year, which has averaged <10 per vessel per year). A dolphin-specific Code of Practice (CoP: see Ward et al. 2018) was drafted by the South Australian Sardine Industry Association (SASIA) and is routinely updated (summary of CoP in Appendix 1). Annual reports by SARDI have provided assessments of the dolphin interactions, the observer program 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, 2024).

Significantly higher dolphin mortality rates recorded by observers compared to rates recorded without an observer present have persisted in the SASF, indicating the potential for on-going under-reporting of dolphin mortalities when observers are not present (see e.g., Ward et al. 2010, Kirkwood and Goldsworthy 2024). Under-reporting of bycatch mortalities in the absence of an observer has been recognised in many fisheries and attributed to various factors (Gilman et al. 2013, Heinemann 2017, Moore et al. 2021). For example, if reporting a mortality event leads to more negative consequences than not reporting it, fishers may decide to under-report when they are unobserved. Additionally, under-reporting may occur because fishers are prioritising safely landing their catch and may miss seeing a mortality, while observers have time and incentive to constantly monitor for dolphin presence: some mortalities could fall out of the net unseen unless close attention is being paid to waters around the net (Archer et al. 2001, Emery et al. 2019, Kennelly 2020).

In other fisheries where the potential for under-reporting of bycatch interactions when observers were absent has been recognised, the observer data have been relied upon to provide estimates of interaction rates (Johnson et al. 1999, Burns and Kerr 2008). However, accurately estimating total interactions using observer data alone assumes that the likelihood of an interaction is the same, regardless of observer presence or absence (Zollett et al. 2015, Luck et al. 2020). If the chance of an interaction (such as mortality of a dolphin) is reduced when an observer is present, interaction rates recorded by observers will not represent rates for the entire fishery.

Assessments conducted within the SASF have indicated fishing behaviour may be different when an observer is present. This includes when an observer was present there were more net-sets per night (or per trip), more net-sets with zero catch, and lower tonnages of sardine catch retained per net-set (e.g., Ward et al. 2013, Goldsworthy et al. 2019). Changes in fishing behaviour when

an observer is present has been documented in many fisheries globally, and are termed 'observer effects' (Burns and Kerr 2008, Benoît and Allard 2009, Duarte and Cadrin 2024).

Harris (1998) suggests that the likelihood of developing an observer effect increases when bycatch interactions reduce catch rates, which may be the case in the SASF. Other causes of observer effects include operational constraints (e.g., the replacement of a crew member with an observer necessitating changes in fishing practices), fishers' reluctance to apply certain fishing methods while being observed (Kelleher 2005, Faunce and Barbeaux 2011), or simply documentation rates being more precise when under observation. Unless observer effects can be addressed (minimised and quantified), observed interaction rates should be considered to minimum rates rather than accurate estimates for the fishery as a whole (Benoit and Allard 2009, Kennelly 2020).

In March 2022, the federal environment department (DCCEEW) extended the SASF's permit to interact with marine mammals until March 2027, provided that by December 2024 (extended from April 2024[1]) suitable systems were in place to ensure accurate information on protected species mortality levels was collected and that under-reporting was not occurring. PIRSA developed a plan for this that included trials of on-board camera systems to aid auditing of dolphin interaction reporting [2]. To improve data on mortality rates, in July 2023, PIRSA also increased observer coverage to 20% of net-sets.

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 2023.

Key objectives of this assessment were to:

1) Examine patterns of observer coverage in 2023,
2) Assess dolphin interaction rates with the SASF in 2023,
3) Assess the effectiveness of the CoP in mitigating interactions in 2023,
4) Assess dolphin interaction rates and fishing patterns with and without observers present, and
5) Collate and present 2023 data against data from previous years.

[1] https://www.dcceew.gov.au/sites/default/files/documents/sa-sardine-letter-dpir-2024.pdf
[2] https://pir.sa.gov.au/__data/assets/pdf_file/0016/430045/sasf-teps-mitigation-monitoring-workplan.pdf

2. METHODS

Three data sets for the 2023 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 an independent observer: 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).

Three spatially discrete fishing areas were in place in 2023: Spencer Gulf, Gulf St Vincent, and the Outside Zone (PIRSA 2020). The Outside Zone comprised the geographically separate west of Eyre Peninsula, termed West Coast, and south-east of Kangaroo Island, termed South-east (indicated in Figure 2).

Observer coverage was designated in ‘nights of fishing’ before 2012, and in ‘net-sets’ thereafter, with observers boarded a vessel usually for one, but up to four-night trips. Observer effort aimed for an even distribution across net-sets by month, vessels, and fishing areas.

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 needed to 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 following 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 Development Core Team 2023). Statistical differences were assessed using *F*-tests and *t*-tests for parametric data, and Wilcoxon *W*-tests (also known as Mann-Whitney *U*-tests) for non-parametric data, using the package dplyr (Wickham et al. 2019). Where appropriate, the data are summarised as means ± standard errors.

Assessments of dolphin encirclement and mortality rates were based on events recorded by observers and by 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. Assessment 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, with 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 zero-catch net-sets. Estimated sardine catch 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 or dolphin encirclement and mortality events, Generalised Additive Models (GAMs) were constructed using the package mgcv (Wood et al. 2016, Wood 2017). Variables included were moon phase, time-of-day, fishing zone, water depth, search time, net-set with dolphins encircled (encirclement event), number of dolphins encircled, net-set with dolphin mortality (mortality event) and estimated tonnage of sardines retained. Separate GAMs were constructed for net-sets in each of 2021, 2022, 2023 to investigate recent trends, and for the period 2013 to 2023, to investigate relationships using a larger sample-size of net-sets. In GAMs, to investigate sardine catch, vessel was incorporated as a random factor because vessels in the fleet had different capacities. In each GAM, the significance of each variable was tested against the range of data for numerical and integer variables, and against the first variable in its category for factorial variables. For example, for moon-phase (factorial), all other phases were tested against the new moon, and for fishing zone (factorial), all other zones were tested against Spencer Gulf. Due to the spatial separation of West Coast and South-east within the Outer Zone, in the GAM models,

these areas were treated as being separate. As each GAM was tested on a range of variables, the results could differ from significance tests for individual variables.

Differences to previous analyses

In reviewing data for this report, a discrepancy was recognised in some historic records (2005 to 2013), between the number of net-sets recorded by an observer and the number recorded for the same trip in the logbook return. The logbook records did not include 146 net-sets present in the observer data. These comprised 79 net-sets with zero catch and 67 net-sets that had been combined with other net-sets (for example, three net-sets in observer data recorded as a single net-set in logbook data, with the total retained catch being the same). The time for the single logbook net-set was often, although not always, the same as that for one of the observed net-sets. Analyses for the previous 2022 report had relied on the logbook data to tally numbers of net-sets (Kirkwood and Goldsworthy 2024), so had missed this discrepancy. Reconciling the logbook and observer data sets for the present report added approximately 20 observed net-sets per year for the years 2005 to 2010. As observer data did not record net-set location, actual locations for the net-sets not documented in logbooks were unknown, so were assumed to be the same as for the single net-set provided. When all net-sets on a trip had zero catch and no logbook entry was made, no location data were available.

An additional adjustment was required to the ‘net-sets per trip’ data after recognition that 298 apparent net-sets in logbook records were entries that had recorded search-time and net-set, but no net had been set (e.g., a school of sardines was not located). Not all vessels routinely submitted logbook data for trips when no net-set was made, and several vessels never recorded a trip in which there was no net-set.

Corrections to net-set records, due to the historic combining of several net-sets into one record or not recording zero-catch net-sets, was possible with observer data. Such corrections were not possible in the absence of observer records. Inclusion of the net-sets improved the reliability of analyses of observer data, but incorporated potential biases for comparisons between observed and unobserved net-sets in years up to 2010. For example, the interpreted proportion of net-sets observed may have been higher than actually occurred.

After 2010, the frequency of required corrections to logbook records reduced, and by 2013 they had ceased. Comparisons of with versus without observer data up to 2010 were considered to be less reliable, therefore, and comparisons after 2013 were attributed with a greater level of confidence. Furthermore, to avoid potential biases of trips with zero-catch being under-reported

in the absence of an observer, the comparison of ‘net-sets per trip,’ excluded all trips that had no net-sets.

An additional adjustment from previous reports on ‘net-sets per trip’ analyses was required due to recognition that while most vessels recorded trips between the date of departure and the date of landing (without recording the date of each net-set), one vessel recorded trips between one day and the next (without recording the date of departure or landing). Thus, when observers were not present, the actual trip dates were not discernible for that vessel and all its unobserved trips appeared to be a single day in duration. For the present report, ‘net-sets per night’ for the unique vessel were examined separately, and ‘net-set per trip’ for all other vessels were examined collectively.

The GAM analyses incorporated the same variables as those included in the 2022 analyses, except for the exclusion of trip duration and search hours in all single-year analyses. These were excluded in the final GAMs as they were recorded differently by vessels or often were not recorded, so their inclusion reduced the sample sizes and potentially included unquantifiable biases. When included in preliminary GAMs, these variables did not change the level of significance for other variables and were not significant themselves, except search hours had a highly significant correlation with observer presence in the collated data from 2013 to 2023. Because of this significance, and because the retained sample size remained large, the GAM for observer presence in years from 2013 to 2023 included search hours.

3. RESULTS

3.1. Fishing effort

In 2023, a total of 992 net-sets were recorded in industry logbooks (Table 1). The majority of fishing effort occurred from March to May (67% of net-sets). Nets were set in Spencer Gulf (66%), Gulf St Vincent (12%) and the Outside Zone (22%: 17% West Coast, 5% South-east).

3.2. Observer coverage

In 2023, observers were present for 13% of net-sets (131 of 992; Table 1). Between January and June 2023, when the target for observer coverage was 10%, the coverage achieved was 12% (109 of 904 net-sets, range per month 9–16%; Figure 1a). After July, when PIRSA increased the target rate to 20%, coverage achieved was 25% (22 of 88 net-sets; range per month 13–100%; the 100% was of the single net-set in September). Observer coverage on individual vessels ranged between 10% and 15% of net-sets, with most of the difference in percentage coverage between vessels being related to the relative number of sets by each vessel in the periods when 10% or 20% observer coverage was targeted (Figure 1). Coverage by zone was: Spencer Gulf 13% (82 of 654 net-sets), Gulf St Vincent 16% (18 of 115 net-sets) and Outside Zone 14% (31 of 223 net-sets; comprising West Coast 17% [29 of 170 of net-sets] and south-east 4% [2 of 53 of net-sets]; Figure 2).

Dolphin sightings delayed 16 observed net-sets, including twice when no net-set was possible at night due to ongoing dolphin presence. Nets were not set on five other observer nights because sardine schools of sufficient size were not encountered (once also because the vessel pumped sardines from another vessel's net set).

Following 78 observed net-sets (60%), common dolphins were identified feeding on fish outside the net (one to >100 individuals, median 10). Following 26 observed net-sets (20%), one to seven seals were feeding on fish in-and-out of the net, identified three times as Australian sea lions (*Neophoca cinerea*) and twice as long-nosed fur seals (*Arctocephalus forsteri*). Following one net-set, a single great white shark (*Carcharodon carcharias*) outside the net was attempting to feed on fish in the net. Bronze whaler sharks (*Carcharhinus brachyurus*), which are not protected species, were recorded around nine net-sets (one to ten individuals per set, a total of 27).

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 2023.

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)

* Target observer coverage not achieved due to covid restrictions.

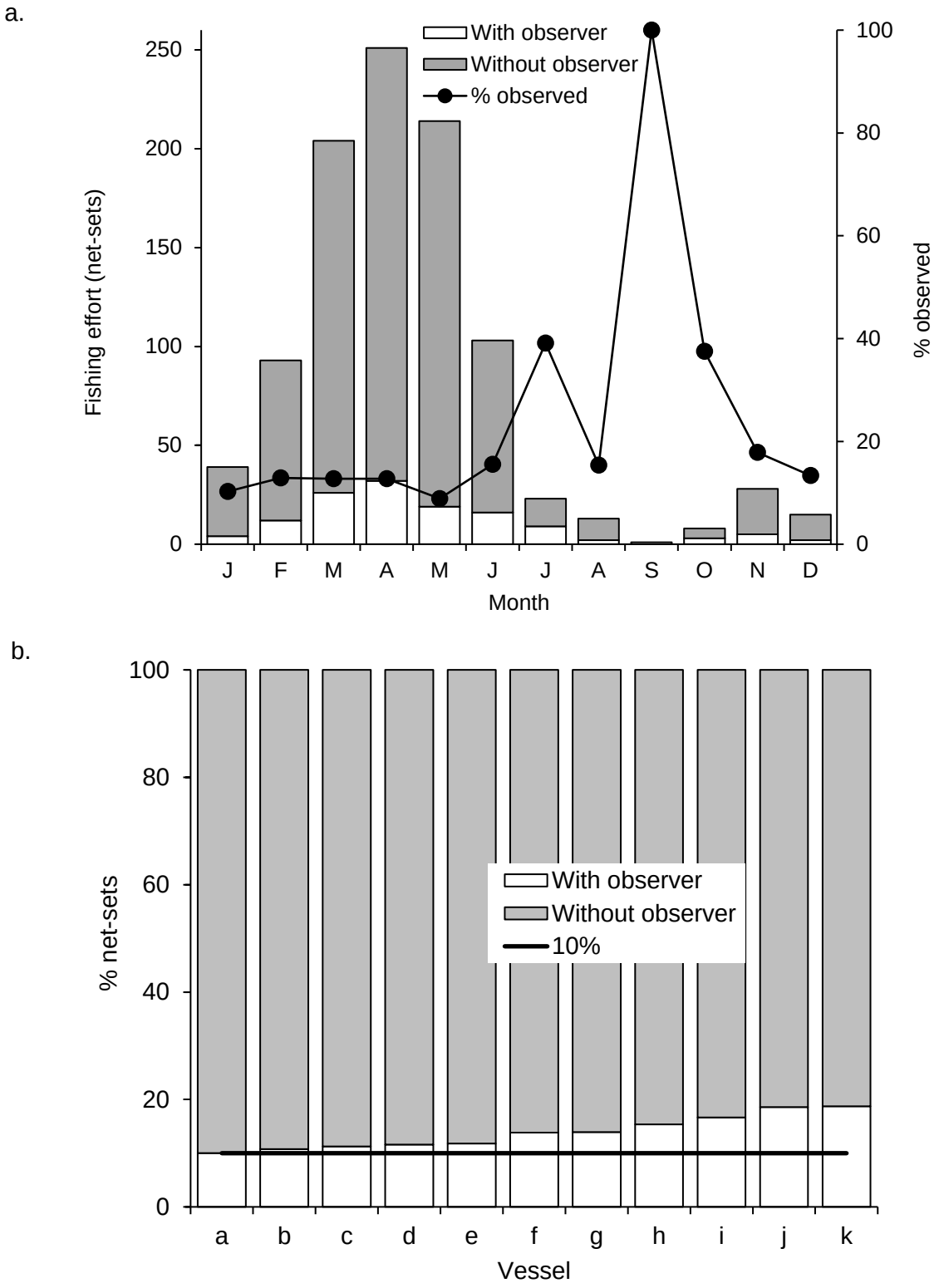

Figure 1. South Australian Sardine Fishery (SASF) observer coverage in 2023 by a) month and b) vessel (ordered by coverage).

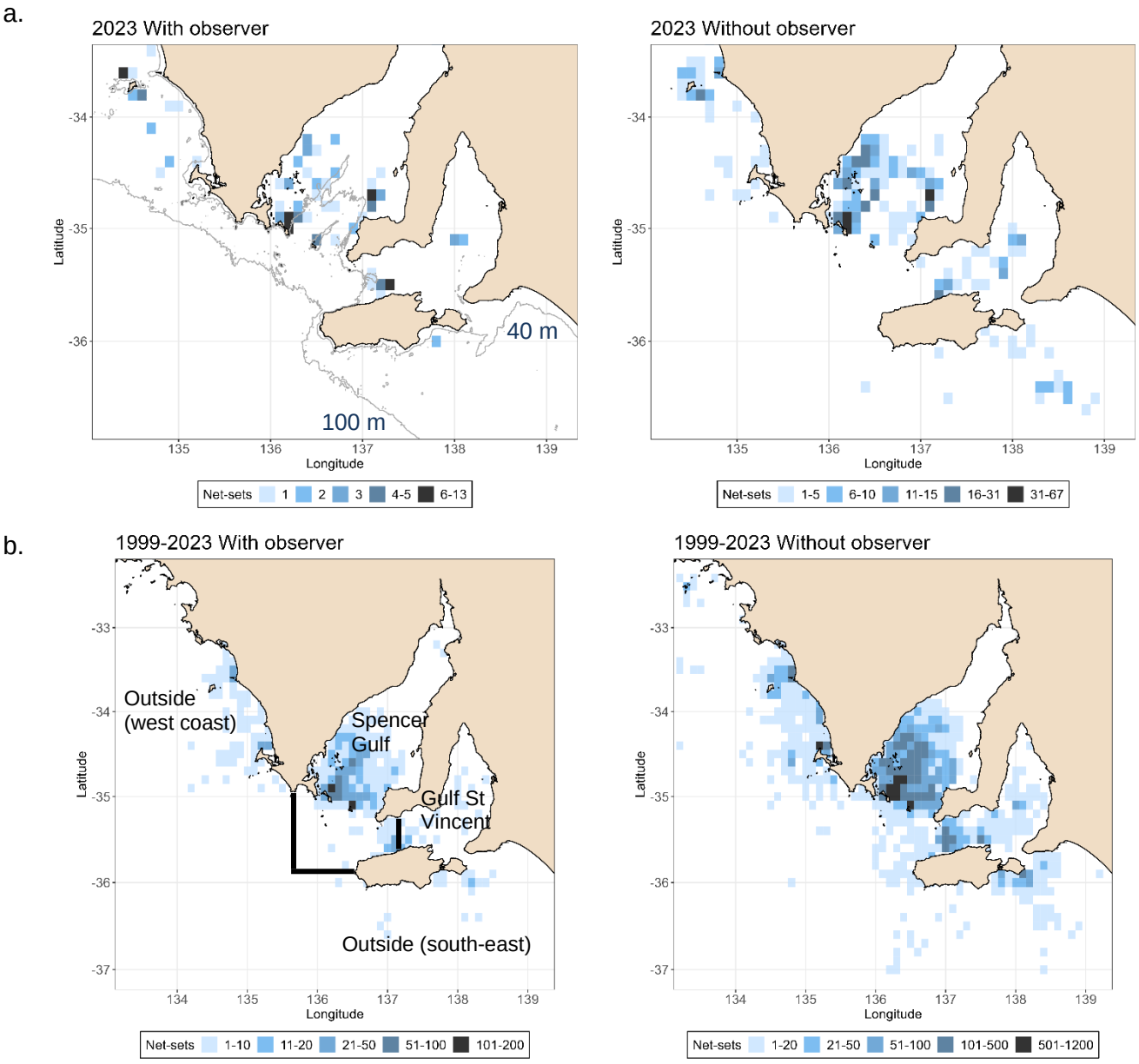

Figure 2. Gridded density plots (0.1° x 0.1°, equivalent to ~11 km^2) showing the distribution of net-sets with and without observers: a) in 2023 (40 m and 100 m depth contours indicated), and b) all years 1999-2023 (Fishing Zones indicated).

3.3. Wildlife interaction forms (WIFs)

WIFs were submitted by fishers for 167 TEPS interactions. Of the 137 WIFs submitted when no observer was onboard, 109 were encirclements of common dolphins, 25 were delays to net-setting due to dolphin presence (with no set possible due to dolphin presence on four nights), two were comments that dolphins were present during pumping, and one reported seals.

All 18 encirclements reported by observers had matching WIFs. Eleven encirclement reports were identical. Five times the only difference was the WIF reported that the net-set had been delayed due to dolphin presence while the observer reported that no delay had occurred, once the WIF reported a delay that was not reported by the observer plus fewer dolphins encircled (five compared with seven), and once the WIF reported more dolphins encircled than did the observer (four compared with one).

3.4. Dolphin interaction rates

Dolphin presence

In 2023, observer reports indicated that fishers always kept a lookout for dolphins before net-setting and always delayed setting when dolphins were sighted. Observers recorded 138 occasions when a vessel was searching for sardines, on four occasions no net-set was possible because a suitable school of sardines was not located. Of the 134 occasions when a school was located, a net-set was possible without a delay 117 times, and 17 times (13% of possible net-sets) dolphin presence caused the net-set to be delayed at least once – including three times when no net was set that night, twice due to ongoing dolphin presence and once because pumping of sardines from another vessel's net-set became possible). In 2023, the rate of delays to observed net-setting caused by dolphin sightings was similar to the rate in 2022 (14% of net-sets delayed by dolphins) and less than the rates in 2020 and 2021 (24% and 21%, respectively).

Also in 2023, observers reported common dolphins feeding on sardines outside 60% of closed-off nets, which was similar to rates recorded in recent years (mean from 2018 to 2020, 64%, range 50–72%).

Encirclements

In 2023, dolphins were encircled in 14% (18 of 131) of observed net-sets with a total of 63 dolphins encircled, with a mean of three dolphins per encirclement (Table 1). In the absence of an observer, fishers reported that dolphins were encircled on 13% of net-sets (109 of 861) with 360 dolphins encircled, also a mean of three dolphins per event. Estimated total dolphins encircled in 2023 based on with and without observer rates were, 136 events and 477 dolphins, and 126 events and 415 dolphins, respectively (Figure 3).

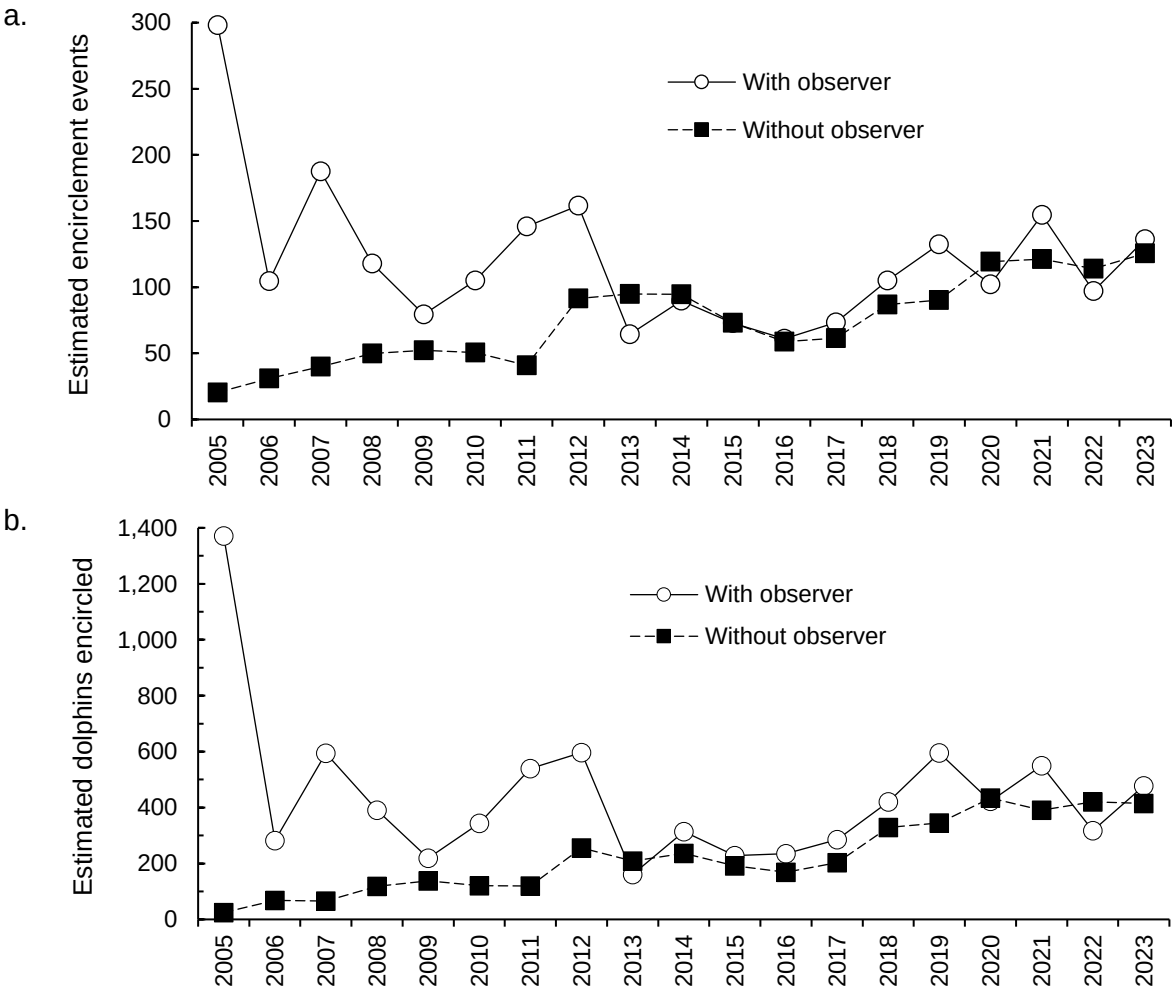

Figure 3. Estimated number of dolphin encirclement events (a) and dolphins encircled (b) by year from 2005 to 2023, based on rates recorded with and without an observer present.

The monthly rate of dolphin encirclements peaked at 12–16% of net-sets, when net-set frequency peaked from February to June (Table 2). In Spencer Gulf, dolphin encirclement rates with observers were higher compared to those without observers (20% vs. 14%), while in the other zones, they were lower (0–6% compared to 8–12%; Table 3). 2023, encirclement rates in two areas were higher than previously recorded: in Spencer Gulf, the rate was 15% compared to a mean of 7% from 1999 to 2022, and on the West Coast (in the Outside Zone), it was 7% compared to a mean of 3% from 1999 to 2022. Encirclement rates in both Gulf St Vincent and the South-east (Outside Zone) remained similar (~11%). There was no seasonal pattern identified in the distribution of encirclement events, that might suggest seasonal movements of dolphins.

Table 2. Net-sets in 2023 by month and fishing area, and the percentage that resulted in dolphin encirclements. SG = Spencer Gulf, GSV = Gulf St Vincent, WC = Outside (West coast), SE = Outside (South-east); '.' = no net=sets, '*' = <10 net-sets.

Month	Net-sets					% net-sets with dolphins encircled				
	SG	GSV	WC	SE	Total	SG	GSV	WC	SE	Total
Jan	36	.	3	.	39	11	.	*	.	10
Feb	89	1	3	.	93	16	*	*	.	15
Mar	193	8	3	.	204	17	*	*	.	16
Apr	160	58	27	6	251	14	10	4	*	12
May	102	44	39	29	214	18	11	10	17	15
Jun	33	3	54	13	103	18	*	11	8	13
Jul	16	1	1	5	23	0	*	*	*	0
Aug	12	.	1	.	13	8	.	*	.	8
Sep	1	.	.	.	1	*	.	.	.	*
Oct	.	.	8	.	8	.	.	*	.	*
Nov	3	.	25	.	28	*	.	4	.	4
Dec	9	.	6	.	15	*	.	*	.	0
Total	654	115	170	53	992	15	10	7	11	13

Table 3. Frequency and rates of dolphin encirclement events in different regions in 2023, with and without observers present.

Zone	With observer			Without observer		
	Sets	Encirclement events	%	Sets	Encirclement events	%
Spencer Gulf	82	16	20	572	81	14
Gulf St Vincent	18	1	6	97	11	11
Outside (West Coast)	29	1	3	141	11	8
Outside (South-east)	2	0	0	51	6	12
Total	131	18	14	861	109	13

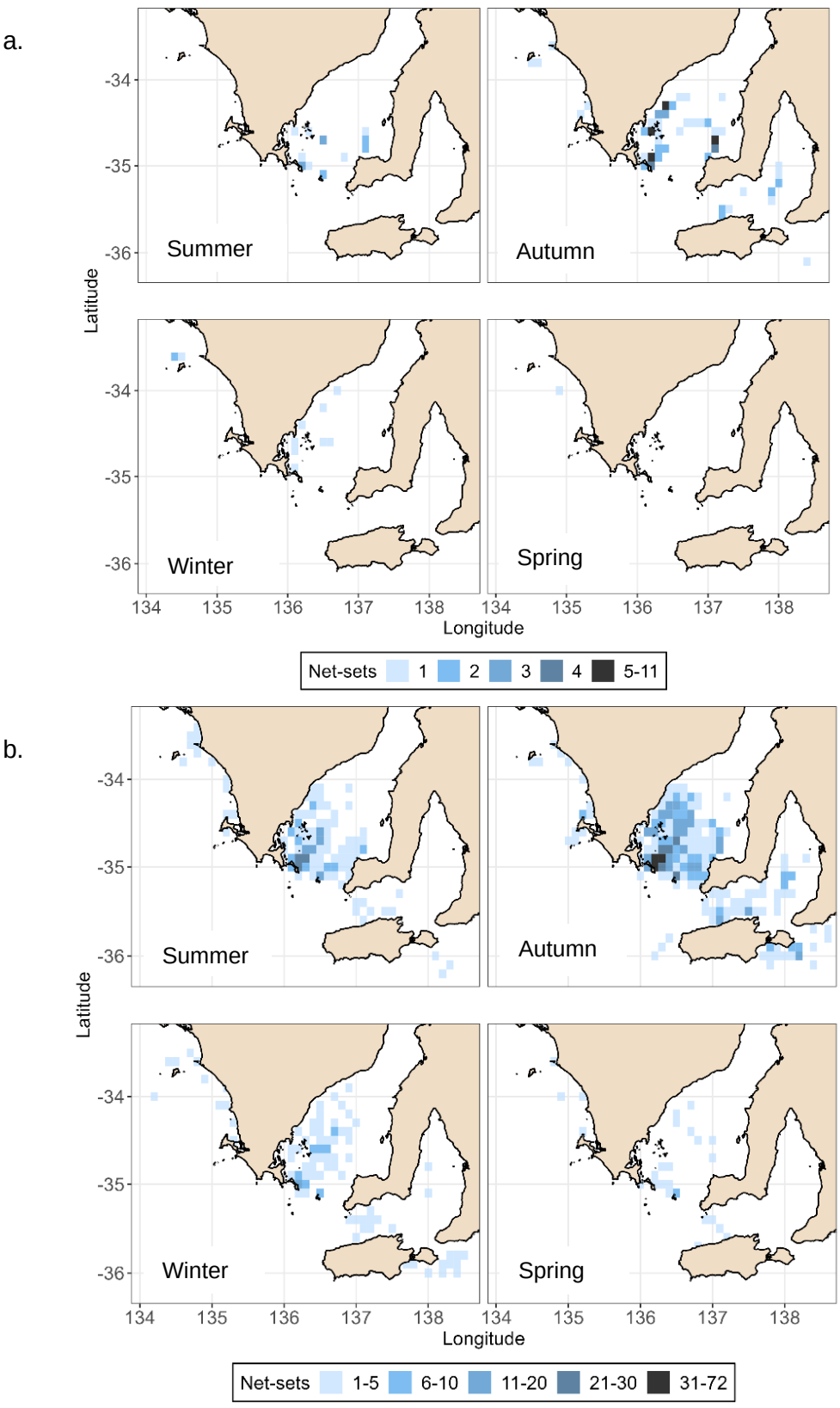

Figure 4. Gridded density plots (0.1° x 0.1°, i.e., ~11 km^2) of the distribution of net-set locations by season where encirclements of dolphins were reported in a) 2023 and b) 1999–2023.

Mortalities

In 2023, observers did not record any mortality events. However, two dolphin mortality events were recorded in net-sets when observers were not present, each involving a single dolphin (Table 4). The record of two common dolphin mortalities marks the lowest annual number since 2018 (Figure 5). Additionally, this the seventh year of the observer program (since 2005) during which observers recorded no mortalities.

Table 4. Details of dolphin mortality events reported in 2023 (both in western Spencer Gulf).

Date	Time	Observer present	After delay	Dolphins encircled	Dolphin mortalities	Entangled	Comment
18-Apr	0:30	no	no	1	1	no	Dead in bottom of net
2-May	1:00	no	yes	1	1	yes	(no comment entered)

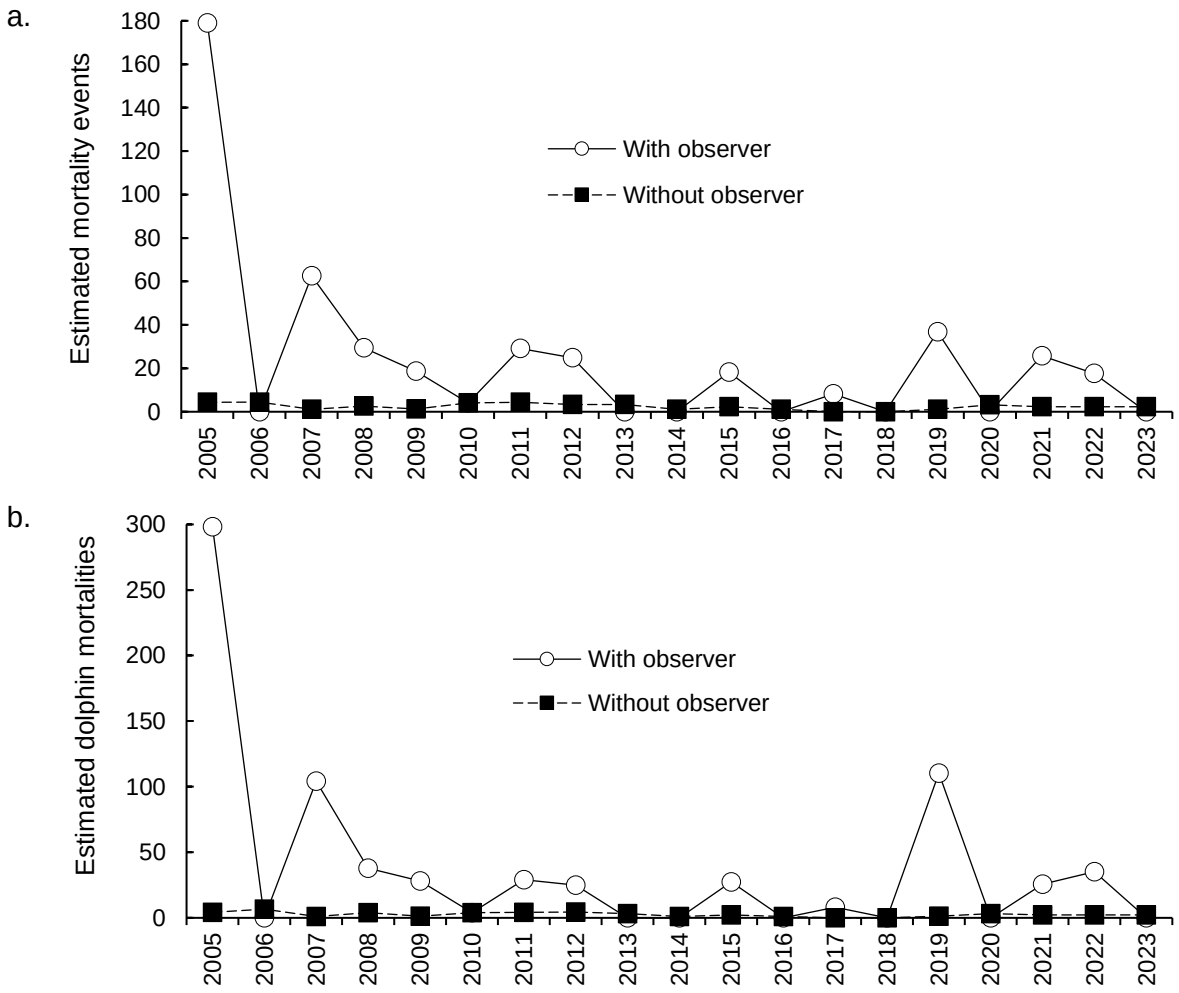

Figure 5. Estimated number of dolphin mortality events (a) and dolphin mortalities (b) by year from 2005 to 2023, based on rates recorded with and without an observer present.

Trend monitoring, based on data aggregated over the 5-year period to 2023, indicated an average of 39 dolphin mortalities per year based on net-sets with observers, and two per year based on net-sets without observers (Figure 6). Up until 2018, the 5-year aggregated data indicate a decline in mortalities per year to seven dolphins per year in net-sets with observers and one dolphin per year in net-sets without observers. In 2019, based on net-sets with observers, 110 dolphin mortalities were estimated, and based on net-sets without observers, one dolphin mortality was estimated (see in Figure 5). If the 2019 data were treated as an outlier and excluded, the 5-year mean to 2023 would be 16 dolphins per year with observers and two per year without observers.

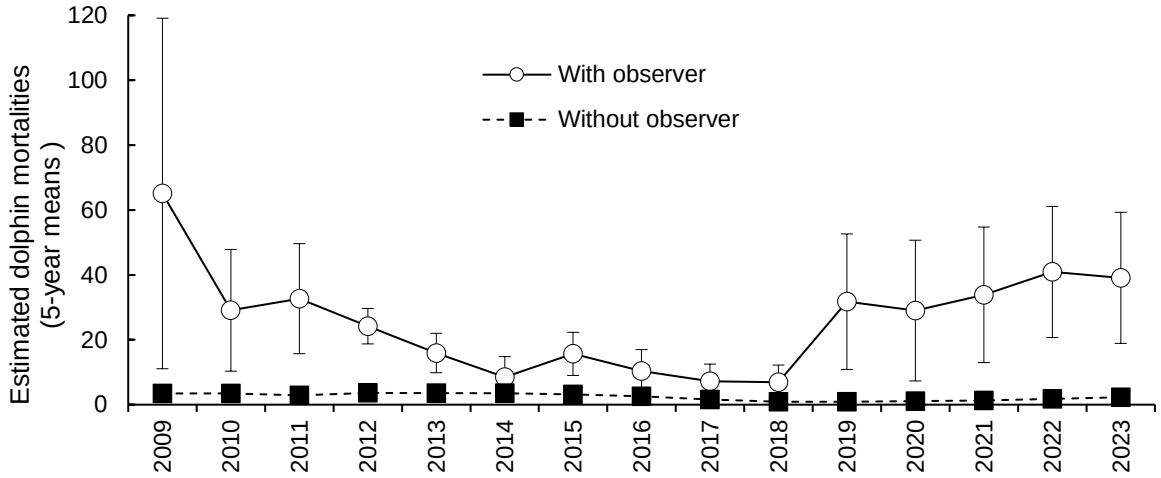

Figure 6. Estimated dolphin mortalities per year in the SASF based on rates recorded with and without an observer present, as 5-year running means from 2009 to 2023.

In the 11 years from 2013 to 2023, observers were present for 11% of 10,161 net-sets and recorded 26 dolphin mortalities, providing a total estimate of 233 dolphin mortalities at a mean rate of 21 per year. In the 89% of net-sets without observers, 17 dolphin mortalities were recorded, providing an estimate of 19 dolphin mortalities at a mean rate of two per year.

Mortality events have predominantly been recorded in Spencer Gulf (79 of 86 events and 108 of 119 dolphins), where there has been most fishing effort (Table 5, Figure 7). During the last five years, from 2019 to 2023, 15 mortality events (23 dolphins) were recorded in the Spencer Gulf Zone, three (seven dolphins) in the South-east part of the Outside Zone, two (two dolphins) in Gulf St Vincent Zone, and none in the West Coast section of the Outside Zone.

Table 5. Dolphin mortality events recorded, % of net-sets in which they occurred, and the numbers of dolphins that died, from 2005 to 2023, separated by fishing zone and observer presence.

Fishing zone	With observer			Without observer		
	Events	% sets	Dolphins	Events	% sets	Dolphins
Spencer Gulf	43	2.37	68	36	0.22	40
Gulf St Vincent	2	2.82	2	1	0.16	1
Outside: West Coast	1	0.35	1	0	0	0
Outside: South-east	1	1.49	5	2	0.29	2
Total	47	2.07	76	39	0.19	43

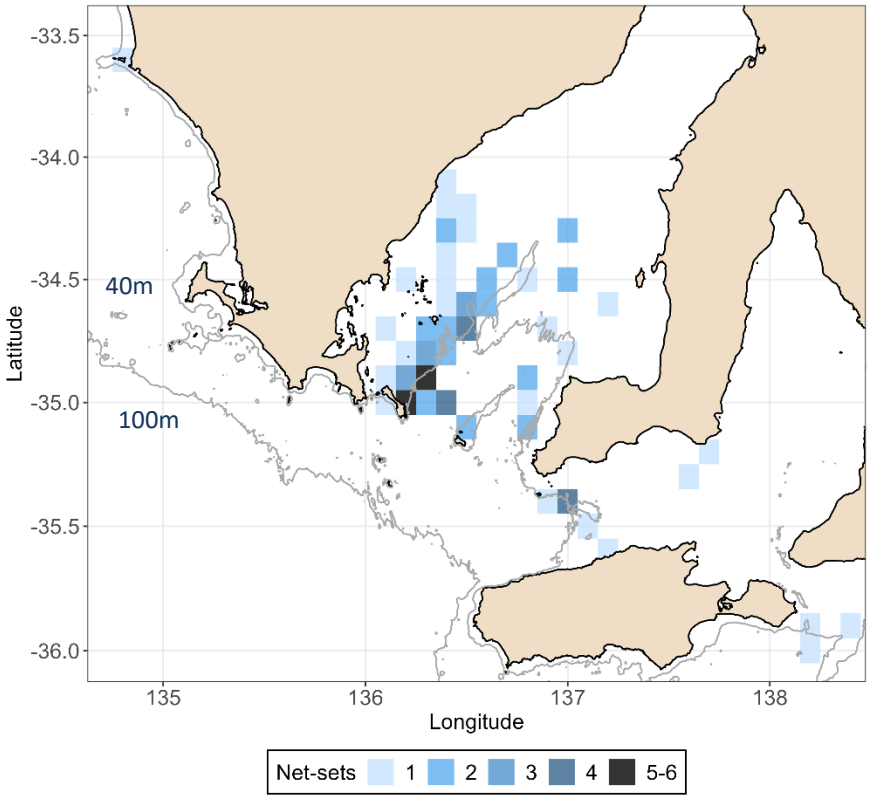

Figure 7. Gridded density plot of the distribution of net-sets in which dolphin mortalities were recorded, from 2005 to 2023.

In the 5-years from 2019 to 2023, dolphin mortalities were recorded in 20 net-sets, 10 with observers present and 10 without observers (Table 6). Of the 12 vessels that operated in the fishery in this period, four recorded mortality events only when observers were present (1–4 events per vessel, 1–6 dolphin-deaths per event), five recorded mortality events only when

observers were absent (1–5 events per vessel, all of single dolphins), and three did not record any mortality events.

Table 6. Net-sets in which there were dolphin mortalities and number of dolphin mortalities recorded in the SASF during the 5-years from 2019 to 2023, indicating those with and without an observer present.

Vessel	With observer		Without observer	
	Mortality in net-set	Dolphin mortalities	Mortality in net-set	Dolphin mortalities
1	4	10	0	
2	3	4	0	
3	2	2	0	
4	1	6	0	
5	0		5	5
6	0		2	2
7	0		1	1
8	0		1	1
9	0		1	1
10	0		0	
11	0		0	
12	0		0	
Total	10	18	10	10

3.5. Code of Practice assessment

In 2023, observers reported that:

1) A search for dolphins was always conducted prior to net-setting.
2) Crew always immediately and clearly communicated dolphin sightings to the skipper.
3) If dolphins were sighted prior to setting, the set was always delayed and often relocated.
4) If encircled or entangled dolphins were sighted, the response to release them was always immediate (acknowledging 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, i.e., released the front of the net and aborted the set.

WIFs submitted by fishers when observers were not onboard document similar rates of dolphin encirclement to observer reports, and two mortality events when observers did not report any.

3.6. Fishing behaviour

Consistent with trends observed in most years since 2013, the presence of an observer in 2023 correlated with higher numbers of net-sets per trip, a greater percentage of net-sets yielding zero sardine catch, and lower tonnages of sardines caught per net-set, even when excluding zero-catch net-sets (Table 7, Figure 8). From 2013 to 2023, the mean annual percentage of net-sets per trip with an observer (21.1% ± 1.0%) was significantly higher compared to trips without an observer (12.8% ± 0.4%; paired t-test following log-transformation to homogenise variances; df = 10, t = 9.6, p = <0.001; Figure 8a). Furthermore, across the 11-year period from 2013 to 2023, net-sets per trip were significantly higher in four years when an observer was present, and the mean catch of sardine was significantly lower in all years (Table 7, Figure 8c). For the single vessel that recorded net-sets per night rather than trip, from 2013 to 2023 there was no significant difference in net-sets per night with and without an observer (df = 10, t = 0.61, p = 0.56).

Table 7. Results from Wilcoxon W-test comparing annual data from 2005 to 2023 with and without an observer for the number of net-sets per trip, sardine catch per net-set (t) with then without zero catch (see Figure 8). Dashed line separation less comparable (pre-2011) and more comparable data recording (see introduction). Bold font indicates a significant difference at p<0.05 (always for more net-sets per trip or less sardine catch per net-set, with an observer present).

Year	Net-sets per trip		Catch per net-set		Catch per net-set excluding zeros	
	W	*p*	*W*	*p*	*W*	*p*
2005	21332	**0.005**	70242	**<0.001**	30734	0.613
2006	10284	0.069	40690	**<0.001**	23659	0.086
2007	11249	**<0.001**	52201	**0.004**	29130	0.515
2008	25655	**0.001**	80198	**0.003**	49108	0.646
2009	24513	**0.001**	93700	**0.002**	69263	**0.040**
2010	30749	**0.002**	106754	**<0.001**	68581	**0.032**
2011	14526	0.198	39422	0.386	24398	0.643
2012	15284	0.211	42296	0.263	29857	0.532
2013	6490	**0.001**	29318	**0.007**	19606	**0.048**
2014	10782	0.055	39056	**0.004**	25486	0.060
2015	11144	0.205	45039	**<0.001**	28617	**0.003**
2016	7112	**0.002**	39624	**0.010**	29341	**0.029**
2017	13945	0.053	77042	**<0.001**	51363	**0.001**
2018	8139	**0.001**	52009	**<0.001**	37702	**<0.001**
2019	16244	0.247	61538	**0.017**	39049	0.288
2020	11400	0.733	42595	**0.003**	29918	**0.002**
2021	11718	0.152	46994	**<0.001**	27905	**0.019**
2022	8561	**<0.001**	65956	**<0.001**	45281	**<0.001**
2023	10682	0.085	67293	**<0.001**	48881	**<0.001**

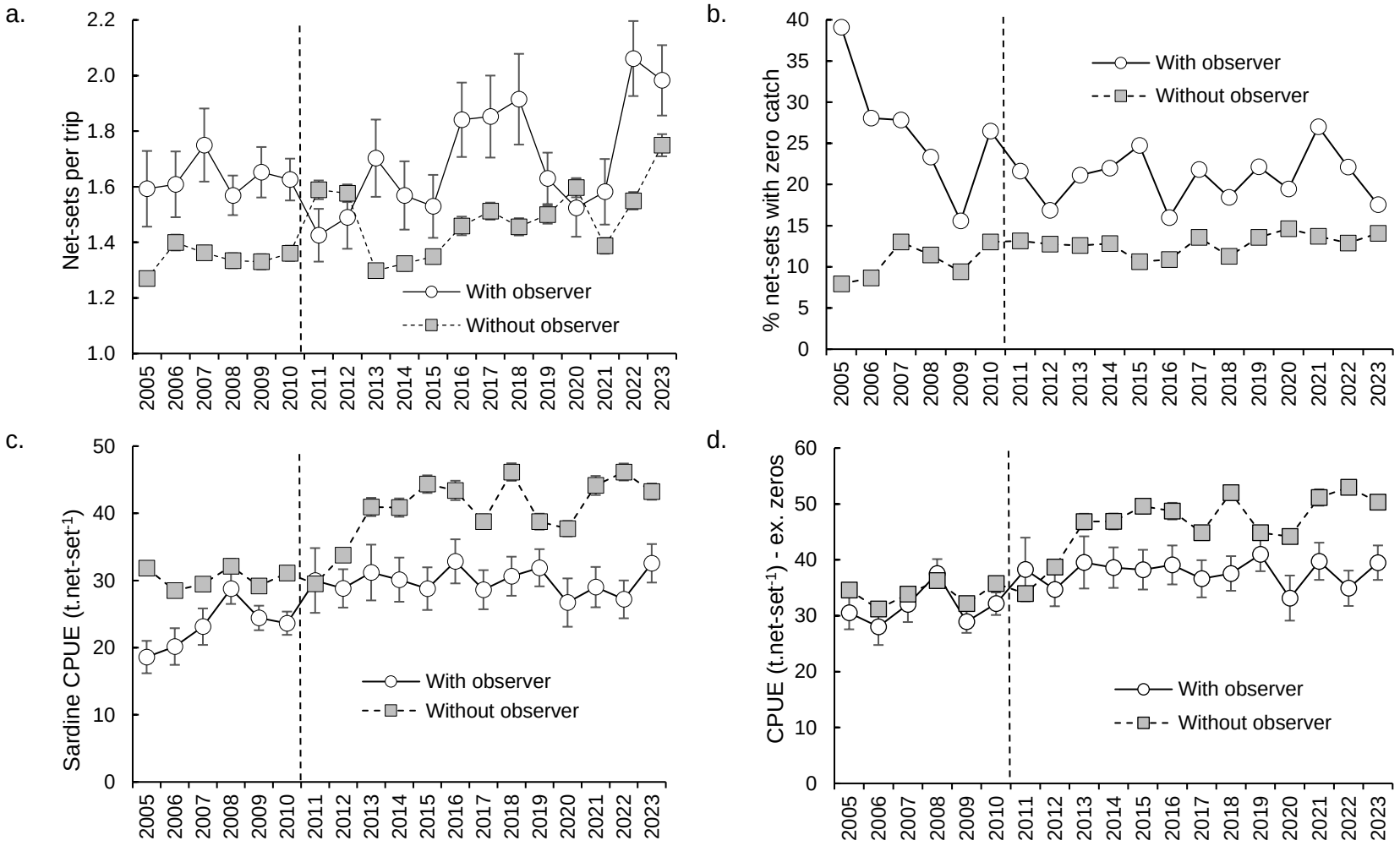

Figure 8. Comparison of indices of fishing behaviour with an observer (circles) and without an observer (squares), by year from 2005 to 2023, (a) net-sets per trip, (b) percentage net-sets with zero catch, (c) sardine catch per net-set (CPUE, tonnes) including zero-catch net-sets, and (d) sardine catch per net-set excluding zero-catch net-sets. Dashed line indicates separation from less comparable to more comparable data recording (see introduction).

In 2023, the mean sardine catch per net-set by individual vessels was 25% lower when an observer was present (range for vessels 6% higher to 59% lower catch per net-set with observer present, Figure 9). This difference was less pronounced than that reported in 2022 (39% lower, range 21–73% lower).

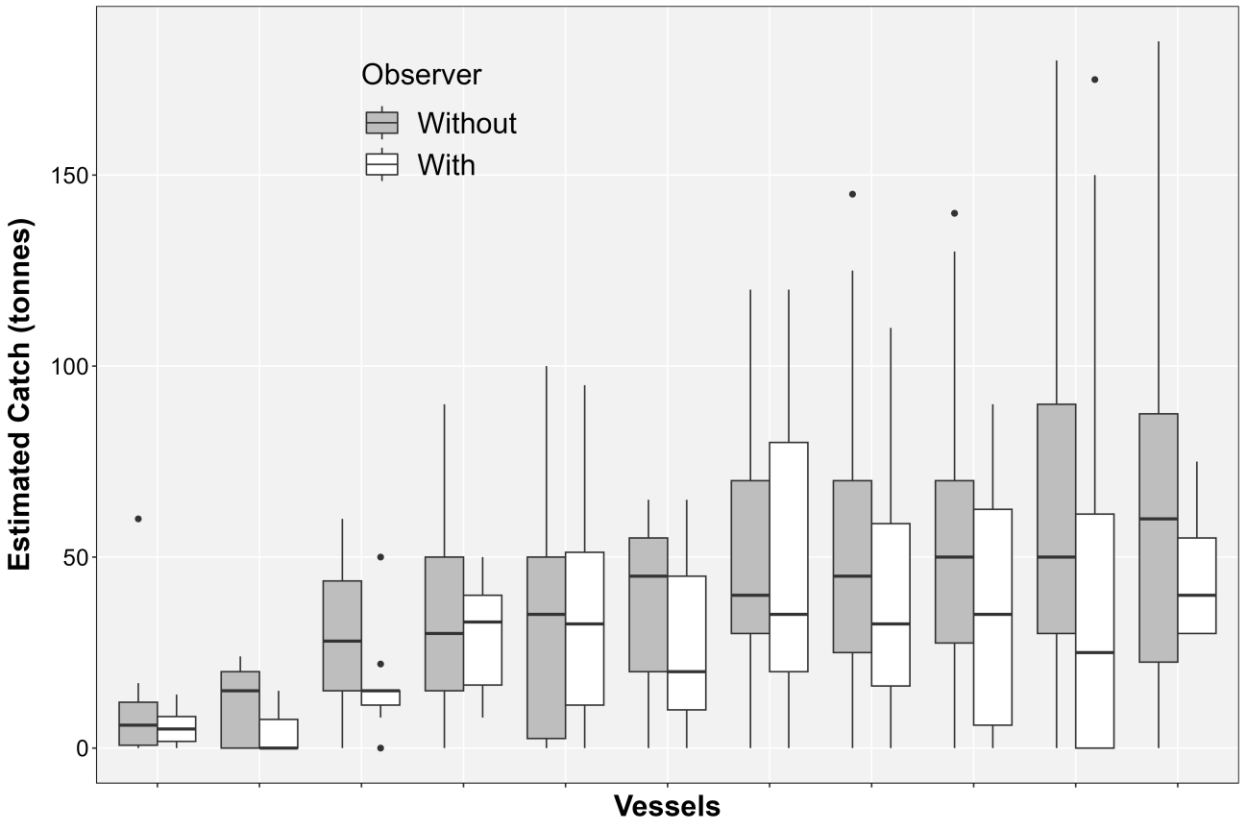

Figure 9. Boxplot of estimated catch (tonnes) per net-set by individual vessels in 2023 (ordered by catch), with and without an observer present. The solid line indicates the median, the box captures the inter-quartile range (25% of data above and 25% below the median), lines from boxes extend to minimum and maximum values, except for outliers (dots), which are beyond 1.5 times the inter-quartile range.

When dolphins were encircled in 2023, the mean retained sardine catch was not significantly different with and without an observer present (Wilcoxon-test, W = 1000, p = 0.878; Figure 10). No sardines were retained on 72% of encirclement events with an observer and 68% of events without an observer. Moreover, when sardines were retained, there were similar amounts with and without an observer (respectively, 31 ± 9 tonnes and 34 ± 5 tonnes; df = 4,32, t = 0.25, p = 0.81). Across encirclement events from 2013 to 2022, there was no significant difference in sardine catch with and without an observer present (Wilcoxon-test, W = 59980, p = 0.31). There

were declines over time from 2005 to 2023 in sardine catch retained during dolphin encirclement events, both with and without an observer (Figure 10).

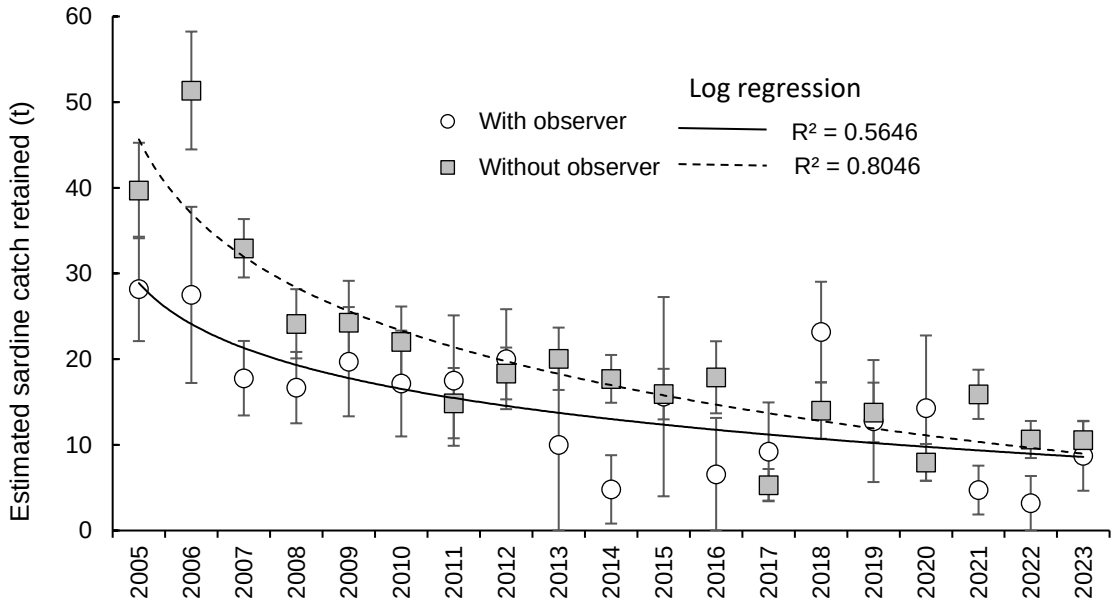

Figure 10. Sardine catch retained per net-set (tonnes, mean ± SE) when dolphins were encircled in years from 2005 to 2023, with (circles) and without (squares) an observer present.

Combining data recorded for dolphin mortality events since 2013, more sardine catch was retained when no observer was present (Table 7, Figure 11). Specifically, no catch was retained on 69% (nine of 13) of mortality events with an observer, compared to no catch retained on 6% (1 of 17) of mortality events without an observer. When catch was retained, the amounts were not significantly different (49 ± 16 tonnes with, 60 ± 9 tonnes without, df = 4,16, $t = 0.56$, $p = 0.58$).

Table 8. Results of Wilcoxon W-tests comparing estimated sardine catch retained (tonnes) on dolphin mortality events from 2013 to 2023. Means do not accurately describe the data but provide an indication of the data spread. Bold font indicates a significant difference at p<0.05.

Event	Year	With observer			Without observer			*W*-test	
		N	Median	(mean)	N	Median	(mean)	*W*	*p*
Mortality	2013-23	13	0	(15)	17	55	(58)	186	**0.001**

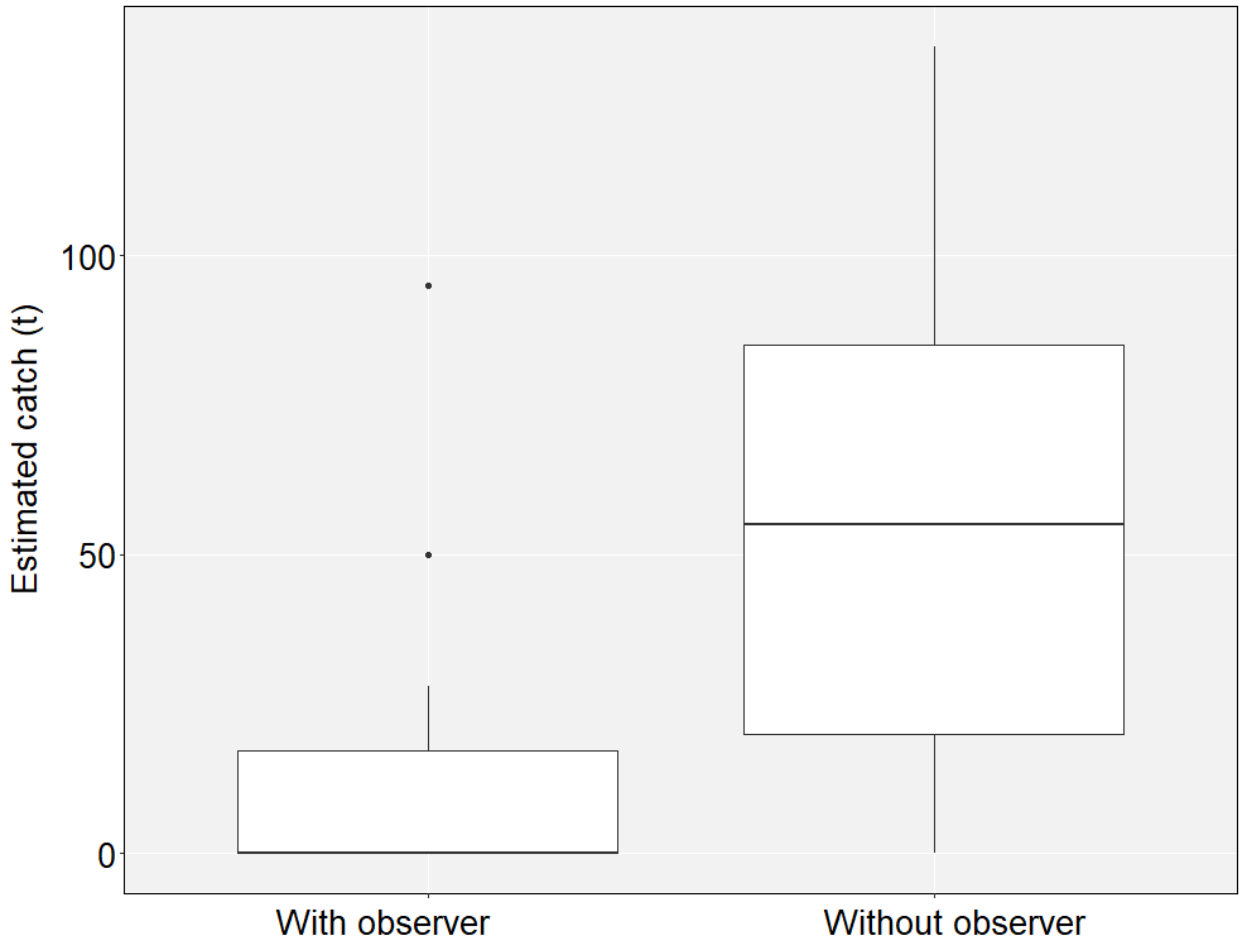

Figure 11. Boxplot comparing estimated sardine catch retained (tonnes) in net-sets that had a dolphin mortality, with versus without an observer present, from 2013 to 2023. See caption to Figure 9 for description.

3.7. GAM analyses

Observer presence

In 2023, the only significant variable that correlated with observer presence was a lower sardine catch per net-set (Appendix 4.1). This was also the strongest correlation with observer presence in 2022, 2021 and across years 2013 to 2023. Other correlations that were significant in previous years, such as observers being more likely to be present for mortality events and less likely to be present for net-sets at shallow depths, were not evident in 2023.

Catch per net-set

In 2023, the most significant correlation was for smaller catches in the West Coast section of the Outside Zone (Appendix 4.2). Other significant correlations were for smaller catches in the presence of an observer and larger catches when the moon was waning from full to last quarter. In GAMs applied to net-sets data in the single years 2021, 2022, and spanning the period from 2013 to 2023, the strongest correlations were invariably for smaller catches in the presence of observers. Smaller catches were also consistently evident in net-sets around sun-rise (6–9 am). Catches were significantly smaller on the West Coast in 2021 and overall for 2013 to 2023, but were not significantly different in size in 2022.

Encirclement and mortality events

In 2023, none of the included variables exhibited a significant correlation with dolphin encirclement events (Appendix 4.3). In GAMs for net-sets in previous years, the strongest correlations evident were of for fewer encirclements on the West Coast in 2022 and spanning 2013 to 2023, fewer encirclements between 3–6 am in 2022, and more encirclements between 6pm and midnight over the period spanning 2013 to 2023.

In the GAM spanning 2013 to 2023, the only variable that correlated significantly with dolphin mortality events was a highly significant positive correlation with observer presence (Appendix 4.4).

4. DISCUSSION

In 2023, the 992 net-sets in the SASF was similar to the numbers in recent years (mean for 2019 to 2022 = 967 net-sets). More than 60% of net-sets were in Spencer Gulf, as has occurred in all years of the fishery. Rates of dolphin-caused delays to net-setting, dolphin encirclement, and dolphin presence following net-sets were similar to the rates in recent years, however, the number of mortalities (2) was the lowest recorded since 2018.

4.1. Observer coverage

Observer coverage in 2023 exceeded targeted levels. Between January and June 2023, when the target coverage was set at 10%, 12% of net-sets were observed. Subsequently, from July to December, when the target increased to 20%, observer coverage was 25%. This coverage distribution was well balanced across months, vessels and zones. However, in the Outside Zone, coverage was concentrated on the West Coast area (17% of net-sets) with less coverage in the South-east (4% of net-sets). While there was no requirement to have even coverage between these areas, given that the West Coast area experienced higher fishing activity (75% of Outside Zone net-sets), having more observer coverage there was beneficial. Within Spencer Gulf, in 2022, several areas of higher effort had relatively low observer coverage. In 2023, though, observer coverage within Spencer Gulf was evenly spread relative to effort.

In 2022, there was just 3% observer coverage of net-sets in the Gulf St Vincent Zone. In 2023, observer coverage in this zone had increased to 12% of net-sets. Most observed net-sets in the zone (13 of 18) were at the western edge of the zone in Investigator Strait, where 53% of net-sets in the zone occurred. Conversely, there was less coverage in the Gulf St Vincent itself, where 47% of net-sets were recorded. This disparity in spatial coverage likely stems from challenges in achieving proportional onboard observer coverage across all spatial components of fishing effort, each year. Considering the potential semi-isolation of the common dolphin population within Gulf St Vincent from populations elsewhere along the coast (Barceló et al., 2021, 2022), ensuring robust independent coverage of fishery-dolphin interactions in this zone may be warranted.

4.2. Dolphin interactions

Dolphin presence

The surveys of common dolphin abundance in the area of the SASF in 2011 and 2021 had broad confidence limits, but indicated dolphin abundance was similar in the two years, i.e. 20,000 to 30,000 individuals (Parra et al. 2021, Goldsworthy et al. in review). Dolphins encircled in nets, however, have increased over time from about 100 per year in 2005, to 200 per year in 2011 and >400 per year since 2020. The increases in dolphins encircled may reflect increased dolphin abundances that were not clear in the survey data, and/or that dolphins were increasingly attracted to the fishing operations. The underwater acoustics during net-setting would be perceptible to common dolphins and, if recognised as an indicator of heightened prey availability, could lead to an increased frequency of dolphin attendance at net-sets over time (e.g., Fertl and Leatherwood 1997, Ridgeway et al. 2014).

While apparently increasing around net-sets up to 2020, since then increases in dolphin numbers around net-sets have not been apparent: net-set delays due to dolphin presence dropped from 24% in 2020 to 13% in 2023; dolphins encircled were 433 in 2020 compared with 423 in 2023; and the percentage of net-sets after which dolphins were seen feeding was 68% in 2020 and 60% in 2023. There may be several factors influencing the relatively stable or even reducing numbers of dolphins around fishing operations in recent years. Either there has been a plateau in the number of dolphins attracted to fishing operations, which may reflect stable population numbers relative to previous years or density-dependent factors, such as reduced attraction due to high levels of inter-individual competition around net-sets. Alternatively, the apparent plateauing in numbers around net-sets could be an artifact of a shift in fishing practices, such as increased avoidance of areas known for frequent dolphin interactions.

Encirclements

Rates of dolphin encirclements in 2023 were similar to those recorded in recent years, indicating that since 2013, an encirclement event occurred on average once every 10 net-sets. This observation is supported by both observer and non-observer data.

Delaying and relocating net-sets when dolphins were sighted potentially prevented some encirclement and mortality events. In two instances following delay/relocations, dolphins were encircled, but on the remaining cases, no encirclement occurred. Therefore, delaying/relocating

net-sets when dolphins were sighted may have reduced encirclements and the likelihood of a mortality in an additional 0–10% of net-sets.

Most encirclements and the highest proportion of net-sets resulting in encirclements occurred in Spencer Gulf. Only two of 18 observed encirclements were outside of Spencer Gulf. Given Spencer Gulf serves as the main fishing area, dolphins have had the greater exposure to purse-seine operations in this region and the feeding opportunity it provides, enhancing the likelihood of encirclement.

Improving knowledge of when and where dolphin interactions occur, could aid the adoption of practices that mitigated against the risk of interactions. Therefore, one objective of the GAM analyses was to identify spatial or temporal factors that correlated with encirclements. In 2023, modelling of dolphin encirclement events against temporal and spatial variables revealed no significant correlations. Highly significant correlations were identified in net-sets in 2021 (more encirclements in the Gulf St Vincent) and 2022 (fewer encirclements on the West Coast in the Outside Zone, and from 3–6 am), and spanning 2013 and 2023 (more encirclements between 6 pm and midnight and fewer encirclements on the West Coast). Overall, the most consistent correlation has been for fewer encirclements in the West Coast region.

Mortalities

Dolphin mortality levels recorded in 2023 were consistent with recent trends in the fishery. The two mortalities recorded in net-sets without observers was equal to the long-term rate recorded without observers, while the absence of dolphin mortalities recorded in observed net-sets in 2023 marked the seventh year when no mortalities were recorded, since the inception of the observer program in 2005.

With observer coverage levels of around 10%, i.e., approximately 100 net-sets per year, single-year data are insufficient to adequately sample dolphin mortality rates, given that mortality events since 2013 have occurred at an average rate of about one per 100 net-sets. To monitor trends effectively, 5-yearly means of mortality data were trialled, but this method has limitations when major deviations in the data, such as the high number of mortalities reported in 2019, skew subsequent levels. Alternative approaches to data collection and assessment may be required to better monitor inter-annual trends in dolphin mortalities in the SASF.

The shift part-way through 2023 to 20% observer coverage occurred after the peak, February to June, peak fishing period. In coming years, coverage at this level may improve the ability of

observer data to reflect trends in mortality rates. However, Debski et al. (2016) suggest that robustly estimating levels of infrequent bycatch events may necessitate observer coverage levels exceeding 50%. At 20% observer coverage, to achieve a dolphin mortality rate equal to that without an observer, i.e., two mortalities per year since 2013, would require there to be two observed mortalities in a 5-year period. Conversely, observer data indicate an average of about 20 dolphin mortalities per year since 2013, so the two mortalities recorded in 2023 cannot be interpreted to demonstrate that under-reporting did not occur in 2023.

GAM-based modelling of mortality events between 2013 and 2023 did not identify significant correlations with fishing zone, water depth, season, time of day, or moon phase. The only significant relationship detected was for mortality events to occur more frequently when observers were present. A more comprehensive analysis of spatial and temporal attributes of encirclement and mortality events, incorporating factors such as location-specific environmental conditions, vessel characteristics, dolphin densities, and other measurable factors, may enhance our understanding of the contributors to dolphin encirclement events and their progression to mortality events.

Fishing behaviour

In 2023, and in all years since 2005, significant differences in fishing behaviour have persisted in the presence of an observer. Although not all comparisons have yielded statistically significant differences in all years, the overarching trend reveals that with an observer present, there have been more net-sets per night, more net-sets with zero catch, lower sardine catch rates (even when excluding zero-catch net-sets), and a higher likelihood of retaining a larger sardine catch in the event of a mortality incident. The GAM results suggest the most consistent factor contributing to the recording of a mortality event and lower sardine catch per net-set, was observer presence.

Such differences in catch and effort between net-sets with and without an observer suggest that fishing behaviour and/or reporting level changes when an observer is present, a phenomenon commonly referred to as the ‘observer-effect’ (Duarte and Cadrin 2024). Drawing insights from analogous scenarios in other fisheries where observer-effects are recognised (e.g., Wahlen et al. 1985, Liggens et al. 1997, Benoit and Allard 2009, Zollett et al. 2015, Debski et al., 2016, Morrell 2019, Kennelly 2020, Luck et al. 2020), it is prudent to interpret dolphin mortality levels based on observer data in the SASF as minimum estimates for the fishery.

Code of Practice assessment

In 2023, observers reported that in their presence, fishers 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.

4.3. Management considerations

The observer coverage of 10% of net-sets across an almost 20-year period has been instrumental in providing insights into fishing practices and interactions between the SASF and common dolphins (Ward et al. 2023). The observer data also demonstrate that fishers complied with the industry CoP when observers were present. However, interpretation of the data also suggests persistent under-reporting of dolphin mortalities in the absence of an observer and the existence of an observer effect, wherein mortalities recorded in observed net-sets may not reflect actual mortality rates.

In July 2023, the observer rate was doubled to 20%. It is likely to take more than five years of monitoring at this rate to ascertain its impact on levels of under-reporting and observer-effects. The level may still be too low to accurately monitor dolphin mortality levels. Given the infrequent occurrence of dolphin mortality events in the fishery, data from more than 50% of net-sets may be required to accurately estimate dolphin mortality levels (after Debski et al. 2016).

To maintain the SASF's Australian Government permit to interact with protected species, suitable systems need to be in place by December 2024 that ensure accurate information on dolphin mortality levels are being collected and that under-reporting is not occurring. One approach to address both issues, and enhance the accuracy of bycatch interaction recording, is the integration of on-board camera systems, also known to as electronic monitoring (Bartholomew et al. 2018, Wakefield et al. 2018, Emery et al. 2019). These systems can enable auditing of logbook records, which has proven effective in improving bycatch reporting in some fisheries (Emery et al. 2019).

In the night-time SASF purse-seine fishery, the potential of camera systems that are currently available to audit logbook data, enhance confidence and accuracy in recorded dolphin mortality rates, supplant or complement on-board observer programs, or elucidate trends in dolphin interactions over time remains uncertain. A trial implementation of cameras would not only dispel doubts about their efficacy but also demonstrate a proactive approach toward addressing potential under-reporting and observer-effects.

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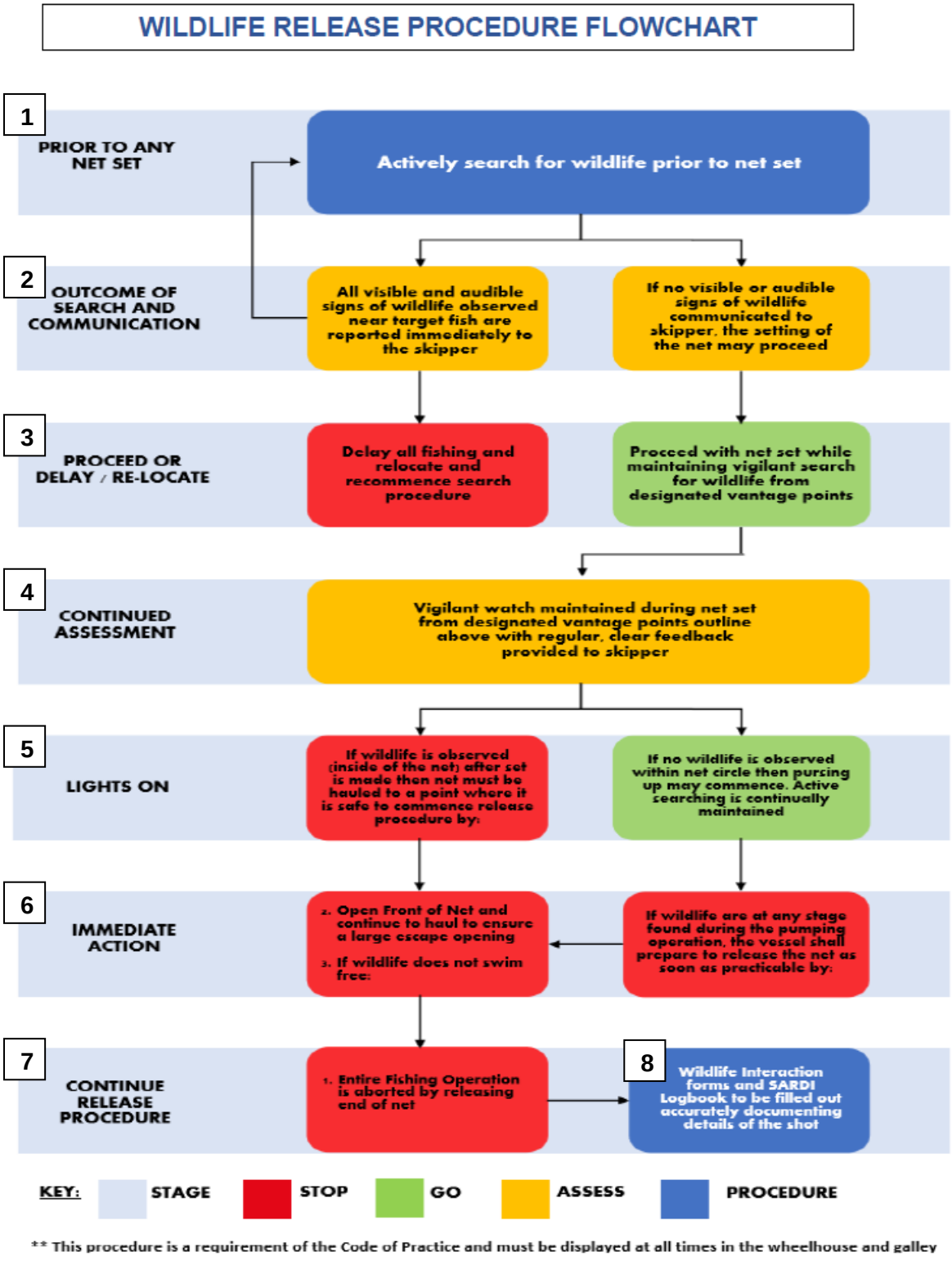
APPENDIX 1. CODE OF PRACTICE FLOWSHEET

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



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 ☐	Pursing ☐	Hauling ☐	Pumping ☐			
Stage release commenced	Setting ☐	Pursing ☐	Hauling ☐	Pumping ☐			
Release method used	Open front of net ☐	Herd with skiff ☐	Other (describe):	Abort shot ☐	Cut out of net ☐		
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							

IF NO FISH CAUGHT THIS SHOT PLEASE √ BOXES

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 ☐ Yes ☐	**Dolphins present – delay** No ☐ Yes ☐ **No. of times:** ________ **and/or** **Dolphins present – relocate** No ☐ Yes ☐ **No. of times:** ________	**Actively search after setting:** No ☐ Yes ☐

Time (24:00HR) first observed		**Stage first observed**	Setting ☐ Pursing ☐ Hauling ☐ Pumping ☐
Time (24:00HR) release commenced		**Stage release commenced**	Setting ☐ Pursing ☐ Hauling ☐ Pumping ☐
Release method used	**Open front of net** ☐ **Abort shot** ☐	**Herd with skiff** ☐ **Cut out of net** ☐	**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:

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	
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: 0–3 am, 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 *raster* 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 (~0–10 m depth), bathymetries above 10 m were changed to 10 m depth. Similarly, few net-sets in the fishery have been in depths >100 m, so net-sets determined to be below 150 m were changed to 150 m depth.
observer	factor	absent, present
entanglement event	factor	en_event: no, yes
dolphins encircled	numeric	en_dolphins
mortality event	factor	m_event: no, yes
estimated catch	numeric	est_catch, in tonnes 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.

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 (1^{-3}), ** = <0.01, * = < 0.05, . =<0.1

Year/s	≥2013 (n = 10034)			2021 (n = 858)			2022 (n = 997)			2023 (n = 992)		
Coefficients	z	p		z	p		z	p		z	p	
(Intercept)	-21.49	$<2^{-16}$	***	-6.97	3.3^{-12}	***	-6.23	4.8^{-10}	***	-6.17	6.8^{-10}	***
Moon:1new												
2wax	-1.04	0.30		1.95	0.05	.	0.78	0.43		-0.72	0.47	
3firstq	1.65	0.10	.	1.85	0.06	.	0.25	0.80		0.31	0.76	
4wax	-1.12	0.26		1.91	0.06	.	1.72	0.08	.	-1.19	0.24	
5full	0.63	0.53		**2.30**	**0.02**	*	1.29	0.20		-0.67	0.50	
6wan	-1.28	0.20		1.69	0.09	.	-0.51	0.61		-1.82	0.07	.
7lastq	1.47	0.14		1.91	0.06	.	**1.99**	**0.05**	*	-1.56	0.12	
8wan	-0.16	0.87		**2.17**	**0.03**	*	-0.65	0.52		0.28	0.78	
Time:0 - 3h												
3 - 6	0.03	0.97		0.63	0.53		-0.68	0.50		0.06	0.95	
6 - 9	**2.60**	**0.01**	**	1.27	0.20		-1.07	0.28		-1.58	0.11	
9 - 12	0.74	0.46		-0.01	1.00		-0.13	0.90				
12 - 15	0.02	0.99		0.00	1.00		1.45	0.15		0.00	1.00	
15 - 18	1.89	0.06	.	**2.58**	**0.01**	**	1.48	0.14		1.63	0.10	
18 - 21	0.22	0.83		0.59	0.55		-0.95	0.34		0.64	0.52	
21 - 24	-0.36	0.72		1.15	0.25		-0.31	0.76		0.27	0.79	
Zone:1sg												
2gsv	-0.81	0.42		**2.23**	**0.03**	*	**-2.00**	**0.05**	*	1.34	0.18	
3se	**-2.66**	**0.01**	**	-0.99	0.32		0.41	0.68		-1.74	0.08	.
4wc	-1.21	0.23		-0.06	0.95		-0.58	0.56		1.07	0.29	
depth	**-3.63**	**2.8^{-4}**	***	-0.53	0.59		**-2.56**	**0.01**	*	-0.14	0.89	
en_event	**-3.70**	**2.1^{-4}**	***	-1.32	0.19		-0.96	0.34		-0.67	0.50	
en_dolphins	1.87	0.06	.	0.65	0.52		-0.97	0.33		0.25	0.81	
m_event	**5.76**	**8.39^{-9}**	***	**2.86**	**4.3^{-3}**	**	**2.59**	**0.01**	**	-0.01	1.00	
est_catch	**-10.67**	**$<2^{-16}$**	***	**-3.67**	**2.5^{-4}**	***	**-5.58**	**2.4^{-8}**	***	**-2.92**	**3.4^{-3}**	**
search_hrs	**-5.76**	**1.2^{-9}**	***									
% Deviance explained	3.49			7.24			12.1			4.75		
REML*	3437			280			318			365		

* 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

Year/s	≥2013 (n=10085)			2021 (n = 858)			2022 (n = 997)			2023 (n =992)		
Coefficients	z	p		z	p		z	p		z	p	
(Intercept)	8.14	4.5^{-16}	***	5.26	1.9^{-7}	***	5.60	2.7^{-8}	***	5.71	1.5^{-8}	***
Season:1sum												
2aut	**2.67**	**0.01**	**	1.83	0.07	.	1.30	0.19		0.32	0.75	
3win	1.74	0.08	.	1.59	0.11		0.05	0.96		-1.40	0.16	
4spr	**-2.54**	**0.01**	*	-0.48	0.63		-0.57	0.57		-0.26	0.80	
Moon:1new												
2wax	0.40	0.69		0.72	0.47		0.58	0.56		0.48	0.63	
3firstq	-0.13	0.89		0.46	0.65		-0.08	0.94		-0.32	0.75	
4wax	0.63	0.53		0.22	0.83		-0.81	0.42		-0.25	0.80	
5full	1.60	0.11		**2.36**	**0.02**	*	0.37	0.71		0.31	0.76	
6wan	**2.27**	**0.02**	*	**2.35**	**0.02**	*	-0.43	0.67		**2.21**	**0.03**	*
7lastq	1.31	0.19		**2.55**	**0.01**	*	0.36	0.72		0.17	0.86	
8wan	0.42	0.67		1.33	0.18		-1.02	0.31		-0.54	0.59	
Time:0 – 3am												
3 - 6	**-4.15**	**3.4^{-5}**	***	-1.91	0.06	.	**-2.33**	**0.02**	*	-0.48	0.63	
6 - 9	**-9.69**	**$<2^{-16}$**	***	**-3.09**	**0.00**	**	**-2.72**	**0.01**	**	-0.82	0.41	
9 - 12	**-2.13**	**0.03**	*	-0.50	0.62		-0.34	0.74		0.00	0.00	
12 - 15	-0.11	0.91		**2.10**	**0.04**	*	0.52	0.60		0.69	0.49	
15 - 18	**2.82**	**4.9^{-3}**	**	1.14	0.25		1.06	0.29		1.14	0.26	
18 - 21	**-5.63**	**1.9^{-8}**	***	-1.25	0.21		-1.50	0.13		-0.10	0.92	
21 - 24	0.97	0.33		1.11	0.27		1.67	0.10	.	0.29	0.78	
Zone:1sg												
2gsv	**-2.63**	**0.01**	**	**-2.47**	**0.01**	*	0.52	0.60		-1.15	0.25	
3se	-1.76	0.08	.	0.93	0.36		-0.29	0.78		-0.90	0.37	
4wc	**-3.14**	**1.7^{-3}**	**	**-2.97**	**3.1^{-3}**	**	0.90	0.37		**-3.48**	**5.2^{-4}**	***
depth	1.44	0.15		1.35	0.18		1.35	0.18		0.62	0.54	
observer	**-11.67**	**$<2^{-16}$**	***	**-4.19**	**3.1^{-5}**	***	**-5.92**	**4.4^{-9}**	***	**-2.51**	**0.01**	*
% Deviance explained	26.4			34.6			31.5			24.2		
REML	48949			4140			4809			4780		

Appendix 4.3 GAMs for encirclement events

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

Year/s	≥2013 (n=10085)			2021 (n = 858)			2022 (n = 997)			2023 (n =992)		
Coefficients	z	p		z	p		z	p		z	p	
(Intercept)	-20.45	$<2^{-16}$	***	-5.16	2.5^{-7}	***	-7.01	2.4^{-12}	***	-5.55	2.8^{-8}	***
Season:1sum												
2aut	0.48	0.63		0.17	0.86		**2.52**	**0.01**	*	0.40	0.69	
3win	-0.94	0.34		-0.58	0.56		1.52	0.13		-0.39	0.70	
4spr	-2.36	0.02	*	-1.92	0.06	.	0.26	0.79		-1.13	0.26	
Moon:1new												
2wax	-0.53	0.60		-0.26	0.79		-1.01	0.32		-0.18	0.86	
3firstq	-0.16	0.87		1.24	0.22		-1.69	0.09	.	0.47	0.64	
4wax	-1.34	0.18		-1.44	0.15		-0.34	0.73		0.04	0.97	
5full	-0.58	0.56		-0.97	0.33		**-2.32**	**0.02**	*	-0.28	0.78	
6wan	-1.55	0.12		**-2.02**	**0.04**	*	-1.19	0.23		-0.70	0.49	
7lastq	0.05	0.96		-0.31	0.76		-0.95	0.34		-0.07	0.94	
8wan	-0.01	1.00		0.41	0.68		-1.16	0.25		0.56	0.58	
Time:0 - 3am												
3 - 6	0.14	0.89		0.41	0.68		**3.68**	**2.4^{-4}**	***	-0.87	0.38	
6 - 9	1.28	0.20		**2.52**	**0.01**	*	0.45	0.65		0.32	0.75	
9 - 12	-0.17	0.87		-0.01	0.99		-0.01	0.99		(no net-sets)		
12 - 15	-0.03	0.98		-0.01	0.99		-0.01	1.00		-0.01	0.99	
15 - 18	0.72	0.47		-0.76	0.45		0.40	0.69		0.30	0.76	
18 - 21	**3.39**	**7.0^{-4}**	***	0.35	0.73		1.85	0.06	.	-0.11	0.91	
21 - 24	**3.41**	**6.4^{-4}**	***	1.87	0.06	.	0.68	0.50		0.54	0.59	
Zone:1sg												
2gsv	1.57	0.12		**2.95**	**3.2^{-3}**	**	0.41	0.68		-1.16	0.25	
3se	-0.74	0.46		0.87	0.39		-1.10	0.27		-0.37	0.71	
4wc	**-8.75**	**$<2^{-16}$**	***	-0.80	0.43		**-3.81**	**1.4^{-4}**	***	-1.05	0.29	
depth	0.46	0.65		1.85	0.07	.	-1.70	0.09	.	0.32	0.75	
observer	0.78	0.44		0.80	0.43		-0.47	0.64		0.48	0.63	
% Deviance explained	2.82			7.86			8.90			2.23		
REML	3291			316			308			371		

Appendix 4.4 GAM for mortality events

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

Years	≥2013 (n=10085)		
Coefficients	z	p	
(Intercept)	-8.09	6.0^{-16}	***
Season:1sum			
2aut	0.15	0.88	
3win	-0.90	0.37	
4spr	0.56	0.58	
Moon:1new			
2wax	-1.11	0.27	
3firstq	-0.08	0.94	
4wax	-0.53	0.60	
5full	-1.55	0.12	
6wan	-0.51	0.61	
7lastq	-1.27	0.21	
8wan	0.36	0.72	
Time:0 - 3am			
3 - 6	-1.07	0.29	
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	-1.03	0.31	
21 - 24	-1.84	0.07	.
Zone:1sg			
2gsv	0.46	0.65	
3se	0.72	0.47	
4wc	-1.58	0.11	
depth	0.02	0.98	
observer	**5.07**	**3.9^{-7}**	***
% Deviance explained	13.9		
REML	137		