Marine Ecosystems

Assessment of dolphin interactions, effectiveness of Code of Practice and fishing behaviour in the South Australian Sardine Fishery: 2022

Roger Kirkwood and Simon Goldsworthy

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January 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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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.

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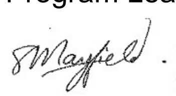
Signed:	
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EXECUTIVE SUMMARY

This report documents common dolphin interactions with the South Australian Sardine Fishery (SASF) in 2022; details patterns of observer coverage; compares observed and fisher-reported rates of interactions and fishing behaviour; and assesses the effectiveness of an industry Code of Practice (CoP) at mitigating interactions. Since 2005, interactions have been reported per financial year. This report shifts to calendar year reporting to align with other fisheries data and the quota-year for the fishery. As such, there is considerable overlap between this 2022 calendar year report and the previous 2021-22 financial year report (Kirkwood and Goldsworthy 2022).

In 2022, there were 997 net-sets in the SASF, with most activity from March to May (70% of net-sets) and most sets in Spencer Gulf (64%). Observers covered 11.3% of net-sets, exceeding the 10% target. Observer coverage was distributed evenly across months and vessels, and in the Spencer Gulf (11% of net-sets) and Outside (15% of net-sets) fishing zones, but was low in Gulf St Vincent (3% of net-sets). Application of the CoP was assessed by observers. Fishers always applied the CoP effectively when observers were present.

A total of 112 dolphin encirclement events involving 404 dolphins were recorded in 2022. On four of the encirclement events, dolphin mortalities were recorded (a total of six dolphins). The observed rate of encirclement events (0.10 events per net-set) was similar to the rate when observers were not onboard (0.11 events per net-set). The observed rate of mortality events (0.018 events per net-set) was eight times the unobserved rate (0.002 events per net-set). In the 113 observed net-sets, there were two dolphin mortality events, one involving a single dolphin and one accounting for three dolphins, while in the 884 unobserved net-sets there also were two mortality events reported, each involving a single dolphin mortality. The observed rate of dolphin mortalities (0.035 per net-sets) was 18 times the unobserved rate (0.002 per net-sets). Persistent differences in the observed and unobserved dolphin mortality rates over the past 15+ years suggests on-going under-reporting of dolphin mortalities in the absence of an observer. This may comprise both under-reporting and higher levels of unseen (cryptic) mortality when observers were not present.

Persistent differences in indices of fishing behaviour when an observer was present versus absent provides evidence of an observer effect in the fishery. For example, in 2022, mean tonnage of sardine catch per net-set by individual vessels was 21 to 73% lower when an observer was present. Also, when an observer was present, fewer nets were set in shallower waters (<30 m), there were fewer net-sets in Gulf St Vincent, and when there was an encirclement event it was less likely for some sardine catch to be retained. In most years since 2013, in the presence of an observer, less time was spent searching for sardines before net-setting, there were more net-sets per trip (except in 2020), more net-sets with zero sardine catch, and less tonnage of sardines caught per net-set. Combining the data from 2013 to 2022 to investigate mortality events shows that if an observer was present and there was a dolphin mortality event, less sardine catch was retained. Due to the apparent observer effect, observer data on dolphin interaction and mortality rates may not be representative of the fishery as a whole.

To have more confidence that the number of common dolphin mortalities being recorded in the SASF is accurate, increases in the level of observer coverage and/or camera systems to audit logbook reporting in the absence of an observer should be considered. Levels of cryptic mortality of dolphins (unseen and post-interaction mortality) with and without observers present may represent an unquantified component of dolphin mortality.

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. 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 the majority represents an important 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. Annual landings of sardines 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).

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). They are abundant in southern Australia waters (Ross 2006). Density estimates of common dolphins in South Australian waters have ranged between 0.5 – 0.7 individuals per km^2 (Filby et al. 2010, Bilgmann et al. 2017, Parra et al. 2021, Goldsworthy et al. in review). Total abundance estimates across Spencer Gulf and associated shelf waters have ranged from approximately 25,000 individuals in 2011 to 27,000 in 2021 (Parra et al. 2021, Goldsworthy et al. in review). Based on available estimates, the abundance of common dolphins off South Australian may number between 50,000 to 100,000.

There is evidence of genetic population structure in south-eastern Australia with dolphins east of Bass Strait being distinct from those to the west, with the potential for some mixing between these (Bilgmann et al. 2008, 2014). Recent genetics studies suggest further that there could be distinct sub-populations off South Australia, one that ranges offshore between the Great Australian Bight and Bass Strait and a second sub-population resident in Gulf St Vincent and western Investigator Strait. (e.g., Barceló et al. 2021, 2022).

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 may apply for permits that allow operations which “take all reasonable steps to ensure that cetaceans are not killed or injured as a result of the 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 (Section 232). Pursuant to the EPBC Act, Australian fisheries must undergo periodic environmental assessments and address recommendations from the Minister before an exemption is granted. In South Australia, legislation regarding interactions with cetaceans include 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 pertain to minimum approach distances, disturbance avoidance, vessel speed in the vicinity of cetaceans, avoidance of injury to individuals, reporting of interactions, and levels of penalties.

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 are inadvertently encircled or become entangled on the outside of the net, at times resulting in their injury or death (Hamer et al. 2008).

Data on dolphin interactions have been recorded in industry logbooks since January 1999. Up to 2003-04, about six encirclement events were recorded per year and a single dolphin mortality was recorded in April 2002 (Hamer et al. 2007). Between November 2004 and June 2005, a South Australian Research and Development Institute (SARDI) observer program estimated 1,728 dolphins were encircled and 377 died (Hamer and Ward 2007, Hamer et al. 2008). In 2005-06, a commercial observer program aimed at covering 10% of net-sets was implemented by the state department of Primary Industries and Regions (PIRSA). Also, the South Australian Sardine Industry Association (SASIA) drafted a Code of Practice (CoP) that described procedures to minimise dolphin interactions.

Operational procedures outlined in the CoP include scanning for dolphins prior to net-setting, delaying net-sets and potentially relocating if dolphins are detected, and taking immediate action to release dolphins if they are encircled (see Appendix 1). The release of dolphins is achieved at the completion of pursing by releasing multiple purse-rings from the vessel, which creates an opening in the net. Occasionally, dolphins will escape promptly through this opening and the fisher may retain some catch. However, the dolphins often move to the far side of the net away from the vessel, and do not escape through the opening until the net-set has been completely aborted and all sardines have moved or been emptied out. Fishing vessels range in size and each vessel has developed its own method to achieve dolphin releases.

Assessments of interactions

Annual assessments of dolphin interactions in the SASF, effectiveness of the CoP and fishing behaviour have been undertaken since 2006-07 (e.g., Hamer and Ward 2007, Kirkwood and Goldsworthy 2022). Ongoing compliance with the CoP is critical for the SASF to receive its exemption under the EPBC Act to interact with protected species. The observer program has been reviewed periodically by a working group comprising members of SASIA, PIRSA, and the state Department for Environment and Water (DEW: Ward et al. 2018).

In 2006-07, there were high dolphin interaction rates and apparent high levels of under-reporting of mortalities when observers were not present, which led to PIRSA increasing observer coverage to 30%. In 2012, however, SASIA introducing ‘real-time’ reporting, by which fishers immediately notified the SASIA executive officer and other vessels when they had significant dolphin interactions (mortalities or multiple encirclements). In support of this initiative, observer coverage was reset to 10% of net-sets.

A spike in dolphin mortalities and apparent under-reporting occurred again in 2018-19 (Goldsworthy et al. 2019), and in response, observer coverage was increased to 20% of net-sets. In the following year (2019-20), no mortalities were observed in 84 net-sets (noting that just 8% of observer cover was actually achieved due to COVID restrictions) and observer coverage returned to 10% for 2020-21. Observer coverage remained at this level in the 2022 calendar year.

The potential under-reporting of dolphin mortalities has been an on-going issue for the fishery and has been highlighted in all annual assessments of the observer program (e.g., Ward et al. 2013, Kirkwood and Goldsworthy 2022). One factor that may contribute to under-reporting of mortalities is that when focussed on fishing operations, some mortalities go unseen due to sinking or drifting away out of the area of floodlights. When present, an observer may have a greater likelihood of seeing these mortalities.

In the fishery, under-reporting of the frequency of dolphin-induced delays and relocations of fishing operations has also been apparent and compromises the ability to assess the value of delays in reducing dolphin interactions (e.g., Goldsworthy 2018). The frequency of under-reporting dolphin-induced delays reduced from 2018-19 to 2020-21 but increased in 2021-22 (Kirkwood and Goldsworthy 2022).

Due to the apparent under-reporting of mortalities in the absence of an observer, observed rates have generally been used to estimate dolphin interaction rates and annual interactions across the fishery. However, such estimates assume that fishing behaviour is the same in the presence of an observer as it is in their absence. If fishing behaviour differs in the presence of an observer, known as an observer effect, then interaction rates based on observed data may not be representative of the remainder if the fishery.

Observer effects have been documented in many fisheries globally (e.g., Wahlen and Smith 1985, Garrison and Stokes 2016, Hall et al. 2017, but see Liggins et al. 1997). The act of being observed may directly cause unintended changes in fishing behaviour (i.e., as a normal reaction to being watched; Mc Cambridge et al. 2018). Fishing behaviour may also change due to operational constraints (e.g., where an observer may replace a crew member), or fishers may deliberately modify their behaviour to minimise bycatch interactions when being observed (Kelleher 2005, Faunce and Barbeaux 2011). Where observer effects are significant, observed rates of interactions under-represent actual rates for the whole fishery (Benoit and Allard 2009, Kennelly 2020).

It can be difficult to recognise that fishing behaviour is different when an observer is onboard. An observer effect in the SASF has been detected by comparing data from observed versus non-observed net-sets per night (or per trip), proportion of net-sets with zero catch and catches of sardine (e.g., Ward et al. 2013, Kirkwood and Goldsworthy 2022). Differences may be explained by less accurate documentation of dolphin interactions when observers were absent (e.g., when unobserved, fishers may not always document a net-set that catches no fish). Alternatively, when observers are onboard, nets may be set in situations where there may be less chance of dolphin interactions, particularly mortality events. While an observer effect is a common feature of observer programs, for the SASF it could mean that rates of dolphin mortality recorded by observers provide a minimum estimate for the total fishery.

Since commencement in 2006-07, the annual reports have assessed dolphin interactions and application of the CoP by financial year, which also approximates fishing year (the majority of net-sets are from January to June). To align with total allowable catch calculations, this year the report has shifted to a calendar year analysis. As such, data in this report are similar to the data presented in the 2021-22 report (Kirkwood and Goldsworthy 2022). A further difference from previous reports is that prior to this report, an external review of the report was conducted. Several changes to data analysis and presentation suggested by the reviewers have been adopted. One has been the incorporation of Generalised Additive Models (GAMs) to examine relationships among variables.

1.2. Objectives

The aim of this report was to assess the SASF observer program, dolphin interaction rates, and level of compliance with the CoP in 2022. The report aligns with previous annual reporting (Hamer and Ward 2007; Hamer et al. 2008, 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).

Key objectives of this assessment were to:

1) Collate and present 2022 data against data from previous years,
2) Examine patterns of observer coverage against target levels,
3) Assess dolphin interaction rates (the frequency of delays in fishing due to dolphin presence, dolphin encirclements and mortalities),
4) Assess the effectiveness of the CoP at mitigating interactions, and
5) Assess dolphin interaction rates and fishing patterns with and without observers present.

2. METHODS

Three data sets for the 2022 calendar year were collated, entered into spreadsheets, 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) – data to link with the logbook records, species (e.g., dolphins, fur seals, sea lions, and white shark), interactions, and comments.

Observer coverage was measured in 'nights of fishing' before 2012, and 'net-sets' thereafter. In 2022, the observer program was operated by Seatec, Port Lincoln. Observer effort aimed for an even distribution across net-sets by month, vessels, and fishing areas. Three spatially discrete fishing areas were in place in 2022: Spencer Gulf, Gulf St Vincent and the Outside Zone (mainly west of Eyre Peninsula, termed West Coast, or south-east of Kangaroo Island, termed South-east: the zones are indicated in Figure 1) (PIRSA 2020). Observers boarded a vessel usually for one, but up to four nights.

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 took into consideration 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 allocated to the next available vessel, increasing its coverage for that month, which would be accounted for with more net-sets before that vessel's next observer placement. Achieving an even spatial coverage relied on there being no bias in fishing area following placement of the observer, and negotiation with fishers to place an observer on a vessel that was heading to an under-sampled zone.

Fishers record in WIFs 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. Reportable interactions with common dolphins include dolphin sightings that delay net-sets, encirclements and mortalities.

Assessments of dolphin sightings, encirclement, and mortality rates were based on data in the observer datasheets and the WIFs. To conform with previous reports, encirclements include actual encirclements as well as dolphins that entangle on the outside of the net. Estimates of total numbers of encirclements and mortalities for the year were derived from the observed rates multiplied by the total number of net-sets. The assessment of the effectiveness of the CoP at mitigating dolphin interactions was based on observer data. Fishing behaviour was evaluated by comparing logbook data on net-sets per trip (previously measured per night but logbook records do not provide the night of each net-set), net-sets with zero catch, and mean catch of sardines per net-set, with and without an observer present.

Data preparation was 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, data are summarised as means ± standard errors.

GAMs were constructed and refined using the package mgcv (Wood et al. 2016, Wood 2017) to investigate the influence of observer presence, encirclement events, mortality events and sardine catch per net-set, on the probability of correlation with other variables. Details of the variables included in the GAMs and GAM results are provided in Appendix 5. GAMs were constructed using 2022 data alone and on the combined data from 2013 to 2022 (the period post introduction of 'real-time' reporting). A separate GAM was constructed for encirclement events in 2022 and individual fishing vessels (un-named and artificially listed). In the catch GAMs, vessel was incorporated as a random factor as vessels in the fleet have different capacities. The outcomes of GAMs can be interpreted as the response variable being influenced by the tested variables. Significance of each tested variable is 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 are tested against the new moon, and for fishing zone (factorial), all other zones are tested against Spencer Gulf (due to the spatial separation, the Outer Zone is split into two: West Coast and South-east). As each GAM tests across a range of variables, the results can differ to the significance tests for individual variables.

3. RESULTS

3.1. Fishing effort

In 2022, a total of 997 net-sets were recorded in Industry logbooks (Table 1). The majority of fishing effort occurred from March to May (70% of net-sets). Nets were set in Spencer Gulf (64%), Gulf St Vincent (10%) and Outside Zone (27%: 18% West Coast, 9% South-east).

3.2. Observer coverage

Observer coverage was spread evenly across months and the 11 vessels (Figure 1). Coverage per vessel ranged from 10 to 15% of net-sets. Coverage by zone was 71 of 632 net-sets in Spencer Gulf (11%), 3 of 99 net-sets in Gulf St Vincent (3%) and 39 of 266 net-sets in the Outside Zone (15%; Figure 2).

Of 129 observer data sheets submitted in 2022, 11 recorded no fishing (steaming or engine breakdown) and four recorded searching but no net-sets due to bad weather (1) or fish being 'not located, not schooling or too small' (3). This left 114 events when a school of fish was located and setting the net was considered possible. On 98 occasions (86%), no dolphins were sighted, and the net was set. On 16 occasions dolphins were sighted and the net-set was delayed. Once, no set was made due to the on-going presence of dolphins and on the other 15 occasions, net-sets were ultimately made. Hence, a total of 113 (98 + 15) net-sets were witnessed by observers, comprising 11.3% of the 997 net-sets for the year (Table 1).

Observers recorded 11 encirclements involving 36 dolphins (Table 1). This included nine encirclement events (in one of these a dolphin also entangled on the outside of the net) and two events when a dolphin entangled on the outside of the net, one died and one freed itself. One of the encirclements (two dolphins) followed a delay/relocation due to a prior dolphin sighting, the others did not.

Table 1. Summary of fishing effort (net-sets), observer coverage, and dolphin encirclement and mortality events recorded in the South Australian Sardine Fishery (SASF), by calendar year between 1999 and 2022.

Year	Fishing effort (net-sets)					Encirclement events (no. dolphins)						Mortality events (no. dolphins)					
	Logbook total	With observer	W/out ob.	% observed	% target	Total		With obs.		W/out obs.		Total		With obs.		W/out obs.	
1999	410		410			6	(13)			6	(13)	0	(0)			0	(0)
2000	337		337			0	(0)			0	(0)	0	(0)			0	(0)
2001	406		406			2	(9)			2	(9)	0	(0)			0	(0)
2002	738	1	737	0.1		15	(29)			15	(29)	1	(1)			1	(1)
2003	856	1	855	0.1		7	(13)			7	(13)	0	(0)			0	(0)
2004	1015	4	1011	0.4		7	(10)			7	(10)	0	(0)			0	(0)
2005	1276	65	1211	5.1	(5)	35	(106)	16	(83)	19	(23)	16	(24)	12	(20)	4	(4)
2006	840	66	774	7.9	(10)	36	(79)	8	(18)	28	(61)	4	(6)	0	()	4	(6)
2007	996	82	914	8.2	(10)	53	(115)	17	(56)	36	(59)	7	(11)	6	(10)	1	(1)
2008	858	181	677	21.1	(30)	63	(175)	25	(85)	38	(90)	8	(11)	6	(8)	2	(3)
2009	955	174	781	18.2	(30)	56	(151)	15	(43)	41	(108)	5	(7)	4	(6)	1	(1)
2010	998	227	771	22.7	(30)	63	(175)	25	(84)	38	(91)	4	(4)	1	(1)	3	(3)
2011	1077	72	1005	6.7	(10)	48	(148)	10	(37)	38	(111)	6	(6)	2	(2)	4	(4)
2012	1028	77	951	7.5	(10)	97	(283)	13	(48)	84	(235)	5	(6)	2	(2)	3	(4)
2013	760	61	699	8.0	(10)	92	(204)	6	(15)	86	(189)	3	(3)	0	()	3	(3)
2014	816	91	725	11.2	(10)	94	(245)	10	(35)	84	(210)	1	(1)	0	()	1	(1)
2015	846	91	755	10.8	(10)	73	(196)	8	(25)	65	(171)	4	(5)	2	(3)	2	(2)
2016	819	88	731	10.7	(10)	59	(176)	7	(27)	52	(149)	1	(1)	0	()	1	(1)
2017	1083	118	965	10.9	(10)	62	(210)	8	(32)	54	(178)	1	(1)	1	(1)	0	(0)
2018	901	104	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)	19	(83)	77	(296)	6	(16)	5	(15)	1	(1)
2020	1049	72	977	6.9	(20)	118	(433)	7	(29)	111	(404)	3	(3)	0	()	3	(3)
2021	859	99	760	11.5	(10)	125	(405)	18	(60)	107	(345)	5	(5)	3	(3)	2	(2)
2022	997	113	884	11.3	(10)	112	(404)	11	(36)	101	(368)	4	(6)	2	(4)	2	(2)

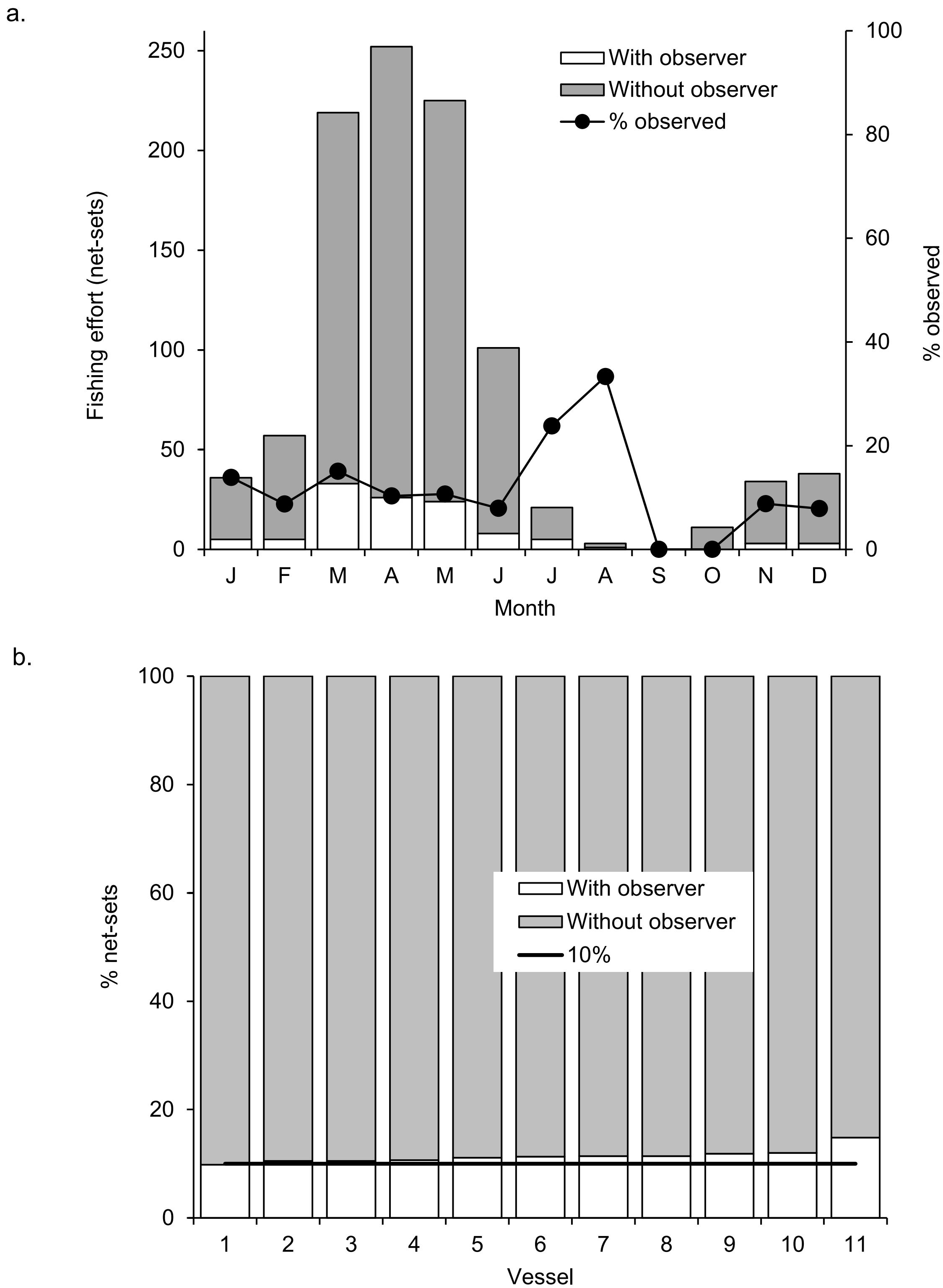

Figure 1. Observer coverage in 2022 by **a)** month and **b)** vessel (ordered by coverage).

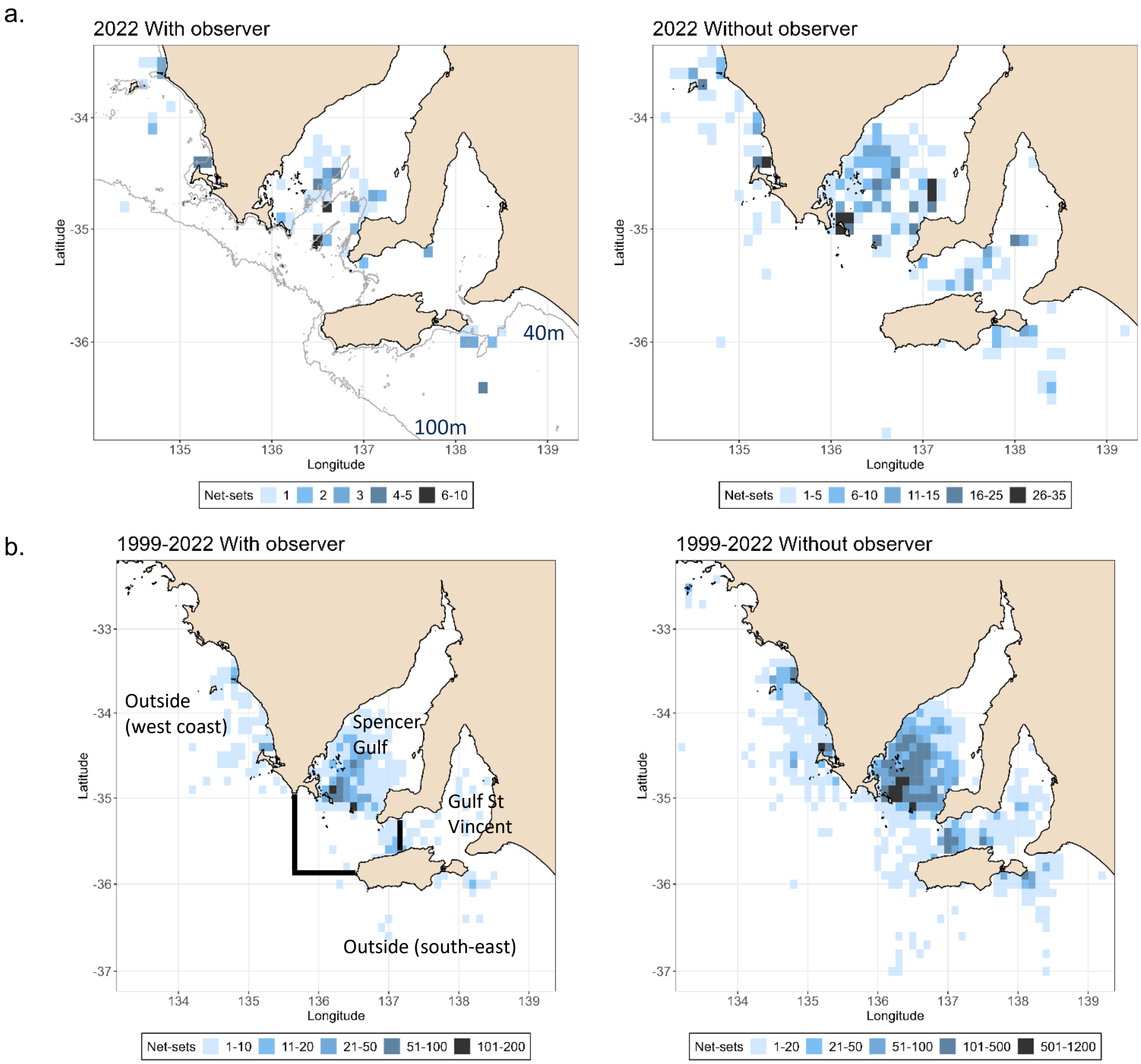

Figure 2. Gridded density plots (0.1° x 0.1°, equivalent to ~11 km^2) showing the distribution of net-sets with and without observers: **a)** in 2022 (40 m and 100 m depth contours indicated), and **b)** all years 1999-2022 (Fishing Zones indicated).

3.3. Wildlife interaction forms (WIFs)

Wildlife Interaction Forms (WIFs) were submitted by fishers for 150 TEPS interactions, 18 with an observer (16% of observed net-sets) and 132 without (15% of non-observed net-sets). Of the 132 interactions reported by fishers without an observer onboard, 128 were with common dolphins, two with Australian sea lions (*Neophoca cinerea*; both jumped over the cork line before pumping began) and three with white sharks (*Carcharodon carcharias*; one died): one of the three shark interactions also was a dolphin interaction.

Of the 128 dolphin interactions when observers were not present, 27 were delay/relocations and 101 involved dolphin encirclements (43 of these followed delay/relocations).

Data from the fisher and the observer were compared for the 18 occasions when WIFs were submitted and an observer was present.

1) On 16 occasions (six delays, nine dolphin encirclements and one white shark encirclement), the data reported by the fisher matched that reported by the observer.
2) On two occasions, the records differed:
    a. One WIF recorded six encircled dolphins, of which one became entangled and died (came on board entangled in the net) and five were released alive; while the observer report indicated 6-8 or more dolphins encircled (taken as eight), of which five became entangled – three dolphins died (one came onboard and two floated away) and five were released alive.
    b. Following encounters with dolphins that caused delays to net-setting, another WIF recorded that no net-set was possible due to on-going dolphin presence, whereas the observer recorded that a net was set and 20 t of sardines was caught.

WIFs were submitted on all 10 occasions when observers reported encirclements. However, WIFS were only submitted for seven of 15 occasions (47%) when net-sets were delayed due to dolphin presence and there was no dolphin encirclement when the net was set. Also, a WIF was not submitted on one occasion when an observer reported a juvenile dolphin became entangled under the net and was able to free itself.

3.4. Dolphin interaction rates

Delays to net-setting

In four out of 118 nights when an observer was present and fishers were anticipating setting a net, nets were not set due to bad weather or because sardines were not schooling. Setting was delayed by dolphin sightings on 16 of the 114 net-set opportunities (14%): 10 times involving a single delay, four times two delays, once four delays, and once no net-set was possible that night due to continued dolphin presence. On the 16 occasions when delays were needed, dolphins were not encircled 15 times (94%) and encircled once (6%).

When no observer was present, fishers reported they needed to delay a net-set due to dolphin presence on 70 of the 884 net-sets (8%): 44 times involved a single delay, 20 times there were two delays, three times three delays, twice four delays, once five delays, and twice no net-set was possible that night due to continued dolphin presence. On the 70 occasions when delays were needed, dolphins were not encircled 27 times (39%) and were encircled 43 times (61%).

Encirclements

Dolphins were encircled in 10% (11 of 113) of observed net-sets with a total of 36 dolphins encircled (3.3 per event). The average rate of encirclements per year for the last 10 years is 11%. In the absence of an observer, fishers reported that dolphins were encircled on 11% of net-sets (101 of 884), with 368 dolphins encircled (3.6 per event).

Rates of encirclement events and dolphins encircled per net-set were similar both with (0.09 events and 0.31 dolphins) and without an observer (0.11 events with 0.41 dolphin). The estimated total numbers were 88 events and 309 dolphins encircled based on observed rates and 113 events and 411 dolphins encircled based on the unobserved rates (Figure 3).

Most encirclements in 2022 (80 of 112, 71%) were in Spencer Gulf, where most fishing occurred (Table 2). The frequency of encirclement events per net-set was higher in Gulf St Vincent (17% of net-sets), than in Spencer Gulf (13% of net-sets), and lowest in the West Coast portion of the Outside Zone (2% of net-sets). The seasonal distribution of encirclements in 2022 and in all years, followed the seasonal distribution of net-sets. There was no apparent seasonal pattern for change in distribution, to indicate seasonal dolphin movement patterns (Figure 4).

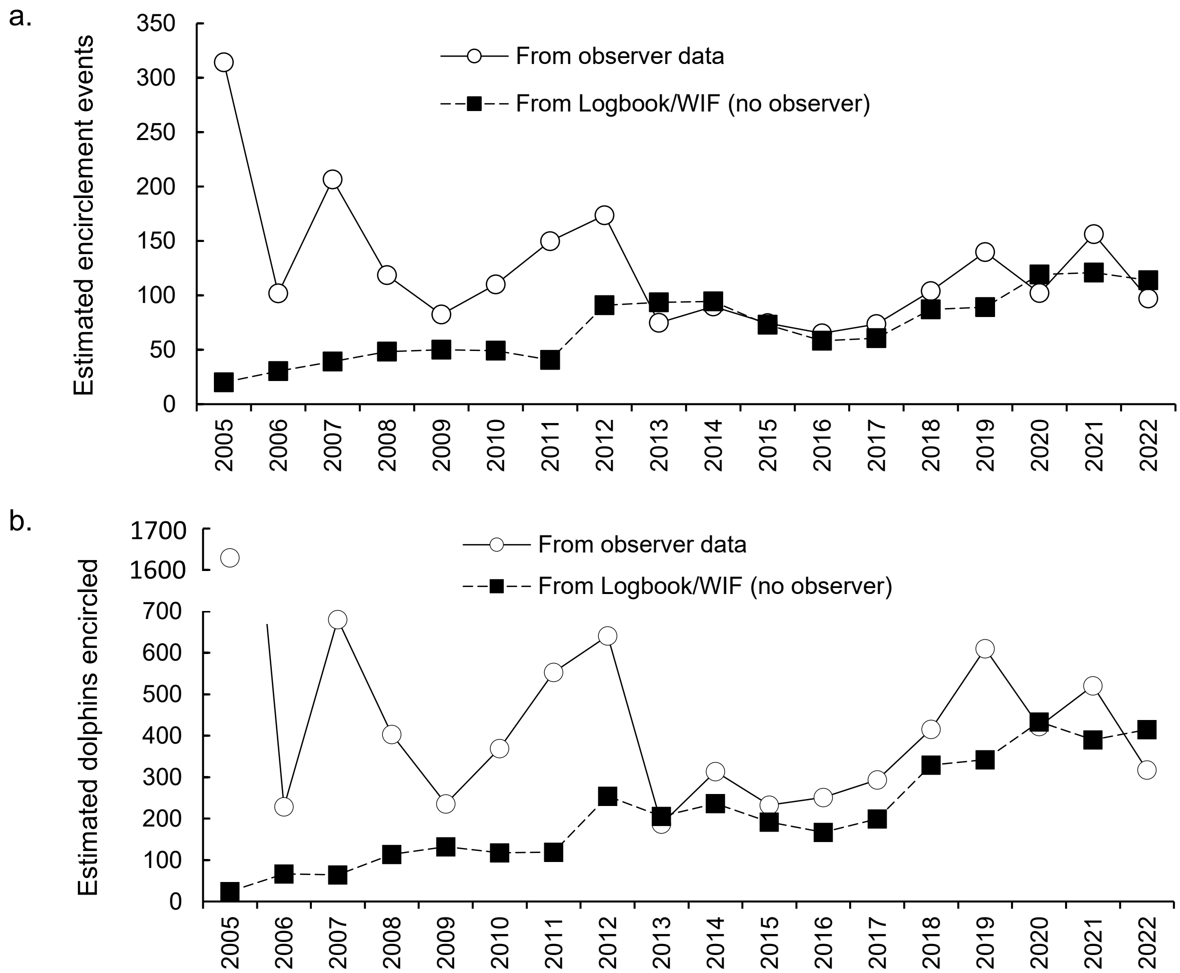

Figure 3. Estimated dolphin encirclements per year from 2005 to 2022 with and without an observer: **a)** encirclement events and **b)** number of dolphins encircled.

Table 2. Frequency and rates of dolphin encirclements in different regions, with and without observers present in 2022.

Zones	With observer			Without observer			Total		
	sets	encircle	%	sets	encircle	%	Sets	encircle	%
Spencer Gulf	71	8	11	561	72	13	632	80	13
Gulf St Vincent	3	0	0	96	17	18	99	17	17
Outside (West Coast)	24	0	0	150	3	2	174	3	2
Outside (South-east)	15	3	20	77	9	12	92	12	13
Total	113	11	10	884	101	11	997	112	11

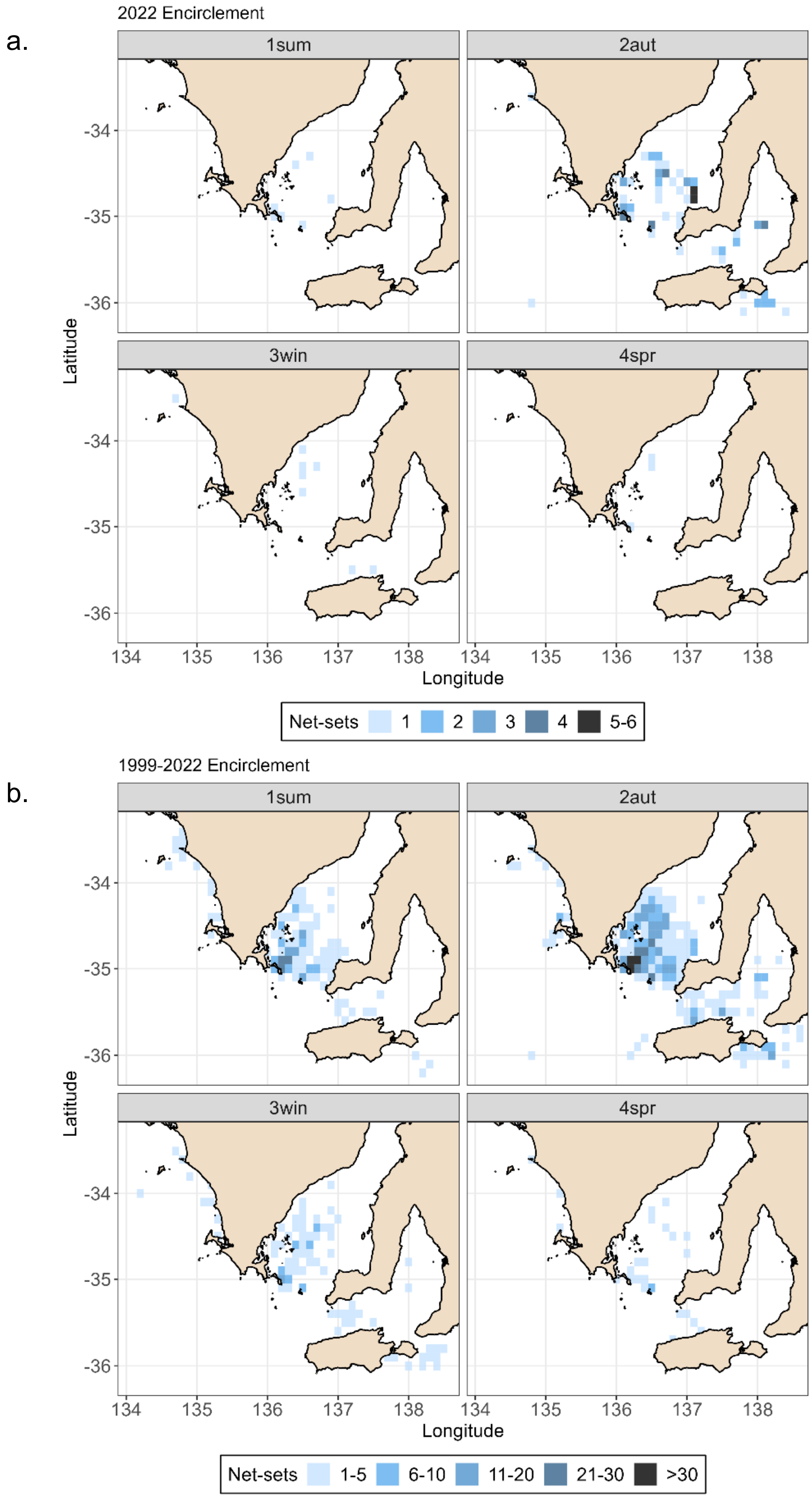

Figure 4. Gridded density plots (0.1° x 0.1°, i.e., ~11 km^2) of the distribution of net-set locations by season where encirclements of dolphins were reported in **a.** 2022, and **b**. 1999-2022.

Mortalities

In 2022, four dolphin mortality events which resulted in six dolphin mortalities were recorded (Table 3). Three events were single dolphins: one entangled on the outside of the net, one was not sighted until at the end of pumping, and once five dolphins were encircled – four were seen to swim away and the fifth was seen floating upside-down. The fourth event involved the encirclement of 6-8 dolphins, of which five became entangled and three died.

Table 3. Details of reported dolphin mortality events in 2022.

Date	Time	Observer present	After delay	Dolphins encircled	Mortality	Entangled	Comment
21-Feb	0:51	yes	no	6-8	3	yes	5 entangled inside
14-Apr	21:40	no	yes	1	1	no	In bag with fish
25-Apr	3:52	yes	no	0	1	yes	Entangled outside
24-Nov	5:30	no	no	5	1	no	Seen upside-down

In 2022, observers recorded two mortality events with a total of four mortalities from the 113 observed net-sets (Table 3). This equated to 0.018 mortality events and 0.035 dolphin mortalities per observed net-set. In the absence of an observer, fishers reported two mortality events with a total of two dolphin mortalities from 884 net-sets, equating to 0.002 mortality events and 0.002 dolphin mortalities per net-set. Consequently, the observed rates were 8 and 18 times the unobserved rates, respectively.

Based on the observed rates of mortality events and total dolphin mortalities, it was estimated that in 2022 there were a total of 18 mortality events and 35 dolphin mortalities from the 997 net-sets (Figure 5). In comparison, based on the rates reported by fishers in the absence of an observer, there would have been an estimated two mortality events involving two dolphins from the 997 net-sets.

Over the past 10 years (i.e., since 2013), an average of 98 net-sets were observed each year and observers recorded 0.012 mortality events and 0.021 dolphin mortalities per net-set. The low frequency of observed mortality events hampers interpretations of trends from year to year.

To facilitate the detection of trends over time, data were summed over 5-year intervals and plotted using a running mean (Figure 6). These analyses suggest a decline in mortality rates up to 2018, both with and without an observer. In 2019, a higher mortality level was recorded by observers (five events and 15 dolphin mortalities, Goldsworthy et al. 2019). Between 2020 and 2022, mortality rates increased, both with and without an observer (Figure 6).

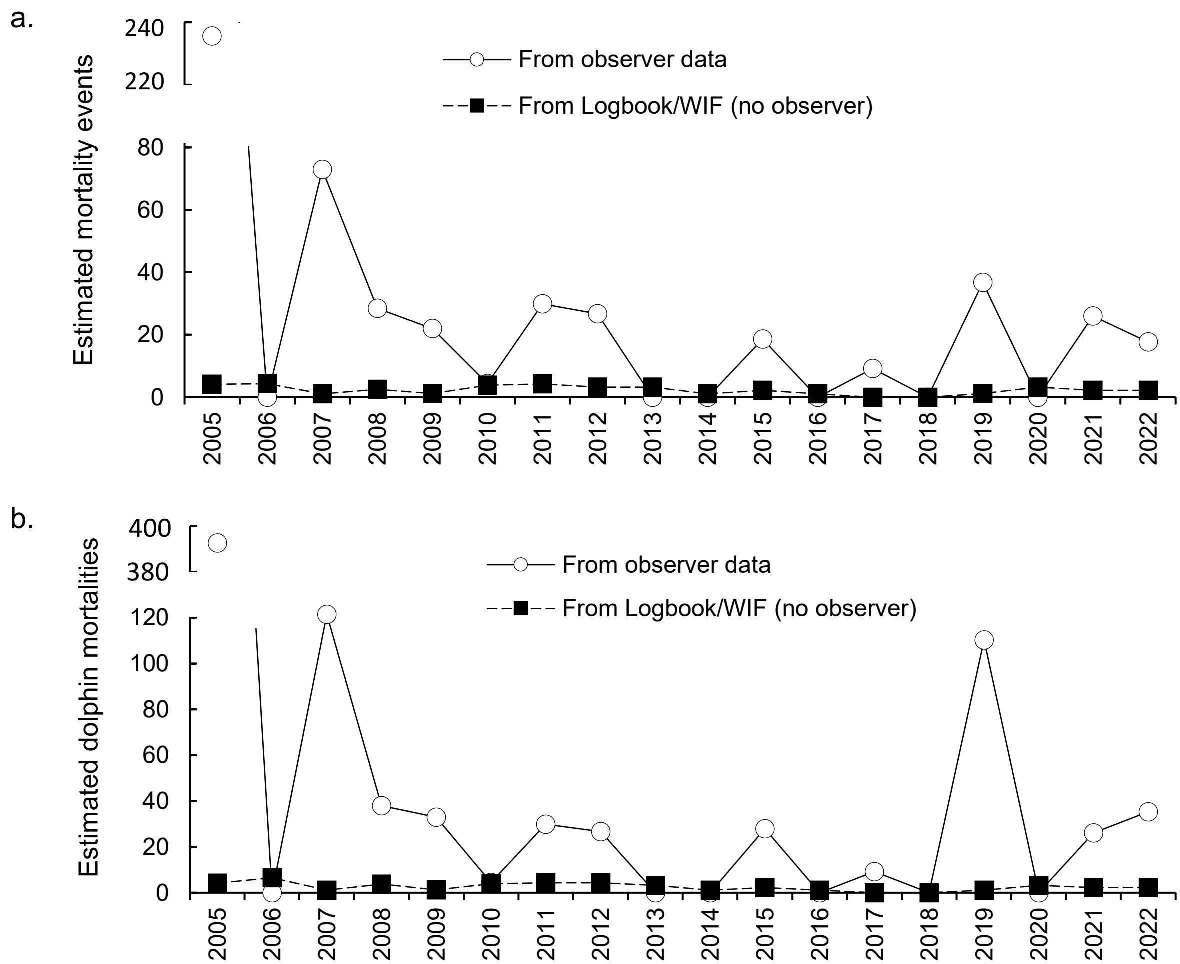

Figure 5. Estimated number of dolphin mortalities per year from 2005 to 2022 with and without an observer: **a)** mortality events and **b)** total dolphin mortalities.

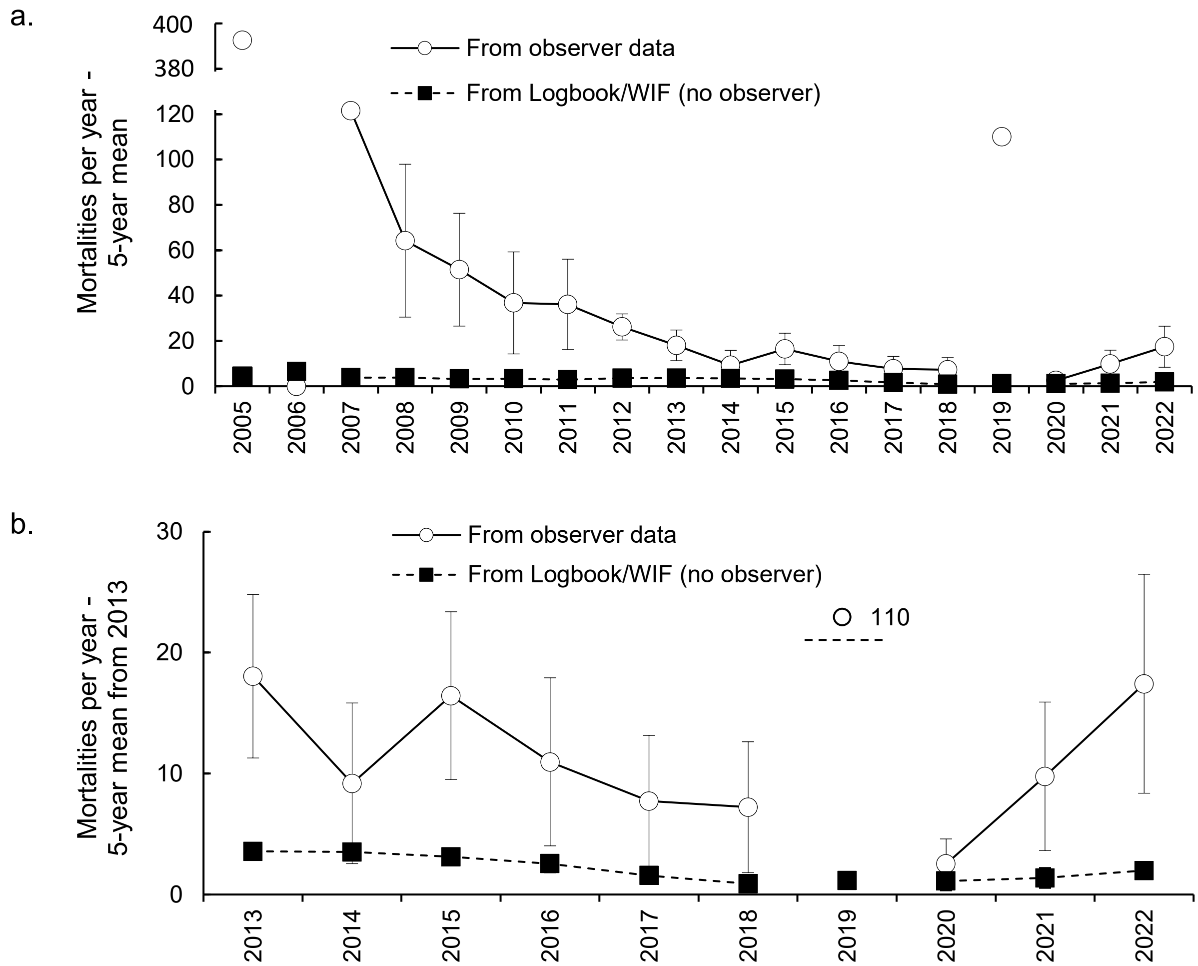

Figure 6. Estimates of annual dolphin mortalities comparing with and without an observer, as a 5-year running mean from 2005 to 2022: **a)** all data and **b)** from 2013 to 2022, to highlight recent trends. The 2019 observer rate (110 dolphin mortalities) is not included in the 5-year means because its inclusion masks the post 2019 trend.

Mortality events by individual vessel were investigated using data from 2018 to 2022 (i.e., the last five years; Table 4). Of the 11 vessels that operated in the fishery in 2022, five recorded dolphin mortality events when observers were absent (one to four events per vessel, all single dolphins), three recorded mortality events only when observers were present (one to four events per vessel, one to six mortalities per event), and three did not record any mortality events. Mortality events have been recorded predominantly in Spencer Gulf (Figure 7).

Table 4. Dolphin mortality events from 2018 to 2022 (i.e., the last five years) for vessels that operated in 2022, indicating events with and without an observer present.

Vessel	With observer		Without observer	
	Mortality events	Dolphin mortalities	Mortality events	Dolphin mortalities
1	4	10	0	
2	2	2	0	
3	1	6	0	
4	0		4	4
5	0		1	1
6	0		1	1
7	0		1	1
8	0		1	1
9	0		0	
10	0		0	
11	0		0	
Total	7	18	8	8

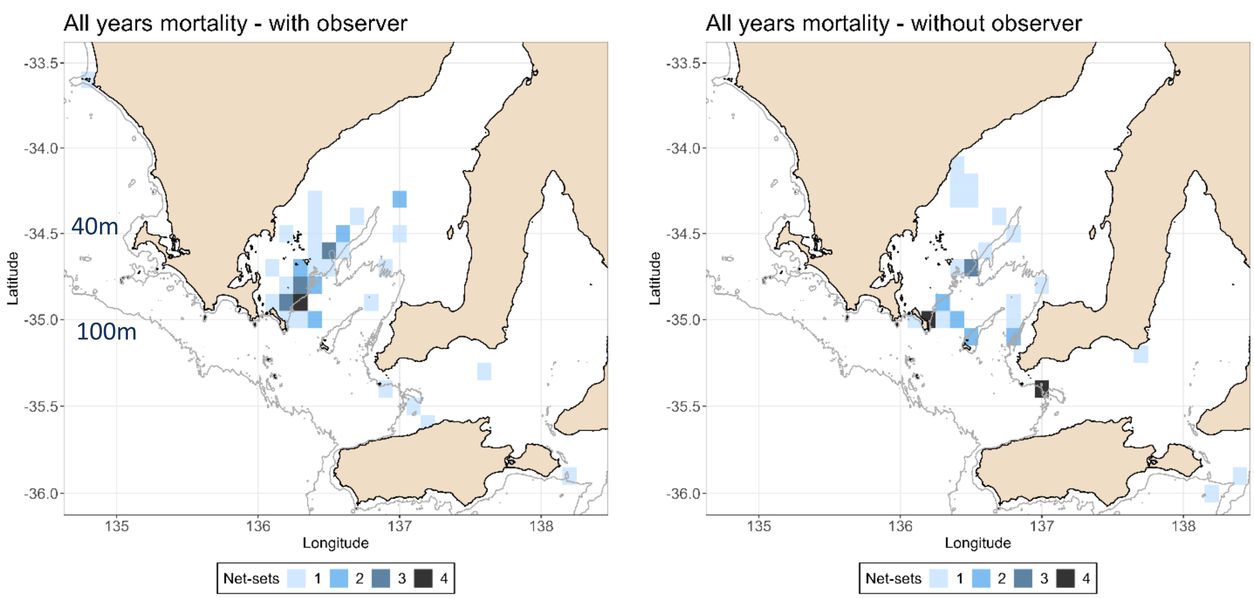

Figure 7. Gridded density plots of the distribution of all net-sets from 1999 to 2022, for which dolphin mortalities were recorded, with and without an observer present.

3.5. Code of Practice assessment

In 2022, the CoP was followed when observers were present. Detailed results of the CoP assessment can be found in Appendix 4. The key findings of the assessment were:

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 net, the set was always delayed/ relocated.
4) If dolphins were sighted encircled or entangled, the response to release them was always immediate (acknowledging that a delay of 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., crew released the front of the net and aborted the set.

WIFs submitted by fishers when observers were not onboard document comparable rates of dolphin encirclement to observer reports, but fewer dolphin mortalities.

A comparison between observer reports and WIFs submitted when observers were onboard demonstrated there was good adherence to the CoP in all steps, except that WIFs were not routinely submitted for delay/relocations if there was no subsequent encirclement (see data presented in Appendix 4).

3.6. Fishing behaviour

In 2022, and for most years since 2013, when an observer was present, there were more net-sets per trip, a higher percentage of net-sets with zero catch of sardines, and less tonnage of sardines caught per net-set (Table 5, Table 6, Figure 8). By individual vessel in 2022, the mean sardine catch per net-set was between 21 and 73% lower when an observer was present (Figure 9).

A proportion of zero-catch net-sets would be the result of encirclements. Encirclements have been recorded at similar rates with and without an observer, so they should not influence this comparison. Even excluding all zero-catch net-sets, sardine catch remained lower when observers were onboard (Figure 8d).

From 2005 to 2013, there were two years when the mean tonnage of sardine caught per net-set was significantly lower when an observer was present (Table 5). However, in all years from 2013 to 2022, the mean catch of sardine has been significantly lower when an observer was present (Table 5, Figure 8c).

Table 5. Results from Wilcoxon *W*-test (non-parametric data) comparing annual data from 2005 to 2022 with and without an observer for the number of net-sets per trip, sardine catch per net-set (t), and sardine catch excluding net-sets with zero catch (see Figure 8). Bold indicates a significant difference at $p<0.05$.

Year	Net-sets per trip		Catch per net-set		Catch excluding zeros	
	W	*p*	*W*	*p*	*W*	*p*
2005	20974	0.294	47444	**0.003**	29992	0.245
2006	12778	0.975	28872	0.118	22960	0.184
2007	17126	0.122	41935	0.073	23136	0.699
2008	30797	0.241	65781	0.127	44711	0.895
2009	36700	0.625	71627	0.263	54504	0.704
2010	38436	0.119	101233	**<0.001**	60857	0.219
2011	17675	0.116	37084	0.722	22999	0.338
2012	17181	0.159	39487	0.251	27910	0.497
2013	8548	**0.012**	24131	0.087	16276	0.299
2014	13396	**0.026**	39056	**0.004**	25486	0.060
2015	15421	0.369	44160	**<0.001**	28430	**0.002**
2016	9369	**0.002**	36691	**0.031**	27714	0.052
2017	16144	**0.021**	69904	**0.001**	46530	**0.001**
2018	12729	**0.010**	51942	**0.001**	37654	**<0.001**
2019	21858	0.637	61135	**0.016**	39421	0.219
2020	14879	0.613	42595	**0.003**	29918	**0.003**
2021	15532	0.136	46568	**<0.001**	27465	**0.023**
2022	11314	**<0.001**	65956	**<0.001**	45281	**<0.001**

Table 6. Results of *t*-tests (parametric data) comparing mean values for indices of fishing behaviour with and without an observer present across all years from 2013 to 2022, and for water-depth of net-sets in 2022. Bold indicates a significant difference at $p<0.05$.

	With observer		Without observer		*t*-test			
Parameter	Mean	SE	Mean	SE	Variance	*t*	*df*	*p*
2013 to 2022								
Net-sets per trip	1.7	0.1	1.5	0.0	equal	2.10	18	**0.002**
% net-sets with no catch	21.2	1.1	12.7	0.4	unequal	2.17	18	**<0.001**
Catch (t)	30.2	0.8	42.1	1.0	equal	2.10	18	**<0.001**
Catch (t) ex. no catch sets	37.5	1.2	48.1	1.0	equal	2.10	18	**<0.001**
2022								
Depth (m) – (in 2022)	38.2	1.3	34.7	0.5	equal	2.65	951	**0.008**

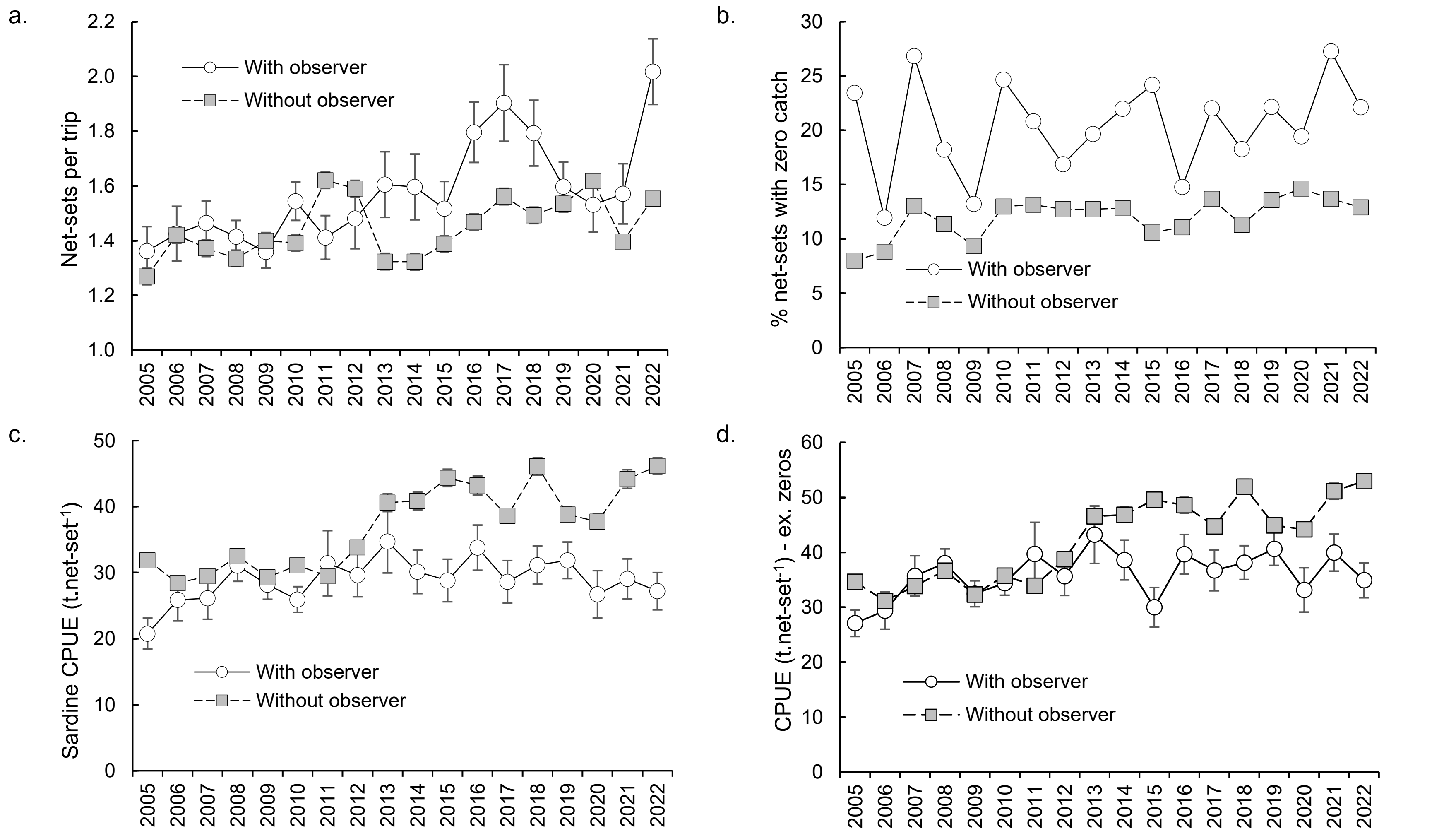

Figure 8. Fisher behaviour from 2005 to 2022 with (circles) and without (squares) an observer: comparison by **a)** net-sets per trip, **b)** percentage net-sets with zero catch, and sardine CPUE (tonnes per net-set) **c)** including zero-catch net-sets, and **d)** excluding zero-catch net-sets.

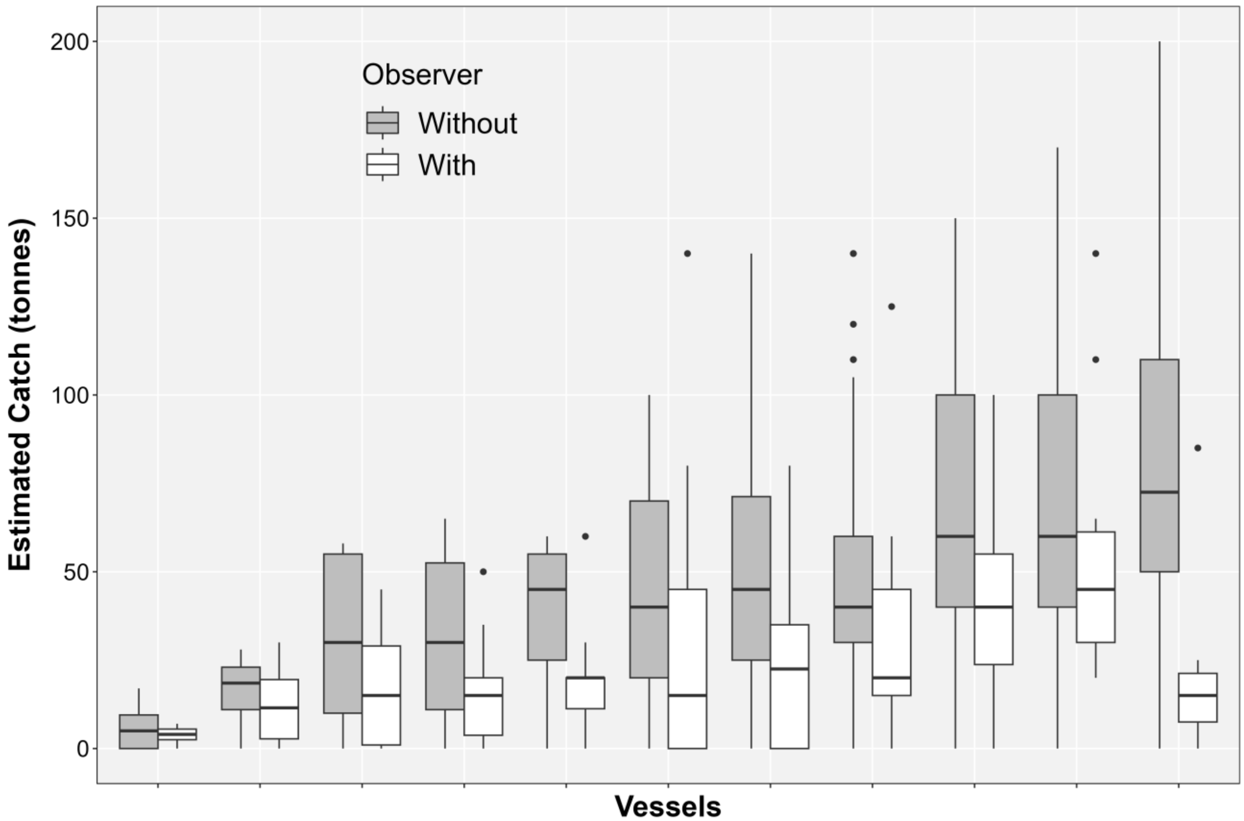

Figure 9. Boxplot of estimated catch (tonnes) per net-set by individual vessels in 2022 (artificially ranked), without and with an observer present.

In 2022, analyses also indicated that nets were set less frequently in shallower depths when an observer was onboard (Table 6). For this analysis, locations that were erroneously recorded on land or where water-depth were <10 m (considered unlikely) were removed. The mean depth where nets were set was significantly deeper when an observer was present than without an observer onboard. Nonetheless, the mean depths were similar (Table 6). The difference was likely due to a greater frequency of net-sets in depths between 10 and 30 m when there was no observer, and a greater frequency of net-sets in depths between 40 to 50 m when an observer was present (Figure 10).

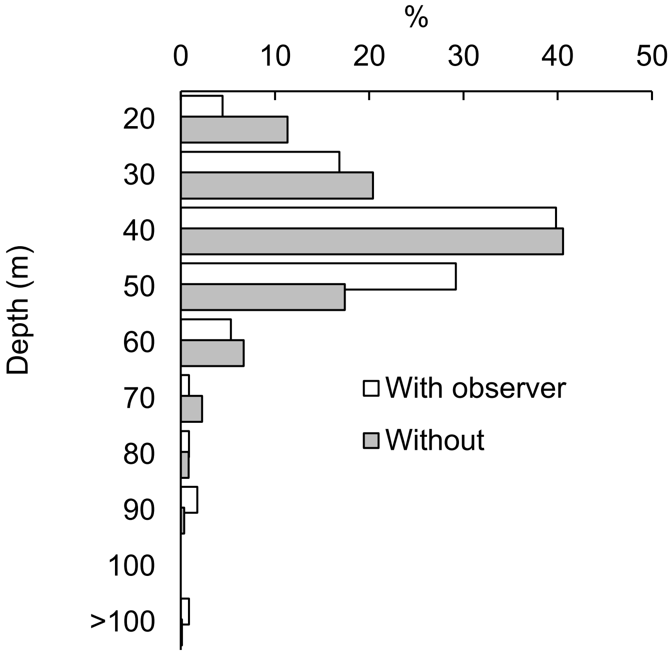

Figure 10. Binned depth (10 m intervals) where nets were set in 2022, comparing with (clear) and without (grey) an observer present.

Sardine catch was investigated in net-sets when dolphin interactions were reported. In 2022, when encirclements were reported and an observer was present (n = 11), sardine catch was zero on 10 net-sets (91%) and 35 t on one net-set (9%, i.e., when a dolphin entangled on the outside of the net and freed itself). When encirclements occurred without an observer present (n = 101), there was zero sardine catch on 73 net-sets (72%) and on 28 net-sets (28%), sardines were caught (38 t ± 4.8, range 10 to 120 t). In 2022, and for the period 2013 to 2022, the differences in mean sardine catch with and without an observer present were not significantly different (Table 7). Since 2006, there has been an overall decline in the catch per net-set when an encirclement occurred with and without an observer present (Figure 11).

There were too few dolphin mortality events in 2022 to compare sardine catch rates in mortality events with and without an observer in the single year. Combining data recorded since 2013, sardine catches retained when there was a dolphin mortality were significantly lower when an observer was present (zero catch on nine of 13 events, compared with zero catch on one of 15 events without an observer; Table 7, Figure 12). Furthermore, encirclement events in which there was a dolphin mortality were more likely to retain sardines than encirclement events without a dolphin mortality. Potentially, endeavouring to retain catch when dolphins are encircled may increase the risk of a mortality.

In 2022, there was no statistically significant difference in the number of hours spent searching for sardines prior to net-setting, with or without an observer present (Table 7).

Table 7. Results of Wilcoxon *W*-tests (non-parametric data) comparing estimated sardine catch on dolphin interaction events, and search time (hours) prior to net-setting. Bold indicates a significant difference at *p*<0.05.

Event	Year	Measure	With observer		Without observer		*W*-test	
			Median	(mean)	Median	(mean)	*W*	*p*
Encircle	2022	Catch (t)	0	(3)	0	(11)	653	0.190
Encircle	2013-22	Catch (t)	0	(10)	0	(14)	44745	0.322
Mortality	2013-22	Catch (t)	0	(15)	50	(54)	161	**0.003**
Search	2022	Hours	2.0	(2.9)	2.2	(3.4)	51676	0.087

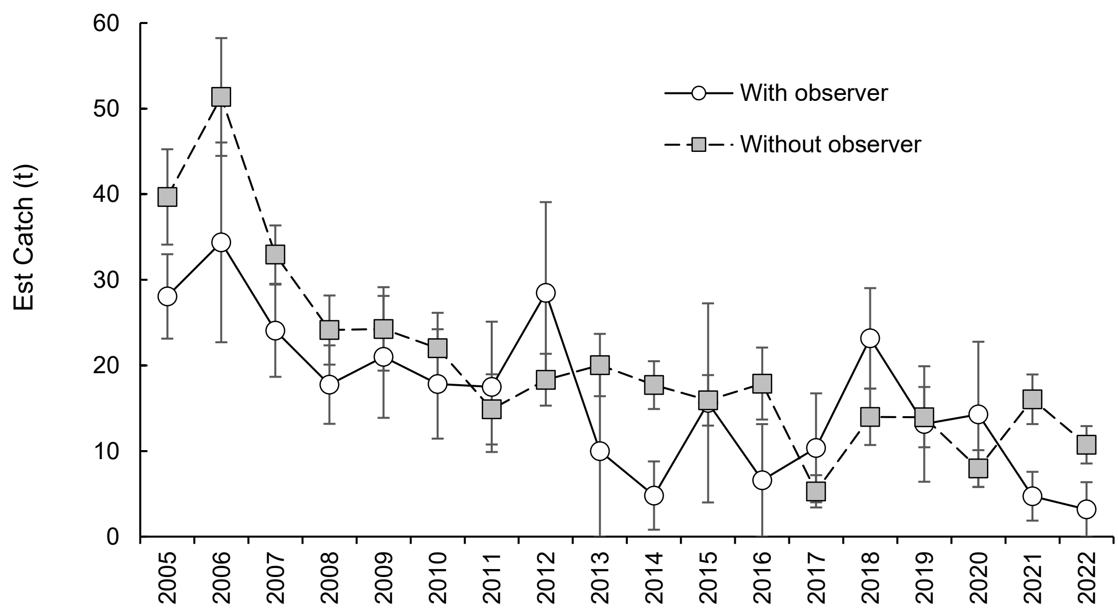

Figure 11. Estimated sardine catch (t) per net-set when an encirclement occurred in years from 2005 to 2022, comparing with (circles) and without (squares) an observer present.

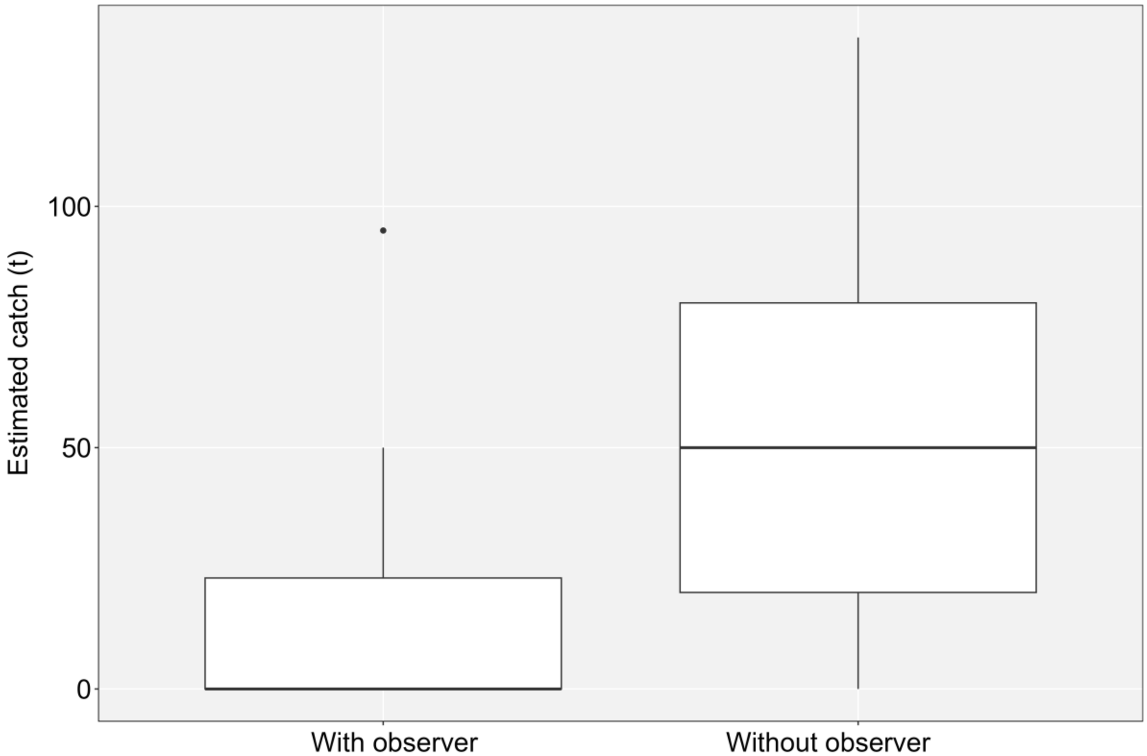

Figure 12. Boxplot of estimated sardine catch (t) per net-set when a dolphin mortality event occurred between 2013 and 2022, comparing with and without an observer present.

3.7. GAM analyses

1. Observer presence/absence – 2022

In 2022, the most significant correlation with observer presence was for lower sardine catch per net-set (Appendix 5.1). Other significant correlations were that observers were more likely to be present for mortality events, more likely to be present for shorter search hours before net-sets, less likely to be present for net-sets at shallow depths, and less likely to be present for net-sets in Gulf St Vincent.

2. Observer presence/absence – 2013 to 2022

The most significant correlations with observer presence were for lower sardine catches per net-set, more dolphin mortality events and less search time before net-sets (Appendix 5.2). Other highly significant correlations with when an observer was present were fewer encirclement events, fewer net-sets in shallower water, and more observer coverage of pre-sunset and post-dawn net-sets. There was no significant relationship between observer coverage and either fishing zone or phase of the moon.

3a. Encirclement events – 2022

In 2022, there were significantly fewer encirclement events in the West Coast portion of the Outer Zone (Appendix 5.3a). There were also significantly more encirclements in the hours prior to dawn, and more encirclement events in Autumn. There was a tendency for fewer encirclements on nights with a full moon.

3b. Encirclement events – for vessels – 2022

In 2022, one vessel had significantly more dolphin encirclements than did other vessels and one vessel had no encirclements. The remaining vessels had similar levels of encirclements (Appendix 5.3b).

4. Encirclement events – 2013 to 2022

Spatially, the rate of encirclements was significantly lower on the West Coast region of the Outer Zone and higher in Gulf St Vincent (Appendix 5.4). Other significant correlations were for more encirclements when less time was spent searching before net-setting, for encirclements to be more likely between sunset and midnight, and to be less likely in spring.

5. Catch per net-set – 2022

In 2022, there was a highly significant correlation for lower catches in the presence of observers. (Appendix 5.5). Other significant correlation were for lower catches around dawn, and smaller catches when trips were longer.

6. Catch per net-set – 2013 to 2022

Across all years, the most significant correlations were for smaller catches per net-set when observers were present, smaller catches on longer duration trips, and smaller catches just after sunset or around dawn (Appendix 5.6).There were also larger catches just before sunset.

7. Mortality events – 2013 to 2022

Across 2013 to 2022, there was a highly significantly correlation between dolphin mortality events and observer presence (Appendix 5.7).

4. DISCUSSION

4.1. Observer coverage

The targeted observer coverage of 10% of net-sets for 2022 was achieved. The design of the program allowed for an even coverage across months and vessels. However, coverage across the geographic range of net-sets was not even, with particularly low coverage of net-sets in Gulf St Vincent (3%). The frequency of SASF net-sets in Gulf St Vincent has increased in recent years, from <6 per year in 2017 to 2019, to 161 in 2020, 85 in 2021 and 99 in 2022. As such, observer effort should be increased in this region in future years.

Observers usually will not know where fishing will take place when they board the vessel and, therefore, the low coverage in Gulf St Vincent is unlikely to be related entirely to how observer effort is distributed. Low observer coverage in Gulf St Vincent may be either by chance or because fishers avoided fishing in Gulf St Vincent when observers were onboard. The reasons for the low observer coverage in Gulf St Vincent in 2022 could relate to being >200 km from the home port of Port Lincoln, so an observer would be onboard for longer than if fishing in Spencer Gulf. However, observer coverages of other distant fishing areas, west of Eyre Peninsula (>200 km) and south-east of Kangaroo Island (>250 km), were approximately 10%. Another potential reason for the low coverage in Gulf St Vincent is that fishers were avoiding fishing with observer coverage in this area due to the relatively high frequency of dolphin encirclement events that occur there, 17% of net-sets compared with 13% in Spencer Gulf and 2% in the Outside Zone.

In addition to the regional bias, observer effort within Spencer Gulf in 2022 was also not spatially uniform. Observers most frequently witnessed net-sets in central Spencer Gulf, whereas net-sets when observers were not on board were most frequent in the south-west of the Gulf. In 2022, there was also an area inshore along the western side of Spencer Gulf that had low observer coverage. There is also the potential that some fishers avoided net-sets in shallower waters when observers were onboard. Dolphin interactions appear more likely in shallower water.

4.2. Dolphin interactions

Delays in setting nets due to dolphin sightings

To mitigate dolphin encirclements, the SASF's CoP requires that fishers maintain a look-out for dolphins before net-setting and delay net-setting if dolphins are sighted. In 2022, when observers were not present, fishers reported delays due to dolphin sightings on 8% of net-sets, and that following such delays, dolphins were encircled on 61% of net-sets. This rate was much higher than the overall rate of encirclement of about 10% of net-sets and suggests delays were ineffective at reducing encirclements. However, this high rate most likely resulted from fishers not routinely reporting delays due to dolphin presence, with them being more likely to do so if dolphins were encircled in the following net-set. Therefore, the unobserved data should not be relied on to assess compliance with and efficacy of this part of the CoP. Observers reported that, in their presence, great attention was placed on looking out for and delaying net-sets when dolphins were sighted. Delays due to dolphins were required on 14% of observed net-sets and dolphins were encircled on 6% of net-sets that followed such delays, which was lower than the overall encirclement rate of 10%. This suggests that looking out for dolphins and delaying when dolphins are sighted does mitigate dolphin encirclements.

Encirclements

In 2022, the estimated total number of dolphins encircled in the fishery based on rates recorded by observers (i.e., 97 events and 318 dolphins) was lower than the number estimated from rates recorded when observers were absent (i.e., 114 events and 415 dolphins). The reported totals of 112 encirclement events and 404 dolphins encircled in 2022 were comparable to totals recorded in 2020 and 2021 (i.e., approximately one dolphin encirclement event every 10 net-sets).

The number of dolphins encircled each year increased from <200 per year between 2007 and 2011, to ~400 per year since 2020. The increase was predominantly due to the number of dolphin encirclements recorded when observers were not present. Particularly, there was an increase from 77 events involving 296 dolphins in 2019, to 111 events and 404 dolphins in 2020 (see Table 1). This increase may be due to several factors. It may reflect increased levels of reporting of dolphin encirclements over time and/or a (proportionally) greater increase in rates of dolphin encirclement in unobserved net-sets over time. There is also the potential that the number of dolphin interactions increased over time, with the increase being more apparent in the larger data pool of unobserved net-sets. It is also possible that dolphin populations in the fishing area may have increased over time (see Parra et al. 2021, Goldsworthy et al. in review) or that resident dolphins have been increasingly attracted (or habituated) to fishing operations.

The potential increase in numbers of dolphins interacting with the fishery suggests the potential for mortality rates to increase. Having more dolphins present around fishing operations, and more dolphins encircled, increases the risk of a large dolphin mortality event (e.g., >5 dolphins) occurring.

Mortalities

Dolphin mortalities in the SASF have resulted from interactions with both the inside and outside of purse-seine nets as well as due to the stress of encirclement, which has been the cause of dolphin deaths in a number of purse-seine fisheries (Forney et al. 2002, St Aubin et al. 2013), including in the SASF (Hamer et al. 2007). Dolphins, particularly calves, that are not encircled have also succumbed to stress due to separation from their kin (Archer et al. 2001, Edwards et al. 2006). Direct contact with the net is likely to increase stress and entanglement in the net further increases the potential for injury and stress related mortality. An over-riding factor influencing dolphin survival when encircled or entangled is the duration they are entrapped. Accordingly, the SASF industry CoP places great importance on prompt action to release encircled dolphins as soon as possible.

In 2022, four dolphin mortality events and six dolphin mortalities were recorded, which were comparable to numbers recorded in 2020 and 2021. Two mortality events were reported in the 113 observed net sets and two in the 884 unobserved net-sets, indicating mortality events were reported ~8 times more frequently when an observer was present. The difference in the number of dolphin deaths was 18 times more when an observer was present, due to there being three mortalities in one of the observed events. In most years of the observer program, mortality rates reported when observers were present have been higher than when observers were not present. For example, between 2013 and 2022 there were 26 dolphin mortalities in 968 observed net-sets (i.e., 2.7 dolphin mortalities per 100 net-sets) compared to 15 dolphin mortalities in 8,125 net-sets when observers were not present (i.e., 0.18 dolphins per 100 net-sets). Therefore, dolphin mortalities between 2013 and 2022 were reported 15-times more frequently when an observer was present. Based on the persistent difference between observed and unobserved mortality rates over the 10-year period, under-reporting of dolphin mortalities appears to be on-going in the fishery.

Under-reporting of interaction rates with protected species in the absence of observers is common in other fisheries as demonstrated by higher dolphin mortality rates when observers were present (Johnson et al. 1999, Burns and Kerr 2008). Due to this under-reporting in the absence of an observer, fisheries scientists typically rely on observer data (where available) to estimate total mortality of protected species.

Under-reporting of dolphin mortalities may have an intentional component, e.g., to avoid follow-up investigation by compliance officers, or to under-represent the mortality rate. Another component of under-reporting would be unintentional and result from a lower detectability of immediate ‘cryptic’ mortalities when an observer is not present. Cryptic mortality is a recognised element of marine mammal bycatch mortality (Gilman et al. 2013, Heinemann 2017). It includes the sinking or movement away from the vessel of dolphin carcases before they are sighted. An observer has the dedicated role of looking for dolphin interactions and mortalities and, therefore, could be expected to witness more than fishers, who also have the responsibilities of crew safety, equipment management and securing a catch of sardines. While carcases that are encircled and remain inside the purse can be accounted for, carcases of dolphins released from the purse, or entangled outside the net cannot be followed after they leave the circle of light around the vessel in a night-time fishery.

Several interactions witnessed by observers involving multiple dolphins highlight both the possibilities for a higher cryptic mortality in the absence of observers, but also the potential for deliberate under-reporting. In 2022, a fisher recorded on a WIF that six dolphins were encircled and one died, while for the same event the observer indicated 6-8 dolphins were encircled and three died. Similarly for an event in 2019, it was reported on the WIF that six dolphins were encircled, four were entangled and ‘kicking’ so were cut from the net, with all dolphins released alive, while the observer indicated all four entangled dolphins that were cut free floated away dead, while a fifth dolphin was manhandled over the cork-line (injured but still alive), and a sixth came onboard dead in the net. These observations demonstrate that it can be difficult to detect the status of dolphins following interactions and that under-reporting of dolphin mortalities can occur. It also demonstrates a difficulty in determining what has happened when the witness reports differ markedly and there is no corroborating evidence.

While an observer may have the opportunity to witness more dolphin mortalities than a crew member, they will not see all mortalities. Cryptic mortalities include carcases that drift out of sight, plus mortalities that occur later, due to stress of capture, separation or group member loss, or succumbing to injuries. Foetuses and dependant young not directly involved in an interaction, are also a component of cryptic mortality. For example, 11 of 14 adult female common dolphin carcasses recovered following mortality in sardine purse-seine nets in South Australia were pregnant or lactating, and their dependant young would have succumbed (Kemper et al. 2023). Cryptic mortality of marine mammals in fisheries has been estimated to be >50% of the total mortality (Gilman et al. 2013, Moore et al. 2021).

One means of investigating cryptic or unreported mortality of dolphins in a fishery has been through the analysis of beach-washed carcases (Peltier et al. 2012, Carretta et al. 2016). Heinemann (2017), for example, analysed stranding data-sets for 21 cetacean species and concluded that, at most, 35% of mortalities caused by a fishery were detected within the fishery. There are limitations to using beach-washed animals to estimate fishery-related dolphin mortalities, however. For instance, not all carcases will wash ashore. Also, distinctive wounds to implicate an interaction are not always evident (e.g., distinctive net marks may be absent, or indistinct on decomposed carcasses), mortality from drowning or stress cannot be linked to a specific cause, and mortality following an interaction may be by a secondary cause, such as pneumonia from inhaled water, disease enhancement following injury, or vessel collision following disorientation (Heinemann 2017; Kemper et al. 2023). Also, recording of a beach-washed dolphins depends on public visitation rates, and their participation in reporting.

Because monitoring beach-washed dolphins has provided an indication of dolphin mortalities and their causes elsewhere, including cryptic fishery-related mortality, data on the distribution and frequency of beach-washed common dolphins in South Australia may do the same. Since 2005, the number of beach-washed common dolphins reported in South Australia has been low, ranging between four and 38 annually, with peaks in 2005 to 2007, 2019, and 2022 (Figure 13). Currently, potential causes of local dolphin mortalities are being investigated by research staff from the South Australian Museum and the University of Adelaide.

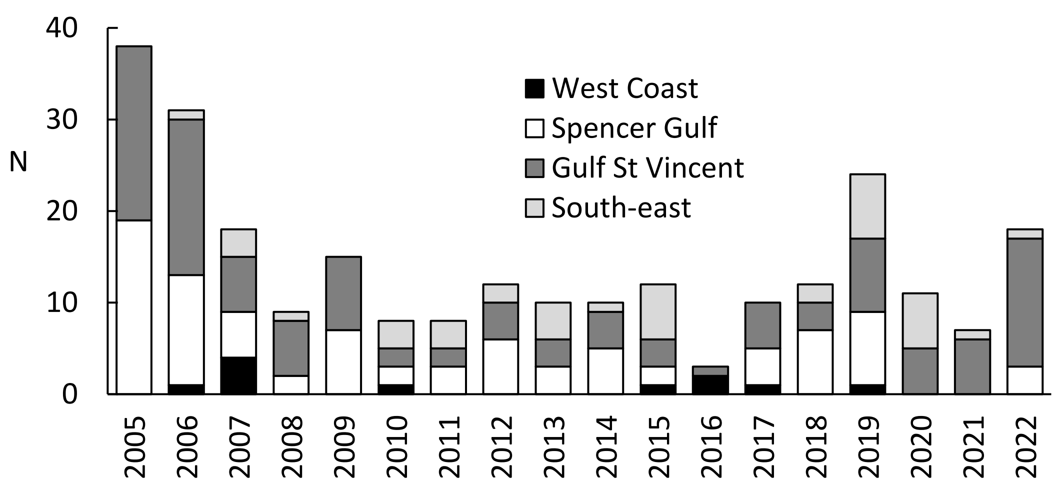

Figure 13. Numbers of dead beach-washed common dolphins in South Australia reported to the SA Museum, by year from 2005 to 2022 and region (data from SA Museum and DEW).

Population level consequences of mortalities

Two surveys of common dolphin abundance in the region and assessments of potential population-level impacts of mortalities associated with the SASF have been conducted (Parra et al. 2021, Goldsworthy et al. in review). Aerial surveys in 2011 estimated approximately 25,000 common dolphins in Spencer Gulf, Gulf St Vincent, and the Investigator Strait (Parra et al. 2021). Similarly, an aerial survey in 2021 estimated 27,000 common dolphins in Spencer Gulf and associated coastal waters (Goldsworthy et al. in review). Using 'Potential Biological Removal' (PBR) analysis (Wade 1998), Parra et al. (2021) estimated that in 2011, the loss of more than 189 dolphins per year through human interactions could have an impact on the population's sustainability. Based on the 2021 population estimate, Goldsworthy et al. (in review) calculated an anthropogenic mortality limit of up to 210 dolphins per year before populations could be affected and, which was only exceeded in 2005, when 393 dolphin mortalities were estimated. Based on an estimated average annual mortality rate since 2006 of 27 ± 9 dolphins per year (based on observer data), suggested the SASF was unlikely to be limiting the growth of common dolphin populations in South Australia.

Goldsworthy et al. (in review) placed several caveats to this conclusion. Firstly, the mortality rates used in the analyses did not include cryptic dolphin mortalities, which to date have not been assessed. Secondly, observer presence appeared to influence fisher behaviour (see next section) such that annual dolphin mortalities may differ from those currently estimated. Thirdly, the estimated annual mortalities included just SASF data, whereas PBR assessments should incorporate all anthropogenic causes of mortality, such as vessel collision, entanglement in other fishing gear, and shortening of life due to exposure to anthropogenically released toxins (e.g., see review by Kirkwood et al. 2022). Finally, the estimates did not consider the potential for sub-population structure within the broader common dolphin population in South Australia i.e., the potential that genetically distinct sub-populations occupy both or each gulf (Barceló et al. 2021, 2022). If this is the case then PBR methods would need to be applied to each sub-populations' abundance, range and anthropogenic factors.

Fishing behaviour

Over the period of observer coverage (2005 to 2022), significant differences in fishing behaviour in the presence of an observer have persisted. The GAM results were consistent with the individual variable and analyses, that in the presence of an observer, fishing behaviour is different (i.e., there is an observer effect). For example, when an observer was present there were more net-sets per night, more net-sets with zero catch, and smaller sardine catch rates (even when zero-catch net-sets were excluded). The most significant factor contributing to variability in catch rates per net-set, apart from vessel size, is observer presence.

This report also highlights further differences between observed and unobserved net-sets. In the presence of an observer there were fewer net-sets in shallower water (<30 m depth), fewer net-sets in Gulf St Vincent (where encirclement rates appear to be higher than elsewhere), less time spent searching for a sardine school before setting a net (this was apparent in GAM analysis but not individual variable analysis), lower chance of retaining a proportion of the catch when there was an encirclement event, and a smaller catch retained when there was a mortality event.

One interpretation for the on-going differences between observed and unobserved net-sets is that fishers either made choices or unintentionally changed their fishing behaviour, in the presence of an observer, to reduce the likelihood of a dolphin interaction (particularly a mortality event). Also, when there was an encirclement and no observer present, fishers were more likely to retain catch. Potentially, when there is no observer, more effort may be made to 'slip' the dolphins, (i.e., to open the net and usher the dolphins out before reclosing the net), to retain the catch, rather than to focus on a rapid dolphin release. This practice may be highly successful at both releasing dolphins and retaining catch, but it could prolong encirclement of the dolphins, and thereby increase their chance of mortality through stress or entanglement. This is consistent with more catch being retained when there is a dolphin mortality event when an observer was not present. Encirclement events with mortalities also had a higher frequency of catch retained than encirclement events without mortalities.

The robustness of using mortality rates from observers to estimate total fishery bycatch is underpinned by fisher behaviour being consistent, irrespective of observer presence (Zollett et al. 2015, Luck et al. 2020). If fishing behaviour changes significantly in the presence of observers, then bycatch rates recorded by observers may not accurately represent the broader fishery. Acknowledging that observer data are not representative of the broader fishery has implications for how the observer data are used and interpreted (i.e., there are limitations to their application to estimate dolphin susceptibility and bycatch mortality), and on how effectively the CoP is applied when observers are not present. A means of reducing observer effects and enabling more accurate documentation of fishery-bycatch interactions, has been electronic monitoring with on-board camera systems (Bartholomew et al. 2018, Wakefield et al. 2018, Emery et al. 2019).

Code of Practice assessment

In 2022, observers reported that in their presence, fishers routinely followed the CoP. Fishers checked for dolphins prior to net-setting and throughout fishing operations, delayed net-sets, at times relocated if dolphins were sighted prior to net-sets, immediately reacted to free dolphins when encircled or entangled dolphins were sighted, released dolphins by opening the front of the net, and aborted the set.

As detailed above, one shortcoming was that WIFs were not routinely submitted when there were delays due to dolphin presence. The success of conducting delays and relocations at preventing encirclements and mortalities cannot be assessed fully unless delays due to dolphin presence are recognised as interactions and are routinely recorded.

When observers were absent, fewer dolphin mortalities were reported, which suggests under-reporting by fishers. Also, indices of fishing behaviour, such as sardine catch per net-set, differed when observers were present. The fishing behaviour in the absence of an observer, e.g., more focus on retaining catch during encirclement events, may pose greater risks to dolphins than the behaviour while in the presence of an observer.

4.3. Management considerations

The observer coverage of 10% of net-sets across an almost 20-year period provides invaluable information on fishing activities and interactions between the SASF and common dolphins (Ward et al. 2023). Certainly, mortality rates recorded in the early 2020s have been substantially lower than levels recorded in the early 2000s. The observer data also demonstrate that fishers complied with the industry CoP when observers were present, and that compliance with the CoP minimises interaction rates. However, coverage of 10% of net-sets is insufficient to accurately monitor mortality events that occur on 1-2% of all net sets. Each observed event can have a large impact on the estimated mortality per year. Considering these rates, it could take an observer multiple years before they witness a mortality event. Also, the rate of 10% leaves 90% of the fishery unobserved. When there are economic pressures to catch fish and bycatch interactions may reduce catch rates, it becomes more likely that an observer effect develops (Harris 1998). Given the uncertainty in the representativeness of observer data, dolphin bycatch estimates derived from observer data should be considered minimum estimates.

Debski et al. (2016) recommend that to robustly estimate bycatch levels of frequently caught species, observer levels of 20% or more may be necessary, whereas to estimate bycatch of species caught infrequently, observer levels of 50% to 100% may be required. More accurate estimates of the mortality rates and total bycatch of common dolphins in the SASF, may come from increases in the level of observer coverage, and confidence in the reporting rates by fishers in the absence of observers may come from using camera systems to audit logbook reporting.

Even with high levels of coverage, a fishery can still have high levels of cryptic mortality. These are difficult to accurately quantify and could require novel means of recording.

Finally, the proposal by Barceló et al. (2021, 2022) that a unique sub-population of common dolphins resides in Gulf St Vincent and western Investigator Strait (see Introduction) warrants further investigation. These may represent a distinct management unit.

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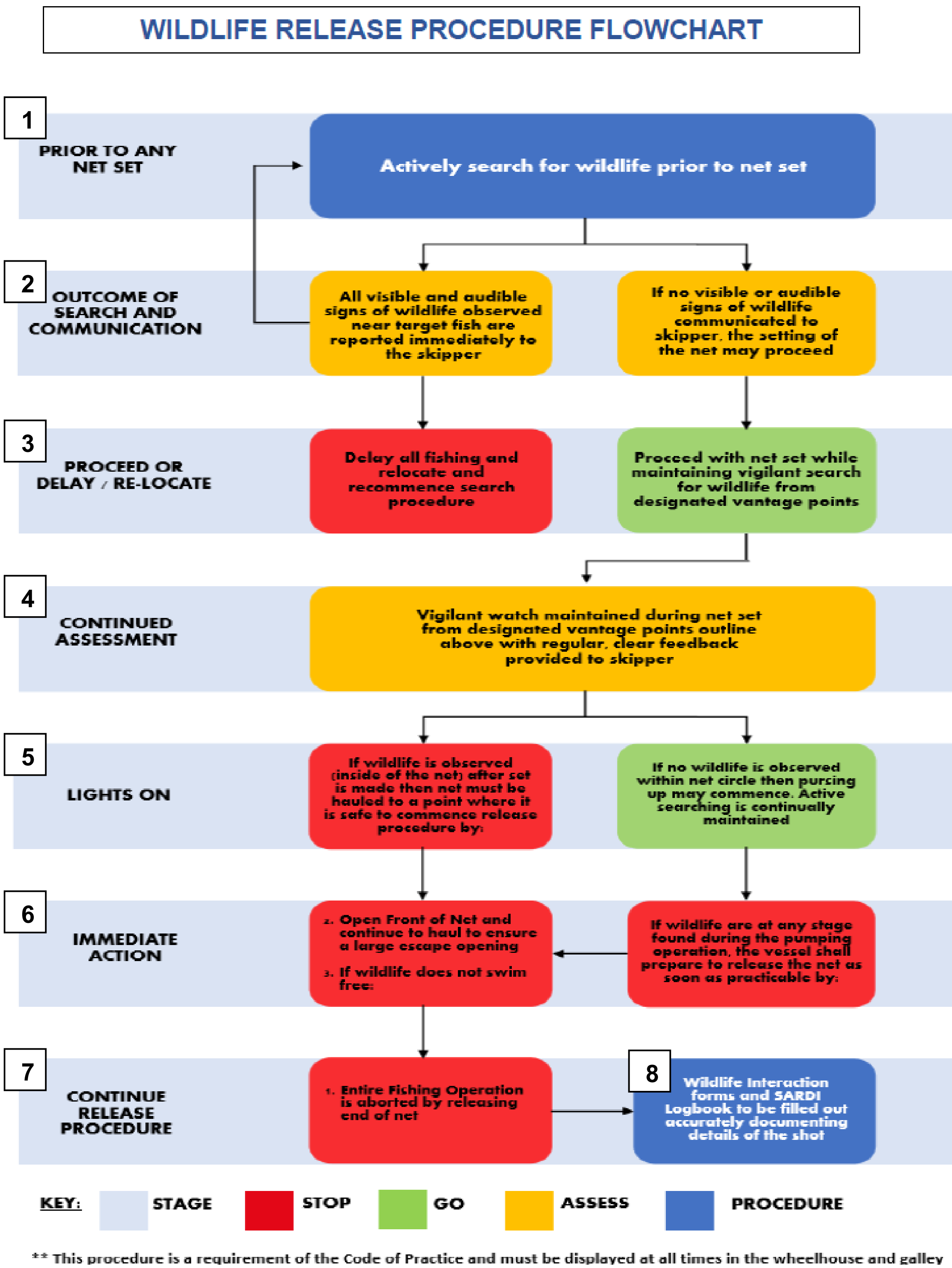
APPENDIX 1. CODE OF PRACTICE FLOWSHEET

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 ☐ 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					

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)	Licence Number	Corresponding Logbook No.
	Yes ☐ 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	Dolphins present				Actively search after setting
No ☐	Dolphins present – delay	No ☐	Yes ☐	No. of times: ___________	No ☐
Yes ☐	and/or Dolphins present – relocate	No ☐	Yes ☐	No. of times: ___________	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 ☐	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:

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

APPENDIX 4. ASSESSMENT OF COP

Dolphin interactions Code of Practice (CoP): Assessment of procedures with and without observers in the SASF in 2022.

1. Active searching prior to net setting

	CoP followed (%)
With observer (OBS)	100

CoP : Success – Observers reported active searches for dolphins always conducted prior to net-sets.

2. Search outcome

CoP : Success. – Observers reported crew always communicated sightings of dolphins.

3. Dolphins sighted - Delay and/or relocate fishing activity

	Events	(%)	Outcomes			
			No encirclement	(%)	Encirclement	(%)
With observer						
Dolphins sighted	15	(13)	14	(93)	1	(7)
Not sighted	98	(87)	88	(90)	10	(10)
TOTAL	113		102	(90)	11	(10)
Without observer (Sightings not always reported)						
TOTAL	884		783	(89)	101	(11)

CoP : Success – Observers reported delays (relocations) always took place when dolphins were sighted. (Encirclement frequency similar with and without an observer)

4. Active search for dolphins after setting

	CoP followed (%)
With observer (OBS)	100

CoP : Success – Observers reported active searches for dolphins always conducted after net-sets.

5. Lights on

6. Immediate action once dolphin/s observed in net-set

	Yes	No	CoP followed (%)
With observer	11*	0	100

**One dolphin entangled on outside of the net freed itself before action could commence.*

CoP : Success – Observers reported immediate action was usually taken once dolphins were observed encircled or entangled. Once an observer recorded there was a delay of 15 min. until the commencement of release procedures.

7. Dolphin encircled – Continue release procedure

	Primary action	(%)	Secondary action		
With observer					
Open net/ abort	10	(90)	Cut from net	1	
Dolphin outside (died)	1	(10)			
Without observer					
Open net/ abort	98	(97)	Herd with skiff	3	
Dolphin freed itself	1	(1)			
Cut from net	1	(1)			
(not recorded)	1	(1)			
Condition 1st sighted	N	(%)	*Condition on release*	N	(%)
With observer					
Alive & free in purse	27	(75)	Uninjured	28	(80)
Entangled	9	(25)	Injured	3	..(9)
			Dead	4	(11)
Without observer					
Alive & free in purse	361	(99)	Uninjured	365	(99)
Entangled	2	(<1)	Injured	1	(<1)
Dead in purse	1	(<1)	Dead	2	(<1)

CoP : Success – The front of the net was opened and net-sets were aborted if dolphins were encircled. However – With observer, dolphins more likely to be recorded as entangled, and mortalities are recorded more frequently.

8. Completed WIF submitted to SARDI (assessed with observer only)

	Yes	No	CoP followed (%)
Delay/relocate no encircle	7	9	44
Encirclement/entanglement	10	1*	91
TOTAL	17	10	63

** No WIF submitted for a dolphin that entangled on the outside of the net and freed itself.*

CoP : WIFs routinely document encirclements but not delay/relocations.

APPENDIX 5. GAM RESULTS

Random factor: vessel

Factor: moon_phase (8 phases), period-of-the-day (3-hour blocks), fishing_zone, observer_presence, entanglement_event (en_event), mortality_event

as ordered factor (integer) in respective GAMs: observer_presence, encirclement_event, mortality_event (m_event)

Numeric: estimated_catch (t of sardines), trip_duration, search_hours, water_depth (m, excluded records <10 m or >150 m, to remove outliers and/or incorrectly entered data), number of dolphins encircled (encircle)

Significance codes: ***=<0.001, **=<0.01, *=< 0.05, .=<0.1

---

1. Observer absence/presence – 2022

observer ~ moon_phase + duration + search_hrs + day_period +
    zone + depth + en_event + encircle + m_event + estcatch

- ocat = ordered categorical family

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-2.792e+00	5.810e-01	-4.806	1.54e-06	***
moon_phase2wax	4.882e-01	5.392e-01	0.905	0.36528	
moon_phase3fq	4.702e-02	5.211e-01	0.090	0.92810	
moon_phase4wax	6.481e-01	4.951e-01	1.309	0.19052	
moon_phase5full	5.254e-01	4.889e-01	1.075	0.28259	
moon_phase6wan	-1.162e-01	5.591e-01	-0.208	0.83532	
moon_phase7lq	9.512e-01	4.902e-01	1.941	0.05231	.
moon_phase8wan	-2.483e-01	5.773e-01	-0.430	0.66718	
duration	2.016e-01	2.748e-01	0.733	0.46327	
search_hrs	-9.549e-02	4.694e-02	-2.034	0.04191	*
day_period5predawn	-1.873e-01	3.381e-01	-0.554	0.57966	
day_period6postdawn	-4.729e-01	4.853e-01	-0.974	0.32982	
day_period7morning	1.630e+01	2.090e+03	0.008	0.99378	
day_period8afternoon	1.779e+01	2.090e+03	0.009	0.99321	
day_period1preset	4.974e-01	4.787e-01	1.039	0.29883	
day_period2postset	-4.641e-01	3.457e-01	-1.342	0.17944	
day_period3premid	-1.459e-01	3.242e-01	-0.450	0.65264	
zone2gsv	-1.563e+00	7.429e-01	-2.104	0.03536	*
zone3se	6.591e-02	4.357e-01	0.151	0.87977	
zone4wc	-4.064e-01	3.531e-01	-1.151	0.24968	
depth	-2.081e-02	9.538e-03	-2.182	0.02912	*
en_event1	-6.337e-01	6.368e-01	-0.995	0.31969	

encircle	-1.556e-01	1.537e-01	-1.012	0.31132	
m_event1	3.223e+00	1.188e+00	2.712	0.00669	**
estcatch	-2.637e-02	4.645e-03	-5.676	1.37e-08	***
Deviance explained = 14.9%					
-REML = 274.75 Scale est. = 1 n = 912					

2. Observer absence/presence – 2013 to 2022

observer ~ moon_phase + duration + search_hrs + day_period + zone + depth + en_event + encircle + m_event + estcatch					
• ocat = ordered categorical family					
Parametric coefficients:					
	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-2.692648	0.173038	-15.561	< 2e-16	***
moon_phase2wax	-0.150340	0.151404	-0.993	0.320723	
moon_phase3fq	0.215419	0.138946	1.550	0.121049	
moon_phase4wax	-0.103576	0.142756	-0.726	0.468118	
moon_phase5full	0.115359	0.143332	0.805	0.420914	
moon_phase6wan	-0.100392	0.150556	-0.667	0.504896	
moon_phase7lq	0.272271	0.139668	1.949	0.051245	.
moon_phase8wan	-0.046203	0.151279	-0.305	0.760047	
duration	0.001701	0.071595	0.024	0.981042	
search_hrs	-0.070197	0.013006	-5.397	6.77e-08	***
day_period5predawn	-0.021030	0.103100	-0.204	0.838373	
day_period6postdawn	0.387669	0.133298	2.908	0.003634	**
day_period7morning	0.297028	0.647006	0.459	0.646176	
day_period8afternoon	0.414793	1.122452	0.370	0.711724	
day_period1preset	0.261319	0.180639	1.447	0.147998	
day_period2postset	-0.018358	0.117675	-0.156	0.876027	
day_period3premid	-0.058177	0.103335	-0.563	0.573439	
zone2gsv	-0.340251	0.202084	-1.684	0.092238	.
zone3se	-0.321115	0.155547	-2.064	0.038977	*
zone4wc	-0.214287	0.105015	-2.041	0.041297	*
depth	-0.008743	0.002684	-3.258	0.001124	**
en_event1	-0.671762	0.201659	-3.331	0.000865	***
encircle	0.070198	0.044040	1.594	0.110946	
m_event1	2.667642	0.433456	6.154	7.54e-10	***
estcatch	-0.013029	0.001305	-9.987	< 2e-16	***
Deviance explained = 3.86%					
-REML = 2863.4 Scale est. = 1 n = 8606					

3a. Encirclement event – 2022

en_event ~ season + moon_phase + duration + search_hrs + day_period +					
zone + depth + observer					
• ocat = ordered categorical family					
Parametric coefficients:					
	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-4.053e+00	7.906e-01	-5.126	2.96e-07	***
season2aut	9.628e-01	4.376e-01	2.200	0.027816	*
season3win	8.985e-01	5.983e-01	1.502	0.133117	
season4spr	7.186e-02	7.590e-01	0.095	0.924573	
moon_phase2wax	-2.625e-01	4.589e-01	-0.572	0.567242	
moon_phase3fq	-6.475e-01	4.405e-01	-1.470	0.141641	
moon_phase4wax	1.980e-02	4.236e-01	0.047	0.962721	
moon_phase5full	-8.217e-01	4.542e-01	-1.809	0.070435	.
moon_phase6wan	-3.034e-01	4.451e-01	-0.682	0.495420	
moon_phase7lq	-3.966e-01	4.401e-01	-0.901	0.367481	
moon_phase8wan	-4.676e-01	4.626e-01	-1.011	0.312182	
duration	5.398e-01	3.147e-01	1.715	0.086280	.
search_hrs	-5.702e-02	4.003e-02	-1.425	0.154286	
day_period5predawn	1.220e+00	3.267e-01	3.734	0.000188	***
day_period6postdawn	5.201e-02	5.463e-01	0.095	0.924161	
day_period7morning	-1.331e+01	2.090e+03	-0.006	0.994918	
day_period8afternoon	-1.162e+01	2.090e+03	-0.006	0.995565	
day_period1preset	7.433e-04	6.280e-01	0.001	0.999056	
day_period2postset	4.295e-01	3.322e-01	1.293	0.195962	
day_period3premid	1.988e-01	3.237e-01	0.614	0.539111	
zone2gsv	-1.455e-02	3.434e-01	-0.042	0.966191	
zone3se	-5.309e-01	4.856e-01	-1.093	0.274289	
zone4wc	-2.930e+00	7.922e-01	-3.699	0.000217	***
depth	-3.840e-03	1.265e-02	-0.304	0.761396	
observerYes	-1.236e-01	3.582e-01	-0.345	0.729935	
Deviance explained = 9.27%					
-REML = 286.19	Scale est. = 1		n = 912		

3b. Encirclement event – by vessel – 2022

en_event ~ vessel					
• ocat = ordered categorical family					
Parametric coefficients:					
	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-3.63906	0.46291	-7.861	3.8e-15	***
Vessel_1	1.41982	0.51392	2.763	0.00573	**
Vessel_2	0.88986	0.55867	1.593	0.11120	
Vessel_3	0.84730	0.53591	1.581	0.11387	
Vessel_4	0.71238	0.53913	1.321	0.18639	

Vessel_5	0.66750	0.56378	1.184	0.23642
Vessel_6	0.49366	0.56199	0.878	0.37972
Vessel_7	0.05506	0.59052	0.093	0.92571
Vessel_8	-0.03509	0.69392	-0.051	0.95967
Vessel_9	-0.25131	0.69150	-0.363	0.71628
Vessel_10	-12.65080	295.57349	-0.043	0.96586
Deviance explained = 5.07%				
-REML = 325.38	Scale est. = 1		n = 997	

4. Encirclement event – 2013 to 2022

en_event ~ season + moon_phase + duration + search_hrs + day_period + zone + depth + observer					
• ocat = ordered categorical family					
Parametric coefficients:					
	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-3.089803	0.192212	-16.075	< 2e-16	***
season2aut	-0.023324	0.093808	-0.249	0.80364	
season3win	-0.181178	0.139190	-1.302	0.19303	
season4spr	-0.606444	0.289661	-2.094	0.03629	*
moon_phase2wax	-0.008361	0.143853	-0.058	0.95365	
moon_phase3fq	0.003328	0.141799	0.023	0.98128	
moon_phase4wax	-0.138006	0.142994	-0.965	0.33449	
moon_phase5full	-0.037694	0.146545	-0.257	0.79701	
moon_phase6wan	-0.136626	0.149444	-0.914	0.36060	
moon_phase7lq	0.060278	0.143895	0.419	0.67529	
moon_phase8wan	0.039017	0.147145	0.265	0.79088	
duration	0.142191	0.080364	1.769	0.07684	.
search_hrs	-0.029319	0.012415	-2.362	0.01820	*
day_period5predawn	0.087470	0.106459	0.822	0.41129	
day_period6postdawn	0.229918	0.152251	1.510	0.13101	
day_period7morning	-0.041667	1.043500	-0.040	0.96815	
day_period8afternoon	-11.685865	502.550637	-0.023	0.98145	
day_period1preset	0.083996	0.206671	0.406	0.68443	
day_period2postset	0.366487	0.118405	3.095	0.00197	**
day_period3premid	0.300040	0.100903	2.974	0.00294	**
zone2gsv	0.326035	0.152573	2.137	0.03260	*
zone3se	-0.124932	0.145491	-0.859	0.39051	
zone4wc	-1.353729	0.164427	-8.233	< 2e-16	***
depth	0.002673	0.003291	0.812	0.41668	
observerYes	0.078435	0.113310	0.692	0.48880	
Deviance explained = 3.08%					
-REML = 2785	Scale est. = 1		n = 8606		

5. Sardine catch per net-set – 2022 (vessel as a random factor)

```
estcatch ~ s(vessel, bs = "re") + season + moon_phase + duration +
    day_period + s(search_hrs) + zone + s(depth) + observer
•      REML = Restricted Maximum Likelihood method
Parametric coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)          46.1836     8.4759   5.449 6.59e-08 ***
season2aut            6.6614     3.7161   1.793   0.0734 .
season3win            3.4625     4.9174   0.704   0.4815
season4spr            0.6024     6.3218   0.095   0.9241
moon_phase2wax        3.1917     4.8108   0.663   0.5072
moon_phase3fq        -0.2499     4.5452  -0.055   0.9562
moon_phase4wax       -1.6134     4.6849  -0.344   0.7306
moon_phase5full       2.1916     4.4774   0.489   0.6246
moon_phase6wan       -1.0782     4.6623  -0.231   0.8172
moon_phase7lq         3.1163     4.6269   0.674   0.5008
moon_phase8wan       -3.2823     4.6647  -0.704   0.4818
duration             -6.1395     2.8569  -2.149   0.0319 *
day_period5predawn   -8.0077     3.2751  -2.445   0.0147 *
day_period6postdawn -11.1165     4.6845  -2.373   0.0179 *
day_period7morning   -7.9354    32.0863  -0.247   0.8047
day_period8afternoon 42.4278    32.2272   1.317   0.1883
day_period1preset     6.9323     5.7576   1.204   0.2289
day_period2postset   -3.3306     3.3343  -0.999   0.3181
day_period3premid     5.6538     3.0748   1.839   0.0663 .
zone2gsv              5.2628     3.8661   1.361   0.1738
zone3se               0.3989     4.8847   0.082   0.9349
zone4wc               3.4848     3.7217   0.936   0.3494
observerYes         -19.2091     3.3790  -5.685 1.78e-08 ***

Approximate significance of smooth terms:
                edf Ref.df      F p-value
s(vessel)     9.663 10.000 26.195  <2e-16 ***
s(search_hrs) 1.038  1.075  0.754   0.406
s(depth)      2.127  2.706  1.358   0.343

R-sq.(adj) =  0.292   Deviance explained = 31.9%
-REML = 4393.4  Scale est. = 997.97    n = 912
```

6. Sardine catch per net-set – 2013 to 2022 (vessel as a random factor)

```
estcatch ~ s(vessel, bs = "re") + season + moon_phase + duration +
    day_period + s(search_hrs) + zone + s(depth) + observer
•      REML = Restricted Maximum Likelihood method
Parametric coefficients:
                    Estimate Std. Error t value Pr(>|t|)
```

(Intercept)	48.2009	5.4464	8.850	< 2e-16	***
season2aut	2.5863	0.8982	2.879	0.00399	**
season3win	3.2722	1.2484	2.621	0.00878	**
season4spr	-4.3530	1.9108	-2.278	0.02274	*
moon_phase2wax	0.1457	1.3753	0.106	0.91562	
moon_phase3fq	-0.2258	1.3599	-0.166	0.86814	
moon_phase4wax	0.9953	1.3271	0.750	0.45330	
moon_phase5full	2.4417	1.3715	1.780	0.07506	.
moon_phase6wan	1.8950	1.3741	1.379	0.16790	
moon_phase7lq	1.4965	1.3713	1.091	0.27517	
moon_phase8wan	0.6717	1.4061	0.478	0.63286	
duration	-5.9667	0.7254	-8.225	2.23e-16	***
day_period5predawn	-3.8692	0.9705	-3.987	6.75e-05	***
day_period6postdawn	-12.5348	1.3995	-8.957	< 2e-16	***
day_period7morning	-13.4617	7.3827	-1.823	0.06828	.
day_period8afternoon	-2.3303	12.7301	-0.183	0.85476	
day_period1preset	5.4985	1.9137	2.873	0.00407	**
day_period2postset	-6.0034	1.1562	-5.192	2.12e-07	***
day_period3premid	0.6985	0.9685	0.721	0.47076	
zone2gsv	-2.8878	1.7084	-1.690	0.09099	.
zone3se	1.3167	1.4134	0.932	0.35158	
zone4wc	0.4464	1.1142	0.401	0.68871	
observerYes	-11.5914	1.0875	-10.659	< 2e-16	***

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value	
s(vessel)	11.924	12.000	195.274	< 2e-16	***
s(search_hrs)	4.361	5.362	3.824	0.00126	**
s(depth)	1.007	1.014	1.021	0.31145	

R-sq.(adj) = 0.269 Deviance explained = 27.2%

-REML = 41776 Scale est. = 964.25 n = 8606

7. Mortality – 2013 to 2022

m_event ~ season + moon_phase + duration + search_hrs + day_period + zone + depth + observer

- ocat = ordered categorical family

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-6.380e+00	1.041e+00	-6.131	8.74e-10	***
season2aut	-1.359e-01	4.786e-01	-0.284	0.7764	
season3win	-1.002e+00	1.094e+00	-0.916	0.3594	
season4spr	5.010e-01	1.107e+00	0.453	0.6507	
moon_phase2wax	-6.896e-01	8.788e-01	-0.785	0.4326	
moon_phase3fq	1.872e-01	6.625e-01	0.283	0.7776	
moon_phase4wax	-7.967e-01	8.774e-01	-0.908	0.3639	

moon_phase5full	-1.543e+00	1.127e+00	-1.370	0.1708	
moon_phase6wan	-1.773e-01	7.188e-01	-0.247	0.8052	
moon_phase7lq	-9.305e-01	8.772e-01	-1.061	0.2888	
moon_phase8wan	3.655e-01	6.811e-01	0.537	0.5915	
duration	-2.492e-01	5.356e-01	-0.465	0.6418	
search_hrs	3.626e-02	5.653e-02	0.641	0.5213	
day_period5predawn	-6.169e-01	5.160e-01	-1.196	0.2319	
day_period6postdawn	-1.702e+01	2.357e+03	-0.007	0.9942	
day_period7morning	-1.606e+01	1.469e+04	-0.001	0.9991	
day_period8afternoon	-1.660e+01	2.676e+04	-0.001	0.9995	
day_period1preset	-1.675e+01	3.387e+03	-0.005	0.9961	
day_period2postset	-3.971e-01	5.944e-01	-0.668	0.5042	
day_period3premid	-1.129e+00	6.484e-01	-1.741	0.0816	.
zone2gsv	9.782e-01	7.804e-01	1.254	0.2100	
zone3se	6.777e-01	7.597e-01	0.892	0.3724	
zone4wc	-1.536e+00	1.079e+00	-1.424	0.1545	
depth	-4.425e-03	1.732e-02	-0.255	0.7984	
observerYes	2.230e+00	4.042e-01	5.517	3.44e-08	***
Deviance explained = 18.1%					
-REML = 107.39 Scale est. = 1 n = 8606					