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Monitoring and mitigating interactions between small pelagic fisheries and dolphins: literature review and analysis of fishery data

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Executive Summary

Rationale and scope

This review compares approaches taken to monitor and mitigate Common Dolphin (*Delphinus delphis*) interactions in the South Australian Sardine Fishery (SASF) with those taken for protected species interactions in other fisheries for small pelagic species, including Australia's Commonwealth Small Pelagic Fishery (SPF). The review informs ongoing refinement of approaches in the SASF to reduce encirclement and mortality rates of Common Dolphins and supports the SASF's commitment to a "continuous process of review and improvement". Ongoing refinement is a key element of the fishery's Code of Practice (CoP) for mitigating interactions with wildlife (SASIA 2023).

This study was also needed to ensure that approaches taken in the SASF are "reviewed with consideration to international standards for mitigating interactions with marine mammals" (Commonwealth of Australia 2016), which is a requirement for the accreditation of the management regime for the SASF under Part 13 of the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*.

Context

The SASF's Wildlife Interaction CoP was first implemented in September 2005 in response to a seven-month independent observer program which estimated 377 dolphin mortalities (extrapolated to 484 dolphins for the 2004-05 financial year) and identified discrepancies in dolphin interaction rates recorded in logbooks and by observers. The CoP documents mitigation strategies, including avoidance and release procedures used in the fishery to minimise dolphin encirclements and mortalities. Annual analyses of observer data show that the CoP is effective in mitigating interactions. Estimates of Common Dolphin abundance in Spencer Gulf and the adjacent shelf in 2011 and 2021, and potential biological removal analysis, suggest that current mortality levels recorded by the observers are unlikely to have had major impacts on the conservation status of Common Dolphins in southern Spencer Gulf. The main unresolved issue is whether observed dolphin mortality rates reflect overall mortality rates in the fishery. Fisher behaviour appears to differ in the absence of observers and logbook mortality rates are ten-times lower than observed rates, providing uncertainty in the estimated number of mortalities and accuracy of dolphin interaction and mortality recording in the absence of observers. How closely the CoP is followed when observers are not present is unknown.

Approaches to monitor interactions between small pelagic fisheries and dolphins

Programs for monitoring interactions between fisheries and cetaceans typically involve a mix of logbook and observer data and, in recent years, electronic monitoring using fixed cameras (e.g., the Cornwall purse-seine fishery, industrial fisheries in Chile). Knowledge of the population status of marine mammals impacted by fisheries is needed to inform the design of monitoring programs, because different approaches should be applied to species with different conservation status (e.g., protected, threatened, endangered, critically endangered species).

- Logbooks are used in most fisheries and usually include records of interactions with marine mammals. However, interaction data may be biased, with under-reporting occurring when, for example, interactions are not recognised or are perceived by fishers to have negative consequences.
- Independent observer programs provide independent estimates of bycatch rates of marine mammals in many fisheries. Observer coverage is usually limited to a proportion of fishing effort and findings are extrapolated across the entire fishery. Observer coverage rates in purse-seine fisheries worldwide vary between 0 to 100% of effort, but most are <10%. Target observer coverage in the SASF has typically been 10% of net-sets. Target coverage has twice been increased temporarily (i.e., 20% and 30%), following higher-than-normal observed mortality rates and larger discrepancies between observer and fisher-reported data. Observer coverage does not accurately measure interaction rates if fishing behaviour differs when observers are present versus absent.
- Electronic monitoring (e.g., cameras) has been used to augment observer programs in pelagic fisheries worldwide, including a night-time purse-seine fishery in the UK, and can improve the accuracy of reporting rates of interactions with protected species and help to ensure mitigation measures are applied diligently.
- Assessments of dolphin abundances are typically conducted by aerial- or ship-based, distance sampling methods. These can incorporate methods to account for individuals underwater at the time of passing. A limitation to abundance estimates is that they provide a single point estimate whereas local dolphin abundances can change rapidly in response to environmental conditions. Abundance estimates also typically have large confidence limits meaning that only substantial changes over time can be detected.
- Best practices for monitoring interactions of pelagic fisheries with marine mammals and their impacts on the population status of bycatch species involve clear management objectives, population assessments with sufficient statistical power and frequency to detect change, accurate recording of bycatch mortality, biological performance indicators and reference

points to guide management decisions. Different jurisdictions have taken a range of approaches (e.g., cumulative risk assessments in New Zealand and marine mammal stock assessments in the USA).

Approaches to mitigate interactions between small pelagic fisheries and dolphins

Effective mitigation of interactions between fisheries and cetaceans usually requires the implementation of an inter-related suite of monitoring (to detect and quantify rates of interaction), management (to direct the need to mitigate), and mitigation measures, which need to be refined over time using an adaptive approach. Approaches taken to mitigating interactions can be specified in documents published by fisheries management agencies (e.g., the Commonwealth SPF, Dolphin Mitigation Strategy), industry CoPs (e.g., the SASF and the Commonwealth Blue Grenadier *Macruronus novaezelandiae* Fishery), and management plans for specific vessels (e.g., SPF Vessel Management Plan, *FV Geelong Star*).

- The avoidance procedure (searching for dolphins and delaying fishing if they are detected) and release procedure (opening the front of the net, and/or aborting the net-set) used in the CoP for the SASF are effective in mitigating dolphin mortalities. Elsewhere, purse-seine fisheries for small pelagic species appear to use similar procedures to avoid dolphin encirclement and release encircled dolphins.
- Acoustic deterrents are reasonably effective in alerting dolphins to the presence of set nets, such as gillnets, but are less effective in preventing dolphins being encircled by purse-seine nets or entering trawl nets. Acoustic devices have been trialled occasionally in the SASF since the mid- 2000s and have not reduced encirclement rates. Net pingers have also been trialled in a Cornwall purse-seine fishery but are not used routinely as dolphin interactions are infrequent.
- Enhanced methods for detecting dolphins (e.g., night vision goggles, thermal imaging, hydrophones) may help to reduce encirclement and mortality rates by increasing the effectiveness of pre-fishing searches and reducing the time taken to detect the presence of encircled or entangled dolphins.
- Dolphin Mitigation Strategies (e.g., the SPF Dolphin Mitigation Strategy) that include objectives, performance indicators, reference points (criterion) and defined management responses are valuable for guiding monitoring and mitigation programs.
- In the SASF, management responses to increases in rates of observed mortality and larger discrepancies between mortality rates recorded in logbooks and by observers, have been

implemented across the entire fishery (e.g., increased observer coverage). An alternative is to apply management responses to individual vessels where reference levels are breached (e.g., the SPF Dolphin Mitigation Strategy).

Conclusion and recommendations

This review compared the approaches used to monitor and mitigate dolphin interactions in the SASF with other small pelagic fisheries worldwide. The review notes the effectiveness of the SASFs CoP in reducing dolphin mortalities and the need to ensure it is always applied. It also highlights that many of the approaches used elsewhere have already been trialled and/or adopted and implemented in the SASF. The primary exception to this is electronic monitoring of fishing activity.

The key opportunities for maintaining and improving monitoring and mitigation of dolphin interactions in the SASF are:

1) Maintain, regularly review, refine (as required) and ensure rigorous application of the CoP and the 'real-time' monitoring program run by the South Australian Sardine Industry Association (SASIA). Maintain SASIA/PIRSA pre-season briefings/training to skippers and crew.
2) Increase observer coverage to reduce the proportion of the fishery where dolphin interaction rates are under-reported and where the application of the CoP is unknown.
3) Conduct trials to assess the potential for using electronic monitoring equipment (e.g., cameras) to evaluate fishing behaviour and the application of the CoP when an observer is not present. Note that the presence of electronic monitoring equipment can help to reduce interaction rates by encouraging fishers to apply mitigation measures diligently.
4) Conduct trials to assess the potential benefits of using new technologies (e.g., night vision goggles, thermal imaging (infra-red), hydrophones) to enhance the searches for dolphins prior to and after setting the net.
5) Evaluate the benefits of applying management responses to increased mortality rates and/or discrepancies between logbook and observer data to individual fishers/vessels rather than across the fishery.
6) Periodic population assessments of Common Dolphins.
7) Establish a SASF Dolphin Mitigation Strategy, ideally informed by an overarching bycatch strategy for South Australia, that includes quantitative objectives, performance indicators, reference points and decision rules.
8) Continue to investigate and trial new opportunities for reducing the encirclement of dolphins and enhancing the successful release of encircled animals.

Broader implications

Limitations and differences in the approaches used to monitor and mitigate interactions with dolphins in the SASF and SPF highlight the potential benefits of establishing a consistent national approach for such Australian fisheries. Best practice approaches to managing interactions with marine mammals involve comprehensive plans that reflect the conservation status of the species/populations, and include regular population assessments, robust estimation of abundance and bycatch mortality, quantitative management objectives and biological reference points to guide management actions, and ongoing development and adoption of mitigation procedures.

Keywords

South Australia, Sardine Fishery, Common Dolphin, *Delphinus delphis*, bycatch, logbook, observer coverage, electronic monitoring, acoustic deterrents, detection.

1.0 Introduction

1.1 Rationale and scope

Worldwide, fisheries for small pelagic fish interact with marine mammals, such as dolphins and seals, resulting in catch loss and mammal mortalities (FAO 2018, Ward et al. 2018). Mammals may be caught incidentally while feeding on small pelagic fish or being attracted to fishing operations which may enhance feeding opportunities. In southern Australia, for example, Common Dolphins (*Delphinus delphis*) can be encircled or entangled in purse-seine nets of the South Australian Sardine Fishery (SASF, Ward et al. 2018) and captured in mid-water trawl nets of the Commonwealth Small Pelagic Fishery (SPF; Lyle and Wilcox 2008). The SASF is almost exclusively a night-time fishery whereas the SPF operates during day and night. These two fisheries collectively take about one third by weight (i.e., ~60,000 t) of the total annual catch of Australia's commercial fishing fleet (i.e., ~173,000 t)[1].

Fisheries and marine mammal interactions are controlled differently in different countries. In Australia, the Commonwealth *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999* requires "all reasonable steps to ensure that cetaceans are not killed or injured as a result of the fishing" and that the fishery "does not, or is not likely to, adversely affect the conservation status of a species of cetacean or a population of that species" (Section 245). In addition, the *EPBC Act 1999* also requires any injuries or deaths of cetaceans to be reported (Section 232). The *Fisheries Management Act 1991* and *Fisheries Legislation (Repeal and Amendment) Regulations 2011 (No 1)* place similar requirements on Commonwealth fisheries.

State-based fisheries are managed by state regulations. In South Australia, for example, legislation controlling interactions between fisheries and cetaceans include the *National Parks and Wildlife Act 1972*, *Animal Welfare Act 1985* and *Fisheries Management Act 2007.* Fisheries in Australia also can be influenced by community attitudes (i.e., they require a social license to operate). In 2012, for instance, community objection influenced the Australian government to impose a moratorium on the operations of a large factory trawler for pelagic fishes, despite a science-based assessment identifying that within the management arrangements the operations could be supported (Tracey et al. 2013).

[1] https://www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-and-aquaculture-statistics/production

The present study was undertaken to support the ongoing refinement of approaches to monitor and mitigate interactions of the SASF with Common Dolphins. It compares the ways that interactions with Common Dolphins are monitored and mitigated in the SASF with approaches taken in other fisheries for small pelagic fishes around the world. Generally, large commercial catches of small pelagic fish are by either purse-seining or trawling, like the SASF and Commonwealth SPF in Australia. Although they apply different methods, it is useful to compare the two Australian fisheries because they operate in the same regulatory and socio-political environment (Patterson et al. 2020, Smith et al. 2020, Ward et al. 2020, Ward and Grammer 2021). Assessing approaches taken by other fisheries to reduce marine mammal interactions represents due diligence, and the "continuous process of review and improvement" of the SASF's Code of Practice (CoP) for mitigating interactions with wildlife (South Australian Sardine Industry Association [SASIA] 2023).

The original proposal for this project included experimental field trials of acoustic deterrents (pingers), but those elements were removed due to the impacts of Covid-19 (restricting researcher access onto vessels). Several SASF skippers did conduct their own trials of acoustic deterrents, however, and results from these are presented in this report.

1.2 Need

To address legislative obligations and fulfil specifications of its Wildlife Interaction CoP, the SASF needs to take all reasonable steps to prevent interactions with Common Dolphins (SASIA 2021). Conducting periodic reviews of approaches and methods used to monitor and mitigate interactions with dolphins in small pelagic fisheries worldwide, and a comparison of these with approaches in the SASF, Australia's largest fishery by weight, can assist the SASF in being a "best practice fishery".

A comprehensive review of methods used to mitigate interactions with dolphins in purse-seine fisheries worldwide was needed to ensure that future strategies developed for the SASF are consistent with world's best practice. The review was also critical because adopting strategies for mitigating interactions with Common Dolphins that are consistent with world's best practice is now a specific requirement of Condition E (*The Department of Primary Industries and Regions of South Australia must ensure the most effective measures to mitigate or eliminate interactions with protected species are adopted in the South Australian Sardine Fishery. This should include working with fishing operators and other relevant parties to consider and, where appropriate, trial any suitable technologies or practices identified in the global literature review of mitigation measures in small pelagic fisheries project* (*FRDC Project 2020-049)*) and relevant to Condition G (*by April 2024, the Department of Primary Industries and Regions of South Australia must implement suitable* *measures to ensure accurate information on protected species mortality levels is collected in the fishery and that underreporting is not occurring*) in the current accreditation of the management regime for the SASF under Part 13 of the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (https://www.legislation.gov.au/Details/F2022N00153).

1.3 Objectives

1. Undertake a comprehensive literature review of methods used to monitor and mitigate interactions between small pelagic fisheries and dolphins.
2. Analyse data from industry trials to identify acoustic devices and deployment strategies that mitigate interactions with dolphins.

1.4 Methods and approach

Literature searches were conducted using Google, the University of Adelaide Library, Scopus and ScienceDirect. The search terms were marine mammal/cetacean/dolphin, interaction/bycatch, pelagic/seine/purse-seine/trawl and fish/fisheries/fishing. Peer-reviewed scientific literature, as well as available industry and government reports, were collated. The review focusses on small pelagic fisheries, particularly purse-seine fisheries, and on interactions with dolphins, rather than marine mammals in general.

Monitoring and mitigation of dolphin interactions in the SASF were collated and compared with the methods described for other fisheries. These are discussed and recommendations for potential additions to the SASF strategy are presented.

Methods and results from the trial of acoustic deterrents by several skippers in the SASF in 2020 are presented in Section 3 – the overview of Common Dolphin monitoring and mitigation in the SASF. They are discussed along with other acoustic methods in Section 4.5 – the application of acoustic deterrents to mitigate dolphin interactions.

2.0 Dolphin interaction rates in small pelagic fisheries

In purse-seine fisheries, recorded encirclement rates ranged between 2.3 dolphins per 100 net-sets in the Portuguese sardine fishery (Marçalo et al. 2015) and 305 dolphins per 100 net-sets off Chile in 2010 (Gonzalez-But and Sepulveda 2016) (Table 1). Encirclements were not observed in some purse-seine fisheries although dolphins were routinely sighted during fishing operations (Wise et al. 2007, Seco Pon et al. 2012, Jaaman et al. 2009). Not all studies could be compared using the same units because of differences in the way information was recorded and reported. In addition, purse-seine fisheries do not all operate at the same times of day. For example, whilst the SASF is a predominantly night-time fishery, in the Portuguese purse-seine fishery, nets are set around dawn.

Mortality rates recorded in trawl fisheries ranged between zero and 28.9 dolphins per 100 trawls (Table 2). For example, mortality rates between zero and 10 dolphins per 100 trawls were recorded in 11 trawl fisheries in the northeast Atlantic Ocean (Table 3). Data presented by Tuck et al. (2013) suggest that between 2001 and 2005, 25 dolphins were incidentally captured in trawls in the SPF from 369 observed trawls (i.e., 6.8 dolphins per 100 trawls) but that no dolphin interactions were reported between 2006 to 2009 after bycatch mitigation measures were implemented. Mitigation measures included: vessel-specific threatened, endangered and protected species (TEPS) mitigation plans, relocation of fishing operations if dolphins are seen, and both metal-grid excluders and exit panels. Information on the numbers of dolphins and other protected species incidentally taken in mid-water trawls in the SPF is published quarterly on the Australian Fisheries Management Authority (AFMA) website (https://www.afma.gov.au/sustainability-environment/protected-species-management/protected-species-interaction-reports). For example, mortalities of four Common Dolphins and three dolphins of unknown species were reported in the SPF in the first quarter of 2021. Numbers of net-sets and mortality rates are not reported.

Table 1. Dolphin interaction rates with purse-seine fisheries targeting small pelagic finfish. Data type: O = onboard observer, L = logbook, S = fisher survey.

Location (Target)	Year	Data type	Coverage (%)	Encirclement (dolphins/100 net-sets)	Mortality (dolphins/100 net-sets)	Comments
Australasia						
South Australia[1] (sardine)	2004-05	O	3.9	37	39	
		L	100	4.9	0.5	
South Australia[2] (sardine)	2005-06	O	8.5	10	1.2	Code of Practice (CoP) established
		L	100	7	0.6	
South Australia[3] (sardine)	2006-20	O	6.6 - 24	22 - 52	0 - 13	CoP maintained and refined
		L	100	10 - 41	0 - 1	
East Malaysia, Sabah[4] (mixed)	1997-2004	S				12/year for whole fleet
	2003-04	O	(10 trips)		0	Dolphins commonly seen around vessels
East Malaysia, Sarawak[4] (mixed)	1997-2004	S				4/year for whole fleet
Europe						
Portugal[5] (sardine)	2003	S	(65 sets on 36 trips)	12.3	1.5	9 sightings during fishing, 3 encirclement events (8 dolphins), 1 known mortality
	2003	O	(72 sets on 48 trips)	0	0	Dolphins present 12.5% of net sets, no interactions
Portugal[6] (sardine)	2010-11	O	0.7 (302 sets on 163 trips)	2.3	1.0	Cetaceans on 16.9% of net-sets, 96% Common Dolphins
Portugal[7] Cantabria (sardine)	2016-19	O	(482 sets)		<1	One dolphin mortality recorded
Spain, Alboran Sea[7] (mixed)	1995	S				5700 encircled/year, 300 mortalities/year
Spain/France, Catalonia and Gulf of Lions[8] (mixed)	1995	O				100 mortalities/year
Spain, Galicia[9] (sardine)	1998-2000	S	2% (6 of 259 boats)		0.2	130 mortalities/year
UK, Cornwall[10] (sardine)	2014-21	L	100	<0.01	0	0-5 dolphins encircled/year, released no mortalities recorded
	2018-19	O	2% (13-16 days)	0	0	Once dolphins seen so net not set
	2020-21	O	2% (20 days)	0	0	
South America						
Peru[11] (anchovy)	?	?	?	0 - 13		640 mortalities/year – by one company
Chile[12] (anchovy, mackerel, herring)	2010	O	(19 net-sets)	305.3	15.8	Total effort unknown
Chile[13] (anchovy, sardine, mackerel)	2015-20	O	1.5 - 17%	max. 0.08	max. 0.02	Assesses all purse-seine fisheries in Chile. Most mortalities (common, dusky, bottlenose) in north zone anchovy fishery
North Argentina[14] (chub mackerel)	2007-08	O	8.5		0	Dolphins present 0.8% of net-sets. No interactions

[1]Hamer et al. (2008), [2]Ward et al. (2018), [3]Kirkwood and Goldsworthy (2022), [4]Jaaman et al. (2009), [5]Wise et al. 2007, [6]Marçalo et al. 2015, [7]Ruiz et al. 2021, [8]University of Barcelona (1995), [9]López et al. 2003, [10]Jones et al. 2022, [11]Sustainable Fisheries Partnership (2018), [12]Gonzalez-But and Sepulveda (2016), [13]Vega et al. 2021, [14]Seco Pon et al. (2012).

Table 2. Dolphin interaction rates (mortality) for mid-water trawl fisheries targeting small pelagic species. Data type: O = onboard observer, L = logbook

Location	Year	Data type	Coverage (%)	Dolphins /100 trawls	Dolphins /day	Dolphins /year	Comments
Australasia							
Australia SPF[1,2]	2002-present	L	10 - 100			11 in 2019	44 dolphins recorded in logbooks since 2012
(redbait, mackerels,	2003-05,	O		2.7			25 dolphins in 369 observed trawls
sardine)	2006-09	O		0			zero in 583 trawls after bycatch mitigation introduced
New Zealand[3] (jack mackerel)	1995-96 to 2012-13	O	6 - 89, mean 30	0 - 12.4		0 - 21	139 Common Dolphins taken between 1995-96 and 2012-13
USA							
New England[4]	2010-14	L & O				(2.2/ trip)	
Europe							
NE Atlantic[5]	1989	L	18			110	Combined - Atlantic white-sided, white-beaked, common, bottlenose
(mackerel, herring)	1990	L	17			156	"
	1991	L	23			264	"
	1992	L & O	18 & 5			48	"
	1993	L & O	18 & 5			65	"
	1994	L & O	95 & 5			117	"
NE Atlantic[6] (horse mackerel)	1994-95	O	3	3.4		112	4 dolphins in 119 observed tows
Italy, Adriatic Sea[7]	2006-08	O		0.06			Dolphins frequently sighted - may be attracted to fishery
Spain/France, Bay	2017	O			0.1		Harbour porpoise
of Biscay[8]		O			1.1		Common Dolphin
(mixed)		O			0.06		Long-finned pilot whale
Western	2017	O			0.02		Bottlenose dolphin
Mediterranean[8]		O			0.3		Striped dolphin
NW Spain[9] (whiting,	2001-03	S	(886 trawls)	(0.7 events)			Mostly 1 x ~9-hour trawl per trip (6% trips second trawl), dolphins caught
mackerel, hake)		O	(891 trawls)	(3.3 events)		394 (2001-2)	during hauling, usually 1 up to 15 dolphins in observed events
NW Africa[10,11]	2001-04	O	~10	24.3			Monthly ranges: observer coverage 4 – 88%, dolphin mortality 0 – 422
(sardinella)		L		1.9			Raw data in Zeeberg et al. (2006), summarised in Heessen et al. (2007)
NW Africa[11] (sardinella)	2005-06	L	100	1.8			1.2/100 hauls with excluder -2.1/100 hauls without excluder

[1]AFMA website, [2]Tuck et al. 2013, [3]Abraham and Berkenbusch (2017), [4]NOAA (2019), [5]Couperus (1997), [6]Morizur et al. (1999), [7]Fortuna et al. (2010), [8]ICES (2019), [9]Fernandez-Contreras et al. (2010), [10]Zeeberg et al. (2006), [11]Heessen et al. (2007).

3.0 Dolphin interaction monitoring and mitigation in the SASF

The SASF commenced in 1991 with the first total allowable commercial catch of 1,000 tonnes set in 1992 (Ward and McLeay 1999). Landings of sardines remained below about 500 tonnes annually until 2000-01, then rapidly increased to 56,952 tonnes in 2004-05 (PIRSA 2014). Catches dropped the next year to about 23,000 tonnes and since then have increased more steadily to approximately 40,000 tonnes from 2017-18 onwards (Grammer et al. 2021).

Data on Common Dolphin (*Delphinus delphis*) interactions started to be recorded in fishery logbooks after January 1999. From January 1999 to June 2004, about six encirclement events were recorded in logbooks per year and a single dolphin mortality was documented, in April 2002. Then, in 2004-05, a 7-month independent observer program estimated 1,728 dolphins were encircled and 377 died in the fishery, and therefore revealed significant discrepancies between rates reported in logbooks and by observers (Hamer and Ward 2007, Hamer et al. 2008). For the 2004-05 financial year, this equated to an estimated 2,216 dolphins encircled and 484 mortalities (Ward et al. 2015). The findings resulted in a two-month closure of the fishery between fishing seasons while industry developed a Code of Practice (CoP) to minimise wildlife interactions. The CoP was first introduced in September 2005 and showed how interactions with protected species, especially dolphins, could be mitigated in the SASF (SASIA 2023). Key elements of the CoP include:

- industry commitment to continuous improvement in preventing dolphin interactions and mortalities;
- training and education processes for skippers and crew, including annual inductions, skippers' meetings and vessel-specific plans for designated search positions and procedures for crew;
- avoidance (prior-to-fishing) search and delay procedures designed to prevent encirclement of dolphins;
- guidance regarding when not to fish, for example, if wave conditions would prevent dolphin sighting;
- release procedures designed to prevent the mortality of encircled dolphins, where the primary method is to release the front of the net and abort the net set;
- a Wildlife Interaction Working Group (which includes the South Australian Department for Environment and Water and other stakeholders) that meets quarterly, and after mortality events, and is responsible for ongoing review and refinement of the CoP; and
- at sea communication among skippers and the industry's 'real-time' monitoring program for wildlife interactions, which was implemented in 2011-12 to identify and address emerging issues (e.g., vessels with high interaction rates and/or large discrepancies between rates reported in logbooks and by observers).

Since 2004/05, an independent observer program has monitored wildlife interactions in the SASF to assess dolphin interactions and evaluated effectiveness of the CoP in reducing interaction rates. Observer coverage has ranged from 3.9% in 2004-05 to 25.2% in 2008-09, with a long-term target of 10% (Kirkwood and Goldsworthy 2022, Table 1). Annual scientific reports based on the logbook and observer programs evaluate the effectiveness of the CoP in mitigating interactions with dolphins (e.g., Hamer and Ward 2007, Goldsworthy et al. 2019, Kirkwood and Goldsworthy 2022). Fishery-specific 'Wildlife Interaction Forms', to improve data collection on interactions with TEPS, including dolphins, were introduced in 2017-18 and superseded the Wildlife Interaction Logbook on which interactions with TEPS reporting had been required since 2007. Also, as dolphins are protected species, all reported dolphin mortality events are investigated by fisheries compliance officers.

Following the 2004-05 observer program and subsequent implementation of the CoP, there was a marked reduction in encirclement and mortality rates recorded by observers and reported in logbooks (Hamer et al. 2008; Kirkwood and Goldsworthy 2022). However, significantly higher rates of interaction continued to be recorded when observers were present compared to logbook records when observers were absent. Following implementation of a 'real-time' reporting program in 2011-12, the discrepancy in dolphin encirclement rates reduced. A discrepancy in mortality rates has continued, however, with on average 6-10 times fewer dolphin mortalities recorded in logbooks when an observer was not present (Kirkwood and Goldsworthy 2022).

Management responses to dolphin interactions to date have been implemented across the entire fishery, rather than by individual vessel. For example, in 2005, the fishery was closed between fishing seasons for two months in response to the results of the initial observer program, and from 2007-08 to 2009-10, observer coverage targeted 30% of effort, following high mortality rates and large discrepancies between observer and logbook data in the preceding year (Hamer and Ward 2007).

The main unresolved issue in the SASF regarding the reporting of interactions has been the ongoing discrepancy between mortality rates reported in logbooks and by observers, with dolphin mortality rates reported in logbooks being much lower than those reported by observers (e.g., Hamer and Ward 2007, Hamer et al. 2008, Ward et al. 2018, Goldsworthy et al. 2019, Kirkwood and Goldsworthy 2022). The CoP appears to be applied effectively when observers are present, but how it is applied in the absence of observers remains unclear. Also, when observers are absent, there is a greater sardine catch-per-unit-effort (CPUE – e.g., per net-set), fewer net-sets per night and fewer net-sets with zero catch (e.g., Goldsworthy et al. 2019, Kirkwood and Goldsworthy 2022). These discrepancies suggests that fishing behaviour may be different when an observer is present and, therefore, that dolphin interaction rates recorded in the presence of an observer may not be representative of rates when an observer is not present.

4.0 Global approaches to monitor interactions between small pelagic fisheries and dolphins

4.1 Overview of approaches

Quantifying interaction rates with dolphins and assessing the effectiveness of mitigation procedures requires fishing activities to be monitored (Northridge 1996, Read et al. 2006). Programs for monitoring interactions between fisheries and cetaceans typically involve a mix of logbook and observer programs and, in recent years, electronic monitoring (e.g., fixed cameras, Dalskov 2010, Emery et al. 2019, van Helmond et al. 2020). Fisher interviews are also used in some circumstances (Jaaman et al. 2009, Marçalo et al. 2015). Peltier et al (2016) used stranding data to estimate bycatch rates in western Europe and concluded this approach was more accurate than existing observer programs.

Knowledge of the population status of marine mammals impacted by fisheries is needed to inform the design of monitoring programs because different approaches need to be applied to species with different conservation status (e.g., protected, threatened and endangered). World's best practice for monitoring interactions of pelagic fisheries with marine mammals, and their impacts on the population status of such species, involves population assessments, robust estimates of abundance and bycatch mortality, and related management objectives, biological performance indicators and reference points (e.g., Wade 1998, Geijer and Read, 2013, Doman et al. 2021, Rogan et al. 2021).

There are four primary categories of approaches taken to monitor bycatch, including: 1) logbooks; 2) observer programs; 3) electronic monitoring; and 4) population monitoring of impacted species.

4.2 Logbook Programs

Self-reported fishery logbooks are used in many fisheries for small pelagic species (Tables 1 and 2). However, the quality of data and value of information obtained for monitoring interactions with marine mammals needs to be validated because, without validation, the accuracy of the reporting is unknown (Hamer et al. 2008, Northridge 2008, Borges 2015, Read et al. 2006, Emery et al. 2019). Reasons for under-reporting are similar to those for non/under-reporting of discards in some fisheries and can be linked to short-term economics and human behaviour when unobserved, including not wanting to report dolphin mortalities, an avoidance of unwanted consequences (e.g., avoiding complexity and burden of reporting), a lack of consequences, or a lack of trust in authorities (Borges and Penas Lado 2019, Kraak and Hart 2019).

4.3 Observer Programs

Because of the limitations of logbook data, observer programs are important for verifying estimates of bycatch rates of marine mammals (Read et al. 2006, Northridge 2008, Borges 2015, Emery et al. 2019). The 'observer effect', whereby observed bycatch rates are higher than rates without observers present, has been recognised in many fisheries and is a reason that observer rates are used in preference to unobserved rates to estimate fishery impacts (e.g., Johnson et al. 1999, Burns and Kerr 2008). A limitation of relying on observer coverage to estimate fishery bycatch is that fishers may alter their behaviour in the presence of observers and be less 'risk averse' to bycatch in the absence of observers, hence rates recorded by observers may under-estimate actual interaction rates (Babcock et al. 2003). Observer programs are also costly and can be cumbersome or not possible in fisheries where the observer replaces a crew member (Lewison et al. 2004).

Observer coverage is often limited to a relatively small proportion of fishing effort and findings are extrapolated across the entire fishery. Northridge and Thomas (2003) suggested that observer coverage of 25% to 30% of total fishing effort is required to obtain accurate and precise estimates of bycatch. However, levels of observer coverage need to consider the objectives of the program and the rates of interaction. Logistical (especially financial costs) and scientific constraints (e.g., bias) also need to be considered. The recent suspension of many observer programs due to the Covid-19 virus pandemic is an example of a logistical limitation of onboard observer programs (Erasmus et al. 2022, Kirkwood and Goldsworthy 2022). High levels of coverage are needed to quantify interaction rates reliably when the frequency of occurrence is low, and to address the scientific limitations arising from 'observer effects' (i.e., changes in fisher behaviour with an observer present). Levels of observer coverage required to gain robust scientific information vary according to the presence/absence and quality of data obtained by other methods (e.g., electronic monitoring). No agreed criteria have been established for setting levels of observer coverage in fisheries for small pelagic species.

Few fisheries for small pelagic species have long-term observer programs with high levels of coverage (see Table 1 and 2). In most jurisdictions, the focus of observer programs is on gillnet and tuna fisheries, where interaction rates with dolphins are often high (e.g., Rossman et al. 2004, Gerrodette and Forcada 2005, Read et al. 2006). Examples of bycatch in small pelagic fisheries come from limited or punctuated observer programs in the European Union (EU), where observer coverage is below 1% of total effort in most fisheries (ICES 2020, Rogan et al. 2021). Observer programs in South America have also been limited. For example, the Chilean Pelagic Fishery observer programs were implemented in 2015 (Gonzalez-But and Sepulveda 2016) and the Peruvian Anchovy Fishery observer program was implemented in 2017 (Sustainable Fishery Partnership 2018). Observer coverage in Chilean purse-seine fisheries has ranged between 1.5% and 17% of net sets, which is low compared with Chilean trawl fisheries, which have 20-100% coverage (Punt et al. 2021, Vega et al. 2019, 2021,). Since 2021, in response to USA import requirements, purse-seine fisheries in

Ecuador, Peru and Chile adopted more stringent systems including increased on-going onboard observer programs, electronic logbooks and installation of electronic monitoring systems (Felix et al. 2021).

In the USA, about half of federally managed fisheries have observer coverage, which limits estimation of current bycatch levels and their associated uncertainty (GAO 2008, Karp et al. 2011). However, the National Oceanic and Atmospheric Administration (NOAA) fisheries do collate data on all marine mammal population statuses, estimated fisheries bycatch, and population viability, and publish species-based, regional-level, status reports every 1-5 years (depending on data availability and species vulnerability: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock). Observer coverage varies among fisheries, depending on historic bycatch and interaction rates, and national and regional priorities, and can range from no observer coverage to >20% coverage of annual effort. Few marine mammal mortalities are recorded in small pelagic, purse-seine and trawl fisheries, compared with other fisheries (Benaka et al. 2019, Savoca et al. 2020). For example, on the Northeast Coast between 2014 and 2018, no marine mammal mortalities were recorded in purse-seine or trawl fisheries for small pelagic fishes, 56 mortalities were recorded per year in bottom trawls (72% were Common Dolphins), and 213 per year recorded in gillnet fisheries (6% Common Dolphins, 85% seals; Josephson et al. 2021). Relative levels of observer coverage were not given for these fisheries. For small pelagic purse-seine vessels in 2022, however, the USA observer coverage was limited to the menhaden fishery in the Gulf of Mexico (Kirsty Long, NOAA pers. comm.). An example of what is considered a 'high' level of observer coverage due to high levels of marine mammal mortalities comes from the North-east bottom trawl and mid-Atlantic bottom trawl fisheries (Lyssikatos et al. 2020). Each year, from 2013 to 2017 (i.e., a 5-year period), these fisheries had mean annual observer coverages of 15.5% and 9.6% of effort, respectively, and mean annual mortalities of 86 and 352 marine mammals, respectively (Lyssikatos et al. 2020).

A notable exception to typically low levels of observer coverage to record marine mammal interaction rates is the New Zealand Jack Mackerel Trawl Fishery which operates predominantly on the west coast of New Zealand's North Island (Abraham and Berkenbush 2017). Observer coverage in this fishery has been 70-90% of effort since 2011-12 (https://www.mpi.govt.nz/dmsdocument/49426-Jack-mackerels-JMA-May-Plenary-Report-2021-Volume-2).

The SPF mid-water trawl fishery managed by AFMA, targets Jack Mackerel (*Trachurus declivis*), Blue Mackerel (*Scomber australasicus*) and Redbait (*Emmelichthys nitidus*) in south-eastern Australian waters (Ward and Grammer 2021). This fishery has a Dolphin Mitigation Strategy that uses a mix of logbook (Dolphin Interaction Evaluation Report for each interaction with dolphins), observer programs (historically up to 100%, currently 20%, Table 2) and electronic monitoring.

AFMA established its Dolphin Mitigation Strategy based on the principles outlined in the AFMA Bycatch Strategy (AFMA 2017) that management responses should:

1) be proportionate to the conservation status of affected species,
2) be consistent with Government Policy and legislative objectives (including to avoid and minimise), and existing national protected species management strategies such as the threat abatement plan and national plans of action,
3) encourage industry-led solutions,
4) account for the cumulative impacts of Commonwealth fisheries, and
5) have consistent monitoring and reporting arrangements across fisheries.

4.4 Electronic Monitoring

Electronic monitoring (EM) involving deck-mounted video cameras is being used, mainly in conjunction with ongoing observer programs, to monitor interaction rates with protected species in a growing number of fisheries worldwide (e.g., Dalskov 2010, Emery et al. 2019, van Helmond et al. 2020). Cameras are placed at vantage points that give a clear view of the onboard fishing operation, especially the catch. Recording is triggered by sensors that detect equipment being switched on, gear being deployed and retrieved, changes in light levels, or can run continuously when out of port. Video footage is stored electronically and is reviewed onshore by an independent analyst. All footage, or a proportion of effort, may be audited to verify logbook data.

In the Cornwall purse-seine fishery, a night-time fishery for sardines, closed-circuit television (CCTV) systems were fitted to all vessels in the 2020-21 season, to monitor fishing behaviour, catch and bycatch (Jones et al. 2022). The systems were fitted by industry members (there was no legal requirement) to demonstrate compliance with the Cornish Sardine Management Association (CSMA) code of conduct. CCTV and observer surveillance data were compared with logbook data and found to be 'on the whole, good' (Jones et al. 2022). In 2022, systems on three vessels were upgraded to i360 camera systems which include the ability for skippers to record audio files alongside the video footage (Gus Caslake, Seafish, UK, pers. comm.).

The potential for restrictions on the export of fish products to the USA if marine mammal bycatch mitigation measures do not meet with USA Marine Mammal Protection Act standards has stimulated increased application of EM. For example, in Chile, all purse-seine vessels of the industrial fleet (i.e., purse-seiners >18 m length) have had camera-based monitoring systems since January 2020, and artisanal boats >15 m length will be required to have camera monitoring by January 2024 (Felix et al. 2021).

An international review of EM systems undertaken by van Helmond et al. (2020) considered 100 trials and 12 implemented programs, but focused primarily on 16 European trials. The review showed that EM is widely used in trawl fisheries but is used less commonly in purse-seine fisheries (although this is changing rapidly with an increasing number of purse-seine fisheries incorporating CCTV techniques). The major benefits of EM were found to be cost efficiency, more representative coverage than observer programs, and enhanced recording of fishing activities and locations (van Helmond et al. 2020). It was noted that EM may enhance and/or replace onboard observers.

In the western Pacific tuna purse-seine fishery, EM catch rates of threatened species were comparable with those recorded by observers (Brown et al. 2021). The Australian SPF Dolphin Mitigation Strategy identifies a mix of observer coverage and EM (EM became mandatory from 2015) as the preferred means for monitoring dolphin interactions.

The review by van Helmond et al. (2020) also found that EM could incentivise compliance with fishery regulations and discard reductions. Emery et al. (2019) showed the implementation of EM led to improved reporting rates of interactions with protected species in several Australian (Commonwealth) fisheries, notably the Gillnet Hook and Trap Fishery sector of the Southern and Eastern Scalefish and Shark Fishery, and the Eastern Tuna and Billfish Fishery.

EM by camera systems of bycatch may have some limitations for some purposes when compared with observer monitoring. For example, Gilman et al. (2019, 2020) found observers in a long-line fishery were better than EM systems at recording the species, condition at the vessel and release condition of dolphins. In that fishery, repositioning of cameras and improved cooperation from crew improved the quality of EM data.

An alternative means of EM is to examine accurate vessel movement data, such as GPS-based Vessel Monitoring Systems (VMS). Many commercial fishing vessels in Australia are required to have VMS systems, which can be used for search and rescue, and compliance monitoring (e.g., to monitor if vessels remain outside of exclusion zones). Comparisons of vessel movement while observers are onboard could be compared with movement without observers to assess activities in the absence of observers. In the case of the SASF, this may enable interpretation of where nets are being set, although it may not be possible to interpret when dolphin interactions occur using such data.

4.5 Monitoring the population status of dolphins

Understanding the population status of marine mammals impacted by fisheries and other marine industries is important because different approaches need to be applied to species with different conservation status (e.g., listed marine species, protected, threatened and endangered species).

Marine mammal stock assessments are undertaken annually in the USA, as required under the *Marine Mammal Protection Act*. Management actions are triggered when bycatch levels rise above defined biological reference points (Wade 1998). Take reduction plans have been established for marine mammals across all fisheries in the USA and have generally been successful in reducing bycatch to below levels at which they could threaten local population viabilities (Geijer and Read 2013, McDonald et al. 2016).

In New Zealand, management of interactions between marine mammals and commercial fishing activities is broadly based on the status of the species, risks to the population, and the intent to minimise mortalities. Observer data are used to estimate capture rates (e.g., Baird 2001, Thompson et al. 2013 a,b) and undertake multi-species, cumulative risk assessments of interactions of marine mammals with commercial fisheries (Abraham et al. 2017). The first risk assessment identified the twelve species at relatively highest risk from commercial fisheries (Abraham et al. 2017). Species-specific risk assessments have been completed for two species: the Maui dolphin and New Zealand sea lion. These risk assessments inform the prioritisation of research and management interventions, which are specified in Fishery Plans and Annual Operational Plans (http://www.openseas.org.nz/wp-content/uploads/2019/05/SDRMarineMammals2019.pdf).

In the EU, there are limited data and high levels of uncertainty in estimates of population abundance, distribution, bycatch, and other threats to small cetaceans (ICES 2019, 2020). Several recently published papers have concluded that the monitoring and mitigation of the bycatch of small cetaceans in the EU is inadequate (Dolman et al. 2016, 2021, Rogan et al. 2021), with both these studies recommending substantial improvements. For example, Rogan et al. (2021) recommended that the EU should adopt a comprehensive plan to conserve dolphins, that includes regular formal population assessments, establishment of quantitative management objectives, generation of estimates of abundance and bycatch mortality, and setting of biological reference points to guide management actions.

The potential for dolphin mortalities in the SASF to impact Common Dolphin populations in South Australia was assessed by Parra et al. (2021). Based on an estimated 22,000 dolphins in South Australia's gulfs and adjacent coastal waters (to 100 m depth) in 2011, and 'Potential Biological Removal' (PBR) analysis, assuming a conservative maximum population growth rate of R_{max} = 0.02 and a recovery factor of F_r = 0.5 for a species of unknown conservation status, Parra et al. (2021) estimated that the loss of between 95 to 120 dolphins per year through human interactions could have an impact on the population's sustainability. Extrapolated observer data indicate this level of bycatch may have been exceeded by the SASF in two years, 2004-05 and 2018-19 (484 and 113 dolphins, respectively; Ward et al. 2015, Goldsworthy et al. 2019). The average annual mortality estimated from observer data between 2005-06 and 2021-22, was 26 ± 7 (mean ± SE; Kirkwood and Goldsworthy 2022). At this rate, based on the estimates by Parra et al. (2021), the SASF alone would not have reduced Common Dolphin population viability in South Australia. In the absence of observers, however, fisher behaviour appeared to differ, so dolphin mortality rates may have differed to those recorded by observers (Ward et al. 2018, Goldsworthy et al. 2019, Kirkwood and Goldsworthy 2022). Due to this uncertainty, and because indirect impacts were not included in the Parra et al. (2021) study, dolphin population impacts from the SASF in South Australian gulfs waters are uncertain. A current Fisheries Research and Development Corporation (FRDC) project (2019-063) is attempting to address this uncertainty.

5.0 Global approaches to mitigate interactions between small pelagic fisheries and dolphins

5.1 Overview of approaches

Successful mitigation of interactions between fisheries and cetaceans usually requires the implementation of an inter-related suite of management, monitoring and mitigation measures which are refined over time using an adaptive approach (e.g., Hamilton and Baker 2019). Methods for preventing or minimising bycatch of marine mammals in fisheries have been reviewed (FAO 2018, 2020, Leaper and Calderan 2018). Approaches taken to mitigate interactions can be specified in documents published by fisheries management agencies (e.g., SPF Dolphin Mitigation Strategy, SPF Gillnet Dolphin Mitigation Strategy), industry CoPs (also called Codes of Conduct, CoCs) such as those for the SASF (SASIA 2023) and the Commonwealth Blue Grenadier *Macruronus novaezelandiae* fishery (Tilzey et al. 2006), and in management plans for specific vessels (e.g., SPF Vessel Management Plan, *FV Geelong Star*, AFMA 2016). There are five primary categories of approaches taken to mitigate bycatch, including: 1) changes to fishing operations and fisher behaviour; 2) technical modifications and exclusion devices; 3) time-area closures; 4) acoustic deterrents; and 5) enhanced detection (FAO 2020).

5.2 Changes to fishing operations and fisher behaviour

Changes to fishing operations and fisher behaviour are critical for mitigating interactions of purse-seine fisheries with dolphins. The stimulus to reduce dolphin interactions can come through financial burdens of time lost to deal with the dolphins, individual fisher or industry desires to minimise impacts on non-target species, or public and legislative pressure. Operational and behavioural techniques that are recognised to minimise the chance of interactions are often documented in CoPs or CoCs.

Several pelagic purse-seine fisheries have deliberately encircled surface schools of dolphins to catch tuna underneath them. Associated high rates of dolphin mortalities and declines in oceanic dolphin populations have resulted in bans on this fishing method in the Pacific Ocean (Joseph 1994, Hamilton and Baker 2019). The technique continues in several oceanic purse-seine fisheries where high dolphin mortality rates have not been recorded (Escalle et al. 2015). This contrasts with a primary aim of most purse-seine fisheries for small pelagic species to not encircle dolphins.

In purse-seine fisheries in India, fishers mitigate interactions with dolphins by delaying fishing operations if dolphins are seen, trying to scare the dolphins by creating noise at the vessel (e.g., hitting the side of the boat or using crackers), or throwing stones (Prajith et al. 2014, Joseph et al. 2021). Active searching for dolphins prior to setting the net, and delaying setting when dolphins are present, are changes that have been critical to the success of the CoP for the SASF at reducing dolphin mortalities.

The ability to detect and avoid dolphin interactions can be simpler in day-time fisheries. Purse-seine fisheries that operate both day and night report higher dolphin interaction rates at night-time (e.g., a Portuguese sardine fishery, Nichols and Scott 2013) suggesting restricting fishing to day-time net-sets would minimise interactions. Other purse-seine fisheries that operate entirely at night, such as in the UK and Italy, report minimal interactions with dolphins (Monteiro 2017, Jones et al. 2022). Switching to day-time setting to reduce dolphin interactions is not practical in purse-seine fisheries that target species which school near the surface predominantly at night, which is the situation for the SASF. Clearly, interaction rates with dolphins can be region- and time-dependant and changes to fishing operations and fishing behaviour to minimise interaction rates will need to be, in part, fishery-specific.

Changes to fishing operations and fishing behaviour are also important components in mitigating interactions with dolphins in trawl fisheries (e.g., Tilzey et al. 2006). CoPs for trawl fisheries can specify mitigation measures such as the need to search and delay prior to setting, for trawling to occur only at night and/or in deep-water, for rapid hauling and/or single direction trawling, as well as removal of dead fish from meshes and prohibition of discarding offal (e.g., Fernandez-Contreras et al. 2010, NOAA 2019, ICES 2019).

5.3 Technical modifications and exclusion devices

Technical modifications and exclusion devices are commonly used to mitigate interactions with dolphins in purse-seine fisheries for small pelagic fishes. While ‘backdown’ procedures and modified net panels (e.g., Medina panels, being fine mesh panels that drag the net down when towed) are used in some tuna purse-seine fisheries to assist the release of dolphins, these are not practical with the small-mesh nets used in purse-seine fisheries for small pelagic species (e.g., FAO 2018, Hamilton and Baker 2019). Instead, different purse-seine fisheries have developed their own styles of ‘dolphin gates’, ‘slipping’ techniques and barrier nets. One ‘dolphin gate’ technique uses a rope that is pulled to release the cork line from a section of the net which then sinks – this is currently applied in several Chilean purse-seine fisheries (Gallardo Lagno 2021). Many EU purse-seine fisheries release encircled dolphins by sinking a section of the floating net-line; this allows dolphins (or excess fish) to ‘slip’ over the top of the net (e.g., Perez et al. 1996, Marçalo et al. 2015). Cornwall purse-seine fishers also open the front of the net to release (or ‘slip’) excessive catch or dolphins, although the latter are uncommonly encircled in this fishery (Jones et al. 2022). Other ‘slipping’ methods, involve opening a zip release on a panel or adding weights to sink a section of the cork-line then ushering dolphins through these (e.g., Nichols and Scott 2013, Prajith et al. 2014, FAO 2018, Hamilton and Baker 2019, Hamer and Minton 2020). A successful technique applied in Indian ring-net (‘mini’ purse-seine net) fisheries has been a 1.0 to 1.5 km 'dolphin wall' net, which is set by a second vessel concurrent with the ring-seine and represents a barrier to the approach of dolphins (Prajith et al. 2014, Joseph et al. 2021).

Sinking a section of the net and opening net panels (dolphin gates) have been trialled in the SASF but both required the launch of a dingy at night and manual operation of ropes, which proved slow, difficult and unsafe. Dolphin walls have not been trialled in the SASF, and likely would be impractical. The most successful technique for releasing encircled dolphins in the SASF has been opening the front of the net and aborting the net-set (Hamer et al. 2008, Ward et al. 2018). However, on-going experience and further innovation may result in further developments and improvements to reduce dolphin encirclements and enhance release procedures.

Technical modifications and exclusion devices are widely used to reduce the capture of small cetaceans in mid-water trawl fisheries. Bottom-opening escape hatches have limited value and can be associated with cryptic mortality as they allow dead dolphins to fall out of the net (Zollett and Rosenberg 2005, Jaiteh et al. 2014, Zeeberg et al. 2006, Wakefield et al. 2014, 2017). Exits at the top of the net have been shown to reduce dolphin mortality rates in some demersal trawl fisheries (e.g., Stephenson and Wells 2006, Allen et al. 2014). The limited data that are available from pelagic trawl fisheries do not provide compelling evidence that excluder devices reduce dolphin mortality rates (e.g., Larnaud et al. 2006, Heessen et al. 2007, Northridge et al. 2011). For example, in the pelagic trawl fishery off north-west Africa, observed bycatch rates with and without an excluder (0.29 and 0.55 dolphins per 100 trawls, respectively) were not significantly different; it was concluded that efficacy of the excluder for small cetaceans had not been demonstrated (Heessen et al. 2007). Barrier nets designed to keep dolphins out of the net and top opening excluder devices designed to allow marine mammals, especially seals, to escape the net, and which included a hood to ensure that all dead animals were retained (e.g., Lyle and Wilcox 2008).

5.4 Time-area closures

The dynamic nature of habitat utilisation by small cetaceans and their strong association with aggregations of small pelagic fishes limit the use of spatio-temporal closures to reduce interactions in both purse-seine and mid-water trawl fisheries (e.g., FAO 2018, 2020). No published examples were found of spatial closures being used to manage dolphin interactions in a purse-seine fishery for small pelagic fish, although the CoP for the SASF requires fishers to avoid fishing in, and to inform other fishers about, areas where large aggregations of dolphins are present. Spatial closures are sometimes used in trawl fisheries and may be linked to biological data on the species at risk, and/or bycatch limits (FAO 2018). For example, the SPF Dolphin Mitigation Strategy establishes a Maximum Interaction Rate (i.e., one dolphin per 50 trawl sets in the six-month review period) as a Performance Indicator (AFMA 2019). If the interaction rate is exceeded in one review period, the Dolphin Mitigation Plan must be reviewed by AFMA or an AFMA-approved reviewer. If the interaction rate is exceeded in two consecutive review periods, the plan must be reviewed, and the individual vessel is excluded from an area (i.e., the East and West zones of the SPF) for six months. If the interaction rate is exceeded for three consecutive periods, the plan must be reviewed, and the vessel is excluded from the fishery for six months. There are also caps on numbers of interactions (one, three and six dolphins) per set or review period which trigger responses ranging from a review of mitigation measures by the operator or by AFMA or an AFMA-approved reviewer, to exclusion from the relevant area (East and West zones) or the fishery for six months. One of the incentives for individual fishers to minimise their interactions with dolphins is that management responses apply to individual vessels rather than across the fishery. However, the biological basis for the trigger values and responses established in the Dolphin Mitigation Strategy are not well documented and are poorly understood.

5.5 Acoustic deterrents

Acoustic deterrents include devices that emit frequencies dolphins can detect and warn them of the presence of fishing equipment, such as gillnets, attempt to mask the presence of prey or scare the dolphins away from operations. Types of acoustic deterrents include electronic ‘pingers’ (of which there is a range of types), crackers, hitting the side of the vessel, or producing play-backs of predator calls (e.g., killer whales, *Orcinus orca*) (Edwin et al. 2017, Götz and Janik 2013). Acoustic deterrents have reduced marine mammal mortality rates in certain fisheries and are mandated in some gillnet fisheries (Barlow and Cameron 2003, Carretta and Barlow 2011, Dawson et al. 2013, Reeves et al. 2013, Mackay and Knuckey 2013, Hamilton and Baker 2019).

Pingers designed to deter dolphins from approaching fishing operations can emit frequencies of 3-120 kilohertz and sound levels up to 180 decibels (Dawson et al. 2013, Kraus et al. 1997, Reeves et al. 2013). Louder acoustic harassment devices (>180 decibels) have been used, but can have adverse biological and ecological impacts on dolphins and other species (Ketten et al. 1993, Dawson et al. 2013, Simonis et al. 2020). Application of pingers classed as harassment devices may be restricted by permit conditions and ‘over-use’ may restrict dolphin movement and have population-level consequences. Different brands of pingers emit different sound levels (decibels) and frequencies (kilohertz), can have different pulse directions, durations, and periodicities, and can be triggered remotely or by echolocation calls from cetaceans. Pingers can be attached to fishing nets in various positions or deployed directly from vessels (FAO 2018, 2020).

The effectiveness of pingers varies with cetacean species, location and fishery (Dawson et al. 2013, Santana-Garcon et al. 2018, FAO 2018, 2020). Common Dolphins appear to be less easily deterred than other dolphin species. For example, several studies have shown evasive responses to pingers by bottlenose dolphins (*Tursiops* spp.) but not Common Dolphins (van Marlen et al. 2007, Berrow et al. 2009, Bowles and Anderson 2012). In some cases, devices that caused evasive behaviour in experiments have been less effective when deployed on fishing gear (Leeney et al. 2007, van Marlen et al. 2007, Dawson et al. 2013).

This can relate to operational issues. For example, a reduction in efficacy of pingers at reducing harbour porpoise (*Phocoena phocoena*) bycatch in a USA gill-net fishery was influenced by low levels of compliance with their use (dropped to <10%) and that a high proportion (40-90%) of pingers being used were not functioning (Kraus et al. 1997, Palka et al. 2008, Northridge et al. 2011). The effectiveness of pingers can also reduce over time (although not always, e.g., Omeyer et al. 2020) through reductions in avoidance behaviours by the dolphins (Kraus 1999, Cox et al. 2001). For example, in studying the behavioural response of bottlenose dolphins to gill nets, Cox et al. (2004) found that although they appeared to be displaced in a 'subtle manner' from the nets, over time interactions increased, potentially because dolphins came to associate them with depredation opportunities.

While effective at alerting dolphins to the presence of set nets, such as gillnets, acoustic deterrents may be less effective at preventing dolphins from entering active fishing gear, such as purse-seine or trawl nets (Leaper and Calderan 2018). Studies have demonstrated short-term successes. For example, in India, during a 3-month trial of pingers attached around the buoy-line of ring-nets (small-scale purse-seine nets) demonstrated a 40% reduction in dolphin entanglement (a range of species) and dolphin depredation on encircled fish (Edwin et al. 2017). FAO (2018, 2020) reviews, however, report that playing acoustic signals and killer whale sounds during net setting has not been successful as a longer-term preventative of dolphin encirclements in purse-seine fisheries. A logistical issue with net-deployed pingers on purse-seine nets is that a large number (20 to 40) is required per net. Frequent checking to ensure ongoing functionality as well as battery replacement, and device replacement due to loss from the net, can be expensive and time-consuming. This has deterred uptake (FAO 2018, 2020).

Various types and numbers of acoustic deterrents arranged in a variety of ways have been used (or at least tested) to mitigate interactions of trawl fisheries with dolphins. Several studies have suggested that pingers are not effective in reducing dolphin bycatch in demersal trawl fisheries (e.g., Santana-Garcon et al. 2018, Stephenson and Wells 2006, Lyssikatos 2015). The effectiveness of pingers in mid-water trawl fisheries is unclear. Some studies have shown reductions in bycatch (Larnaud et al. 2006, van Marlen et al. 2007, ICES 2009), while others have not (Berrow et al. 2009, van Marlen et al. 2007, Northridge et al. 2003, 2008, 2011, De Carlo et al. 2012). None of the acoustic deterrents tested appear to have resulted in large reductions in dolphin bycatch over extended periods of time. Hamilton and Baker (2019) concluded that the only pingers that have shown significant potential for reducing interactions in mid-water trawl fisheries have high volume outputs and may be considered harassment devices. Concerns have been expressed about the expense, enforcement, and collateral impact of pingers in mid-water trawl fisheries (e.g., Northridge et al. 2011). Acoustic scarers such as killer whale vocalisations have not been effective in preventing bycatch of dolphins in trials conducted in mid-water trawl fisheries (ICES 2009).

In 2020, several fishers in the SASF trialled acoustic deterrents to mitigate interactions with dolphins (Figure 1). Two vessels placed 28 *Netguard* pingers (Future Oceans, Queensland) throughout the net. A third vessel deployed a *Sea Master Protector* (Sea Master Enterprises, Taiwan) acoustic device over the side prior to setting the net. There was no significant difference in rates of dolphin encirclement events among vessels (X^2 = 17.333, df = 11, p = 0.098), nor between vessels grouped as: a) without deterrents, b) with pingers, or c) with the vessel-based acoustic device (X^2 = 1.426, df = 2, p = 0.490). Moreover, on vessels that trialled devices, there was no significant difference in encirclement rates between when devices were deployed and when they were not deployed (X^2 = 0.017, df = 1, p = 0.897). Thus, trials of acoustic deterrents did not reduce interactions with Common Dolphins in the SASF. As acoustic pingers operate at a wide range of different frequencies and sound levels, with new devices being produced, further trials and experimentation with a range of acoustic deterrents may be warranted.

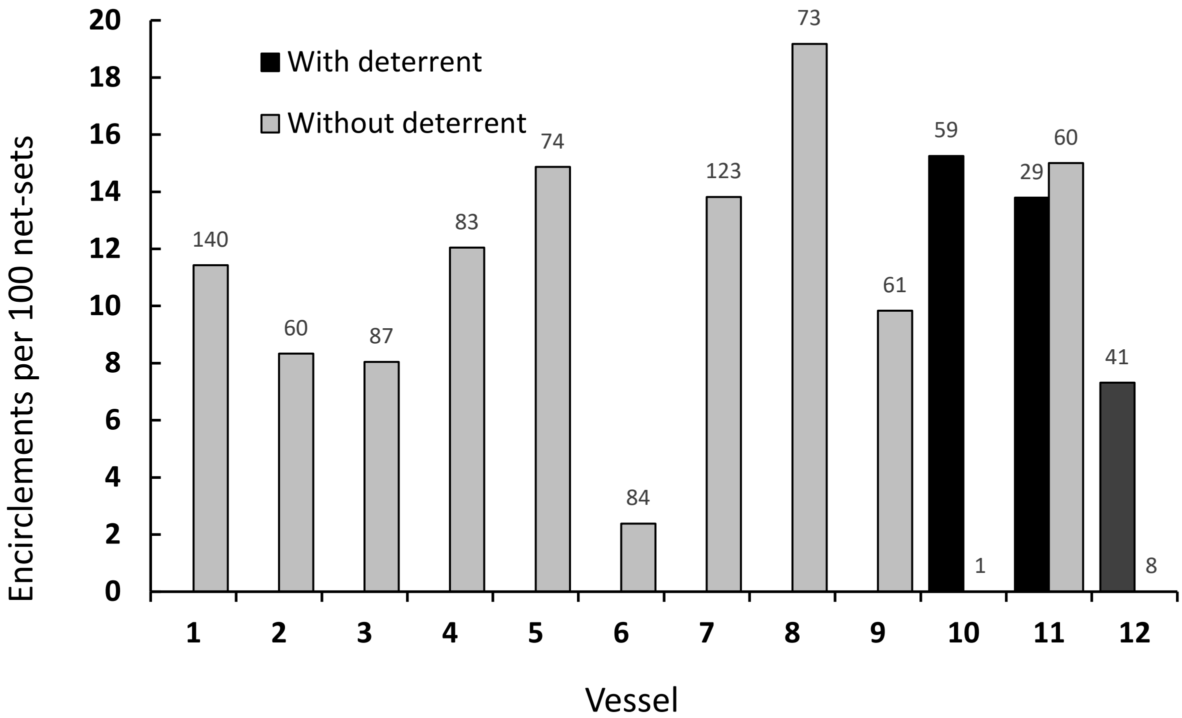

Figure 1. Rates of encirclement (dolphin encirclements per 100 net-sets) recorded by vessels with and without acoustic deterrents in the SASF. Vessels 10 and 11 placed 28 *Netguard* pingers throughout the net. Vessel 12 deployed a *Sea Master Protector* acoustic device over the side prior to setting the net. Numbers above columns are the number of net-sets.

5.6 Enhanced visual and acoustic detection

There are no published results from trials of optical technology (e.g., light-enhancing and thermal, infra-red, imaging) to assist search procedures for dolphins in either purse-seine or mid-water trawl fisheries for small pelagic fishes. Optical equipment comes in a wide range of qualities, from toys to military-grade equipment that is not available to the public. State of the art monoculars include zoom ability and colour enhancement options. Some devices combine both light enhancing and thermal imaging. A light enhancing optical device was trialled in the SASF in the early 2000s but proved of limited value due to its poor optics and small field of view.

Thermal detection of cetaceans may be difficult as their body is well insulated such that their skin is comparable in temperature to the water. However, having accelerated to catch up to a vessel could give the dolphin's body a stronger thermal signature. Previous studies have successfully used thermal imagery to detect cetaceans (Barbieri et al. 2005, Baldaccio et al. 2005, Graber 2011, Horton et al. 2019, Smith et al. 2020, Zitterbart et al. 2020). The technology can detect whales in temperate regimes up to several kilometres away and outperform observers (Zitterbart et al. 2020).

Ease of use at sea, accessibility during net-setting, field of view, cost and sturdiness are all factors that would need to be considered in testing of night vision equipment for detection of cetaceans during active fishing. Due to on-going development of night-vision equipment, there is the potential that current or future devices may enhance dolphin detection during approaches to net-set and while setting nets, allowing for earlier implementation of avoidance practices.

A preliminary study using sonar devices for acoustic detection of cetaceans around pelagic trawls have shown potential, but it was concluded that further investigations were needed to determine their effectiveness (van Marlen et al. 2007). Acoustic monitoring using hydrophones can be used effectively alongside multifrequency echosounders (Lawrence et al. 2016).

While no information was found on the use of hydrophones to monitor cetacean interactions in purse-seine fisheries, hydrophones have been trialled in a mid-water trawl fishery to track spatial distribution of cetaceans in relation to the net (De Haan et al. 1997). In that study, following successful tank-based trials with harbour porpoise, an acoustic deterrent was attached to the bulbous bow of a trawl vessel and an acoustic monitor to the net. While 'technical irregularities and weather conditions' hampered data collection, 34 cetaceans were detected at the net, demonstrating cetacean detection was possible and dolphins visited the net despite the use of the acoustic deterrent.

It is not known how well a hydrophone could detect Common Dolphin echolocation calls beside an SASF purse-seine vessel during net deployment, considering the broad-band of acoustic noise from the vessel, the fishing gear entering the water and weather conditions. Also, detection of dolphins may not alter fishing practices as it would be difficult to equate detection with the possibility of encirclement. However, Canadian company Ocean Sonics currently produce a hydrophone that they report can be employed beside a moving vessel and will record dolphin echolocation calls (https://oceansonics.com/products/iclisten-hf/).

6.0 Discussion

On a world-scale, the SASF is recognised as a purse-seine fishery that has an ongoing observer program, is regularly monitored and has reduced rates of marine mammal interactions and mortalities (e.g., Marçalo et al. 2015, Ward et al. 2018). It is difficult to directly compare cetacean interaction rates and observer coverages between the SASF and other purse-seine fisheries, due to the range of reporting periods, different methods of calculating rates (e.g., observer data, fisher reports, interviews, a combination), and situations (time of day, size of nets, numbers of vessels, dolphin species, etc). However, based on the information collated in this report, mortality rates of dolphins that are recorded by observers in the SASF are similar to those observed in other fisheries for small pelagic species (University of Barcelona 1995, López et al. 2003, Wise et al. 2007, Jaaman et al. 2009, Seco Pon et al. 2012, Marçalo et al. 2015, Gonzalez-But and Sepulveda 2016, Sustainable Fisheries Partnership 2018, Jones et al. 2022). The levels of ongoing observer coverage in the SASF (10%) compares favourably with those in most other pelagic fisheries.

The operations of fisheries world-wide are managed by government regulations that aim to balance maximising catch with both fishery and ecosystem sustainability. In relation to dolphin interaction mitigation in South Australia, the SASF has also adopted several industry-based initiatives aimed at minimising dolphin interactions and mortalities. These include drafting and adopting a Code of Practice (CoP, introduced in 2005) which provides fishers with training and guidelines to reduce the chance of dolphin encirclements, release encircled dolphins and report interactions (dolphin induced delays, encirclements and mortalities). The fishery also adopted a real-time monitoring program in 2011-12, through which issues emerging during a fishing season (e.g., vessels with high interaction rates) could be addressed directly by industry. Another example of the commitment by the fishery to reduce dolphin interactions is the industry-based trials of acoustic mitigation techniques. Annual assessments of dolphin interaction rates based on observer data have demonstrated declines in dolphin mortalities from 484 in 2004-05 to an average of 26 per year between 2005-06 to 2021-22 (e.g., Ward et al. 2015, Kirkwood and Goldsworthy 2022). However, dolphin mortality rates recorded in the absence of observers are about one tenth of those reported when observers are present (Kirkwood et al. 2020). How closely the CoP is followed when observers are not present is unknown. Reducing the discrepancy between data obtained from observed and unobserved net-sets would improve confidence in estimates of dolphin mortality rates and, therefore, potential impacts on the conservation status of Common Dolphins. Methods or policies for ensuring adherence with the CoP (currently a voluntary code) and real-time monitoring within the industry should be explored.

The 'observer effect', whereby observed bycatch rates are higher than rates without observers present, has been recognised in many fisheries and is a reason that observer rates are used in preference to unobserved rates to estimate fishery impacts (e.g., Johnson et al. 1999, Burns and Kerr 2008). Observer programs can provide the highest quality bycatch data but are costly (Lewison et al. 2004). A limitation of observer programs is that if observation is infrequent, fishers may alter their behaviour in the presence of observers, such that observer data does not accurately estimate actual bycatch (Babcock et al. 2003). Methods for improving unobserved data include varying observer coverage (up to 100% of effort) and application of EM. Evidence from Australia and overseas fisheries suggests that the introduction of EM, including onboard cameras, has led to improved fishery-dependent reporting of interactions with protected species (e.g., Dalskov 2010, Emery et al. 2019, van Helmond et al. 2020).

Current data suggest that while net-mounted acoustic deterrents are effective at alerting dolphins to the presence of set-nets, such as gillnets, they are less effective in preventing dolphins from interacting with moving fishing gear, such as purse-seines and trawls. The trials conducted in the SASF in 2020 support findings from other purse-seine fisheries that suggest acoustic deterrents may not be effective in preventing encirclements. However, developments in acoustic deterrent technology are on-going and further testing of new types of acoustic devices in the SASF warrants consideration.

Improved detection of dolphins using new technology (night vision, thermal (infra-red) imaging, and hydrophones), may provide an opportunity for reducing dolphin mortality rates in the SASF. These devices could potentially increase the effectiveness of pre-fishing searches and help fishers detect and respond to dolphins that are encircled or entangled in the net.

Despite operating in similar regulatory and socio-political environments (Tracey et al. 2013) the SASF and SPF have taken different approaches to managing interactions with dolphins (ABARES 2020, Smith et al. 2020, Ward et al. 2020, Ward and Grammer 2021). Key elements of the approach taken in the SPF include: AFMA's overarching Bycatch Strategy (AFMA 2017) and the SPF Dolphin Mitigation Strategy (AFMA 2019); up to 100% observer coverage (currently 20%); EM; vessel specific mitigation plans and application of management responses to individual vessels; and establishment of formal performance indicators, trigger limits and decision rules that guide management decisions. For the SASF, key components of dolphin interaction monitoring and mitigation include: the industry CoP; up to 30% observer coverage (currently 10%); real-time monitoring by industry, investigation of reported mortality events; annual assessment of interactions; and industry-wide rather than individual vessel management responses. Examples of industry-wide (rather than individual vessel-based) management in the SASF include temporary closure of the fishery in 2005 and increases in observer coverage (to a 30% target from 2007-08 to 2009-10, and 20% in 2019-20) following high rates of dolphin mortality and disparity in interaction rates recorded by observers and in logbooks. In contrast, in the SPF, pre-defined responses to interaction rates being triggered are applied to individual vessels, which is feasible as all interactions can be detected with 100% EM. Another key difference between the SPF and SASF is that the SPF Dolphin Mitigation Strategy (AFMA 2019) is informed by AFMA's overarching Bycatch Strategy (AFMA 2017) which is not replicated in South Australia. Limitations and differences in the approaches taken to monitor and mitigate interactions with dolphins in the SASF and SPF highlight the potential benefits of establishing a consistent national approach for

Australian fisheries. Best practice for managing interactions between fisheries and marine mammals involves establishing comprehensive plans that reflect the conservation status of the species/population and include regular population assessments, robust estimation of abundance and bycatch mortality, mitigation approaches and quantitative management objectives and biological reference points to guide management actions.

Management and mitigation of interactions between fisheries and protected species in Australia is currently conducted on a fishery-by-fishery basis. This can make it difficult to investigate overall impacts on regional populations of protected species, which is required for potential biological removal and population viability analyses. An alternative approach, which is adopted in the US by NOAA fisheries (for example), is to assess the vulnerability of protected species populations to all anthropogenic causes of mortality within regions. An aim of this approach is to be able to direct resources toward those interactions which are, nationally, most significant. Strategic, co-ordinated and consistent national approaches can involve cumulative risk assessments like those undertaken in New Zealand or the marine mammal stock assessments done in the US. A national approach can help to ensure that cumulative impacts are accounted for in monitoring and mitigating programs established in individual jurisdictions and fisheries.

7.0 Summary, conclusions and recommendations

Successful mitigation of interactions between fisheries and cetaceans usually requires the implementation of an inter-related suite of management, monitoring and mitigation measures which are refined over time using an adaptive approach (e.g., Hamilton and Baker 2019). This review compared the approach used to monitor and mitigate dolphin interactions in the SASF with other small pelagic fisheries worldwide. The SASF has reduced its interactions with Common Dolphins through recognition of the interaction, adoption and implementation of a CoP and real-time monitoring, compliance monitoring, and annual assessments of interactions. The review notes the effectiveness of the SASFs CoP in reducing dolphin mortalities and the need to ensure it is always applied. It also highlights that many of the approaches used elsewhere have already been trialled and/or adopted and implemented in the SASF. The primary exception to this is electronic monitoring of fishing activity. Further reductions in interaction rates may be achieved through improved detection and avoidance of dolphins, and enhanced monitoring (both observer coverage and electronic approaches). There is also a need to better understand differences in the application of the CoP and fishing behaviour when observers are present/absent.

The key opportunities for maintaining and improving monitoring and mitigation of dolphin interactions in the SASF are:

1) Maintain, regularly review and refine (as required) and ensure rigorous application of the CoP and the ‘real-time’ monitoring program run by SASIA. Maintain SASIA/PIRSA pre-season briefings and training of skippers and crew.
2) Increase observer coverage to reduce the proportion of the fishery where dolphin interaction rates are under-reported and where the application of the CoP is unknown.
3) Conduct trials to assess the potential for using electronic monitoring equipment (e.g., cameras) to evaluate fishing behaviour and application of the CoP when an observer is not present. The presence of electronic monitoring equipment can help to reduce interaction rates by encouraging fishers to apply mitigation measures diligently.
4) Conduct trials to assess the potential benefits of using new technologies (e.g., night vision goggles, thermal imaging (infra-red), hydrophones) to enhance the searches for dolphins prior to and after setting the net.
5) Evaluate the benefits of applying management responses to increased mortality rates, and/or discrepancies between logbook and observer data, to individual fishers/vessels rather than across the fishery.
6) Periodic population assessments of Common Dolphins in the area of the fishery.
7) Establish a SASF Dolphin Mitigation Strategy, ideally informed by an overarching bycatch strategy for South Australia, that includes quantitative objectives, performance indicators, reference points and decision rules.
8) Continue to investigate and trial new opportunities for reducing the encirclement of dolphins and enhancing the successful release of encircled animals.

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