Measurement, management and mitigation of operational interactions between the South Australian Sardine Fishery and short-beaked common dolphins (*Delphinus delphis*)

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ABSTRACT

This study arose from recommendations given in response to a legislated ecological assessment of the South Australian Sardine Fishery in 2004, urging it to: (i) attempt to mitigate operational interactions with marine mammals if excessive levels were detected; and (ii) improve the accuracy of their reporting of these events. An initial observer program revealed high rates of encirclement and mortality (1.78 and 0.39 dolphins per net-set, respectively) of short-beaked common dolphins (*Delphinus delphis*). This equated to an estimate of 1728 encirclements and 377 mortalities across the entire fleet over the same period. The average time taken for fishers to respond to encirclements was 135.93 ± 3.72 min and 21.3% of encircled animals subsequently died. During that time, fishers only reported 3.6% of encirclements and 1.9% of mortalities recorded by observers.

A code of practice (CoP) was subsequently introduced aimed at mitigating operational interactions. A second observer program revealed a significant reductions in the observed rates of dolphin encirclement (0.22; down 87.3%) and mortality (0.01; down 97.1%) with an estimate of 169 and eight, respectively. The average time taken for fishers to respond to dolphin encirclements also reduced to 16.33 ± 4.67 min (down 76.9%) and the proportion of encircled animals that subsequently died reduced to 5.0%. Agreement between industry reports and observer records improved, with the fishery reporting 57.9% and 58.9% of the rate of encirclements and mortalities, respectively, recorded by observers.

A number of avoidance and release strategies in the CoP may have been responsible for these improvements. In particular, fishers were required to delay or relocate their activities if dolphins were observed prior to fishing and to release encircled dolphins immediately or abort the fishing event if release procedures were unsuccessful. Future improvements to the CoP include: (i) improved response times when an encircled dolphin is detected; (ii) better use of behavioural cues for deciding when to abort a net-set; (iii) ceasing fishing during rough weather; and (iv) continuing to increase reporting accuracy by fishers. It is also recommended that the abundance, movements and boundaries of the common dolphin population in the region be determined, so that the impact of fishing activities on their status can be established.

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1. Introduction

1.1. Dolphin interactions with purse-seine fisheries

There is now sufficient evidence confirming the occurrence of marine mammal by-catch in numerous trawl, gill-net, long-line and purse-seine fisheries in many parts of the world (Northridge, 1984, 1991; Francis and Orbach, 1992; Silva and Best, 1996; Gosliner, 1999; Hale et al., 1999; Trippel et al., 1999; Staunton-Smith and Ward, 2000; De Master et al., 2001; Kemper and Gibbs, 2001; Barlow and Cameron, 2003; Shaughnessy et al., 2003; Bell et al., 2006; Hamer and Goldsworthy, 2006; Read et al., 2006). However, few have described the nature of these encounters, or quantified them in any detail. Operational interactions occur when both marine mammals and commercial fishing activities converge on the same spatially retracted school of fish (Hamer and Goldsworthy, 2006). In doing so, marine mammals may come into direct physical contact with the fishing gear, which may ultimately result in their injury or death (Beverton, 1985; Shaughnessy et al., 2003).

Operational interactions between dolphins and purse-seine fisheries have received considerable attention in the available literature (Francis and Orbach, 1992; Di Natale and Notarbartolo di Sciara, 1994; Gosliner, 1999; Hale et al., 1999; Staunton-Smith and Ward, 2000). The most notable example is the millions of spotted (Stenella attenuata), spinner (S. longirostris) and common (Delphinus spp.) dolphins incidentally killed by the tuna purse-seine fishery in the eastern tropical Pacific (ETP) between the 1960s and 1990s, with the annual kill peaking at 457,903 in 1969 (Francis and Orbach, 1992; Joseph, 1995; Wade, 1995; Gosliner, 1999; Archer et al., 2001, 2004). Dolphins indicate the presence of tuna in the eastern tropical Pacific because the two are closely associated, thus resulting in the intentional targeting of dolphins during 41.7% of the 18,609 net-sets conducted by the 132 United States registered vessels in 1974 (Joseph, 1995; Gosliner, 1999). The US Marine Mammal Protection Act was introduced in 1972, partly in response to this issue. An observer program was implemented during the mid 1980s and the practice of deliberately setting purse-seine nets around dolphin pods was subsequently prohibited (Gosliner, 1999). A 'back-down' procedure was also introduced to facilitate the escape of encircled dolphins, by creating an escape route between the top of the submerged net and the surface of the water. By 1983, dolphin mortalities had declined to 8513, or 98.1% when compared with the 1969 peak (Gosliner, 1999).

In Australia, the only published reports of operational interactions between dolphins and purse-seiners originate from a developmental pilchard fishery in southern Queensland, during the mid 1990s (Hale et al., 1999; Staunton-Smith and Ward, 2000). An independent observer program recorded 77 encirclements and 9 mortalities from 63 net-sets, producing an encirclement rate of 1.22 per net-set and a mortality rate of 0.14 per net-set (Hale et al., 1999; Staunton-Smith and Ward, 2000). Encirclements were defined as animals swimming freely within the pursed net and mortalities were defined as those animals that ultimately died. A working group comprising industry representatives and researchers was established to address the issue. They recommended changes to fishing practices be introduced, including improvements to avoidance and release procedures. In particular, it was suggested that encircled dolphins should be released by lowering a portion of the corkline to create an opening, or by aborting the fishing operation entirely before dolphins became stressed and died (Staunton-Smith and Ward, 2000). However, a blanket prohibition on purse-seine fishing in Queensland waters was declared before the effectiveness of these measures could be tested (State of Queensland, 2000; Staunton-Smith and Ward, 2000).

1.2. South Australian Sardine Fishery

The South Australian Sardine Fishery (SASF) was established in 1991 to provide food for wild-caught southern bluefin tuna (Thunnus maccoyii), ranched in sea cages off Port Lincoln, South Australia (Fig. 1). Most of the sardine (Sardinops sagax) catch is taken from southern Spencer Gulf, although some fishing occurs west of Coffin Bay and off the north coast of Kangaroo Island. Catches in the fishery increased from 3241 t (number of net-sets unknown) in 1994 to 39,839 t (1275 net-sets) in 2005, making it the largest fishery by weight in Australia. There are no spatial or temporal closures and the total allowable commercial catch (TACC) is currently set for each calendar year (Rogers and Ward, 2006).

The sardine fishery is a typical, modern purse-seine fishery. Most fishing occurs at night or at twilight. About 14 vessels operate under licence and although they vary between 18 and 42 m in length, they all use nets that are 500–700 m in length and are between 40 and 70 m deep, with mesh size ranging from 14 to 22 mm. The floatline holds the top of the net at the surface, while the leadline causes the bottom of the net to sink rapidly, thus creating a 'curtain'. Once a target school is selected, it is encircled with the curtain of net and the leadline is pursed to prevent the escape of the catch (Fig. 2). The bulk of the net is then hauled aboard, until the catch is brought alongside the vessel and pumped into onboard holding tanks.

1.3. Statutory protection of marine mammals in South Australia

Marine mammals in South Australian waters are protected under both South Australian state and Australian Commonwealth legislation (Bache, 2003). The relevant state legislation includes the National Parks and Wildlife Act 1972, the Fisheries Act 1982 and the Wilderness Protection Act 1992, which specifically prohibit the intentional or negligent killing and exploitation of marine mammals. The Commonwealth Environment Protection Biodiversity Conservation Act 1999 (EPBC Act), which is administered by the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA), also prohibits the intentional killing or exploitation of any listed marine species, including dolphins, in both South Australian and Australian Commonwealth waters. All major Australian fisheries must now undergo an environmental assessment under the guidelines for the ecologically sustainable management of fisheries, pursuant to the EPBC Act, and address any subsequent recommendations by DEWHA before the required exemption to remove or export a native species is granted.
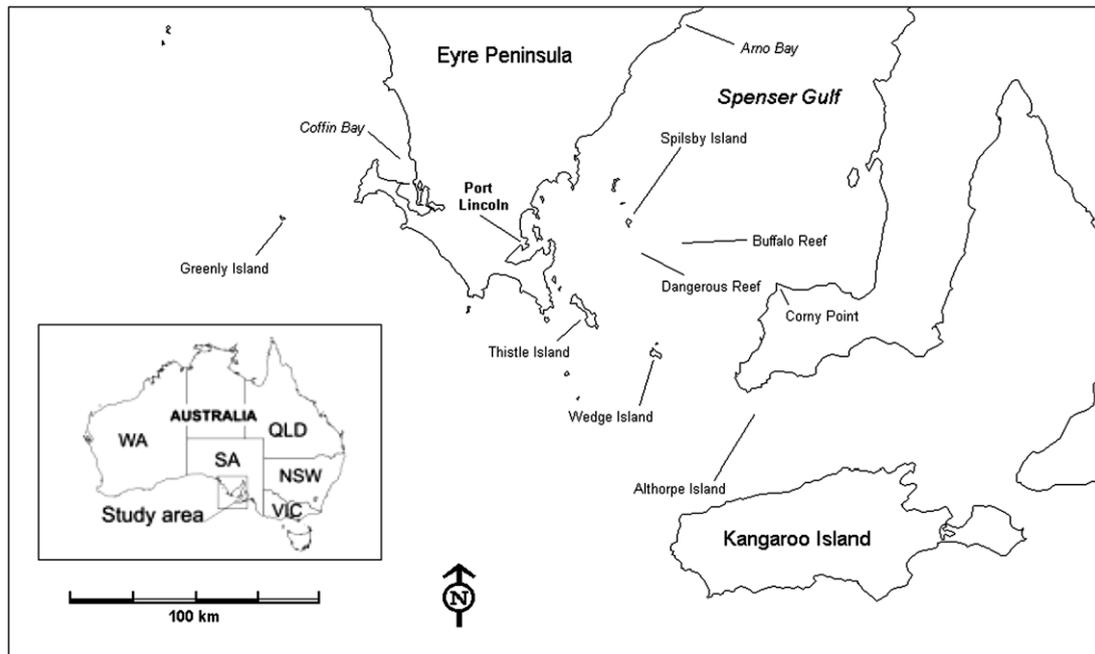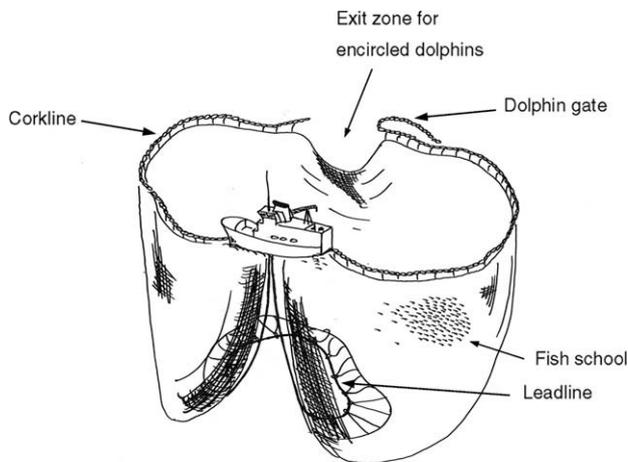
Fig. 1 – Location of the study and important sites.

Fig. 2 – Schematic diagram of a typical purse-seine net, depicting the dolphin gate and the net folds beneath the vessel that form during pursing.

An environmental assessment of the sardine fishery was undertaken by the Department of Primary Industry and Resources South Australia (PIRSA; the manager of the fishery) in September 2004, pursuant to the EPBC Act, to identify possible effects of its activities on the wider marine ecosystem (Shanks, 2004). The fishery was subsequently given approval by DEWHA, although PIRSA were specifically required to address a number of recommendations for improving the management arrangements of the fishery (Tailby, 2004). Two of these recommendations stated that the fishery should: (i) establish a mechanism that ensures operational interactions with marine mammals are reported accurately; and (ii) devel-

op appropriate mitigation measures if a significant level of operational interactions are occurring.

1.4. Development of a code of practice for dolphin by-catch mitigation

A study to address these recommendations was implemented by the South Australian Research and Development Institute (SARDI) in November 2004. An observer program was initiated to assess the accuracy of logbook data and measure interaction rates. Rates of encirclement and mortality of short-beaked common dolphins (*Delphinus delphis*) recorded by observers were found to be much higher than those reported in logbooks. The fishery was then closed as a precautionary measure during August and September 2005, to prevent further interactions with dolphins, while a code of practice (CoP) was finalised (South Australian Pilchard Fisherman's Association, 2005).

A working group was established that included industry representatives, licence holders, fishers, researchers and fishery managers, with a mandate to improve reporting accuracy and mitigate future operational interactions with dolphins through the CoP. The underpinning principles were that it must: (i) significantly reduce operational interactions with dolphins; (ii) facilitate improvements in fishing practice through ongoing development based on input from all stakeholders; (iii) be sufficiently flexible to be safely and practically applied on all vessels under all conditions; and (iv) be cost-effective to implement. The CoP aimed to mitigate operational interactions between dolphins and the fishery through:

● *Early detection.* At least one crewmember was required to determine the presence/absence of dolphins before and

during each fishing event and to immediately report any sightings to the skipper.

- *Avoidance.* The skipper was required to delay or relocate the fishing event if dolphins were detected before commencing fishing.
- *Swift action.* The skipper was required to initiate release procedures without delay when encircled dolphin(s) were detected during the fishing event.
- *Abort fishing operations.* The skipper was required to abort the fishing event altogether if attempts to release encircled dolphins failed.

In addition to the abovementioned changes in fisher behaviour, two gear modifications were also included in the CoP. Firstly, a dolphin gate was added to the purse-seine net, which comprised a removable section of corkline along the top of the net (Fig. 2). When removed, the unsupported section of net sank, creating an opening for encircled dolphins to exit. Secondly, all vessels were required to carry purpose-built attachable weights to sink the corkline.

The fishery was reopened in late September 2005, with all fishing operations subject to the newly developed CoP. A second observer program was then conducted to assess the effectiveness of the CoP in mitigating operational interactions with dolphins.

1.5. Aims of this study

The aims of this study were to:

1. Compare rates of encirclement and mortality of dolphins reported by fishers and recorded by independent observers.
2. Estimate the number of dolphins encircled and killed during each of the two study periods.
3. Measure the effectiveness of the CoP in reducing operational interactions of the SASF with dolphins.

2. Methods

2.1. Historical logbook data

It has been mandatory for the fishery to lodge data relating to operational interactions with dolphins since April 1999. This information was obtained from SARDI to determine the level of fishing effort, plus the number and rate of operational interactions over that time. In addition, the monthly variation in fishing effort was calculated and compared with the incidence of operational interactions with dolphins, for the period between April 1999 and May 2004. The percentage of encircled animals that subsequently died was calculated and regressions analysis was used to determine if there was a relationship between the time of year and the incidence of encirclement.

2.2. Assessing the effect of introducing the CoP

Two observer programs were conducted, one before and one after the introduction of the CoP, during November 2004–June

2005 and November 2005–June 2006, respectively. The two programs were conducted in the same months to reduce seasonal effects on sampling outcomes. Logbook data for these periods were collated and summarised.

During each of the two observer programs, one or more vessels carried one independent observer per trip upon the request of SARDI. Observations were made from a high, unobstructed vantage point such as the wheelhouse, wheelhouse roof or the bow, depending on the vessel and the prevailing weather conditions, and were concentrated within the corkline (Fig. 1). As all fishing occurred at night, observations were carried out either with the naked eye, assisted with binoculars (Gerber® DLX/R 10×50) during moonlit periods, or with a night vision monocular (ITT® N160) during periods of reduced visibility. As it was unlikely dolphins encircled at the beginning of the net-set could escape the pursed net without human assistance, it was unlikely encirclements or mortalities would not be detected, thus avoiding the chance of underestimation.

The date, location (latitude and longitude), total number of individual encirclements and mortalities and the number of encirclement and mortality events were recorded for each observed net-set. These data were used to determine temporal and spatial trends, plus the rates of operational interactions. Other details about the nature of the interactions were recorded, including: (i) the stage of the operation (net deployment, pursing, hauling and pumping) during which encircled dolphins were first detected; (ii) the time taken for crews to respond when encircled animals were detected; (iii) the nature and success of the release procedures; and (iv) swell height (to determine if it was related to the incidence of by-catch mortality).

In spite of low light conditions, encircled dolphins were typically detected early on during the fishing event. The behaviour of encircled dolphins was observed and categorised, using a combination of 'focal group sampling' (assessment of group behaviour) and 'predominant activity sampling' (the most frequent behaviour over a given sampling period; Altmann, 1974; Martin and Bateson, 1993; Mann, 1999). This was done to determine if behavioural cues indicating imminent death due to capture myopathy could be identified (Coe and Stuntz, 1980).

2.3. Data analysis

The spatial and temporal distributions of fishing effort (the number of net-sets) were calculated from data obtained from each observer program and from concurrent logbook data. Regression analysis was used to determine the degree to which encirclement and mortality rates were correlated with the spatial and temporal distribution of fishing effort. For spatial data, the regression was based on the level of fishing effort and number of encirclements in each ten-by-ten kilometre grid square.

The effectiveness of the CoP was determined by comparing the mean encirclement and mortality rate before and after its introduction. To test the significance of change after implementing the CoP, a 1-tailed t-test was applied, because a reduction in encirclement and mortality rates were expected. Although observer and logbook data approximated a Poisson

distribution, the *t*-test used is robust, provided the pooled sample size is greater than 40 (Moore and McCabe, 2003). This assumption was met in this study, with 49 observations made prior to the CoP being introduced and 89 observations after.

The *t*-test for the null hypothesis of no difference in the mean rates of encirclements and mortalities of sets observed pre-CoP compared with those observed post-CoP was calculated (Rice, 1995). The variance of data collected pre-CoP was larger than during the post-CoP period, so was dealt with by pooling them and using the approximate formula for degrees of freedom (Rice, 1995; Moore and McCabe, 2003).

Power analysis was used to estimate the number of observations (ie. the number of net-sets monitored by observers) required to detect future changes in the encirclement and mortality rates, based on data obtained during the second observer program (post-CoP). The power to detect rate increases or decreases depended on the sample variance, sample size, the magnitude of the change that occurred and the degree of statistical significance of the change. Standard levels of significance ($\alpha = 0.05$) and power ($\varphi = 80\%$) were used for these calculations. The sample size required to achieve this power and significance was calculated for prescribed levels of change in either encirclement or mortality rates: $\Delta_p = (\mu_Y - \mu_X)/\mu_X$.

Power was written as a probability integral for the null hypothesis of no change in the *t*-distribution over tested levels of change in the observed rates $(\bar{Y} - \bar{X})$, from $(\bar{Y} - \bar{X})_{crit}$ to infinity, in order to determine if significant increases in either encirclements or mortalities had occurred. Thus, the probability that a future *t*-test with the same sample variance would yield a significant difference was calculated from

$$\text{Power} = \int_{(\bar{Y}-\bar{X})=(\bar{Y}-\bar{X})_{crit}}^{+\infty} f \left[t = \frac{(\bar{Y} - \bar{X}) - \Delta_p \cdot \bar{X}}{\sqrt{\left(\frac{(n_X-1)s_X^2 + (n_Y-1)s_Y^2}{n_X + n_Y - 2}\right) \cdot \left(\frac{1}{n_X} + \frac{1}{n_Y}\right)}}, \, \mathrm{df} = n_X + n_Y - 2 \right] \mathrm{d}(\bar{Y} - \bar{X}) \quad (1)$$

where $f(t, df)$ = probability density function of the *t*-distribution, with df degrees of freedom.

Assumed levels of change in encirclements and mortalities were calculated using power analysis and plotted as: (i)

decreases of 10–90% (in increments of 10%); and (ii) increases of 100–700% (in increments of 100%). A 1-tailed *t*-test was applied in the power analysis because it was used to detect increases and decreases separately, relative to post-CoP encirclement and mortality rates.

3. Results

3.1. Historical logbook data (1999–2004)

Logbook data for the SASF between April 1999 and May 2004 indicated that operational interactions with dolphins were minimal, but variable between years. From the 3915 net-sets conducted over the five-year period, fishers reported 69 encircled dolphins and one death (Table 1). Encirclement and mortality rates reported were 0.0176 and 0.0003 dolphins per net-set, respectively. According to the logbooks, only 1.5% of the encircled dolphins subsequently died.

The number of encircled dolphins was strongly and positively associated with the location of reported fishing effort (Encirclement = $0.01 \cdot$ location of effort + 0.01; $P < 0.01$; $R^2 = 0.50$), with most occurring in areas of high fishing effort in southern Spencer Gulf. No interactions were recorded along the north coast of Kangaroo Island and west of Coffin Bay, where the water was deeper than 60 m. There was no relationship between the number of encirclements recorded in each year and the corresponding level of fishing effort ($P = 0.77$; $R^2 = 0.06$). However, there was a significant, positive relationship between the number of encirclements recorded and monthly fishing effort (Encirclement = $0.01 \cdot$ monthly effort + 2.68; $P = 0.02$; $R^2 = 0.44$). Fishing occurred in all months and encirclements occurred in each of them except November, although more occurred between April and June, when fishing effort was greatest. The only reported mortality occurred in April 2002.

3.2. Before the introduction of the CoP (2004–2005)

3.2.1. Initial observer program
The initial observer program was conducted between November 2004 and June 2005. A total of 87 encircled dolphins and 19 deaths of short-beaked common dolphins were recorded

Table 1 – Summary of short-beaked common dolphin encirclements and mortalities derived from observer records and industry logbook reports, presented as the total number of individuals, the number of events in which they occurred, plus the corresponding rate and estimate

| Period	Net-sets	Operational interactions							
		Encirclements				Mortalities			
		# Of animals	# Of events	Calculated rate (per-net-set)	Fleet wide estimate	# Of animals	# Of events	Calculated rate (per-net-set)	Fleet wide estimate
Observer									
Before CoP	49	87	18	1.7755 ± 0.4882	1728	19	11	0.3878 ± 0.1265	377
After CoP	89	20	9	0.2247 ± 0.0795	169	1	1	0.0112 ± 0.0112	8
Logbook									
1999–04	3915	69	30	0.0176		1	1	0.0003	
Before CoP	973	63	28	0.0648 ± 0.0079		7	6	0.0072 ± 0.0027	
After CoP	753	98	47	0.1302 ± 0.0123		5	5	0.0066 ± 0.0032	

Values are derived from: historical records (1999–2004), plus data collected before (2004–2005) and after (2005–2006) the introduction of the CoP.

during 18 by-catch events, from 49 net-sets monitored over 89 nights (Table 1). The overall encirclement and mortality rates were 1.7755 and 0.3878 dolphins per net-set, respectively. A total of 21.3% of all encircled dolphins died. Given that 973 net-sets were recorded in fishery logbooks across the fishery over the same time period, 5.0% of all net-sets were monitored. Dolphins were observed bow riding and feeding on sar-

dine schools prior to 81.6% (40 of the 49) of net-sets monitored. Assuming encirclements and mortalities occurred at the same rate across the remainder of the fishery over the same period, the estimated numbers of encirclements and mortalities were 1728 and 377, respectively.

Eight of the 11 vessels operating during this period carried an observer when requested by SARDI. Fishing activity was
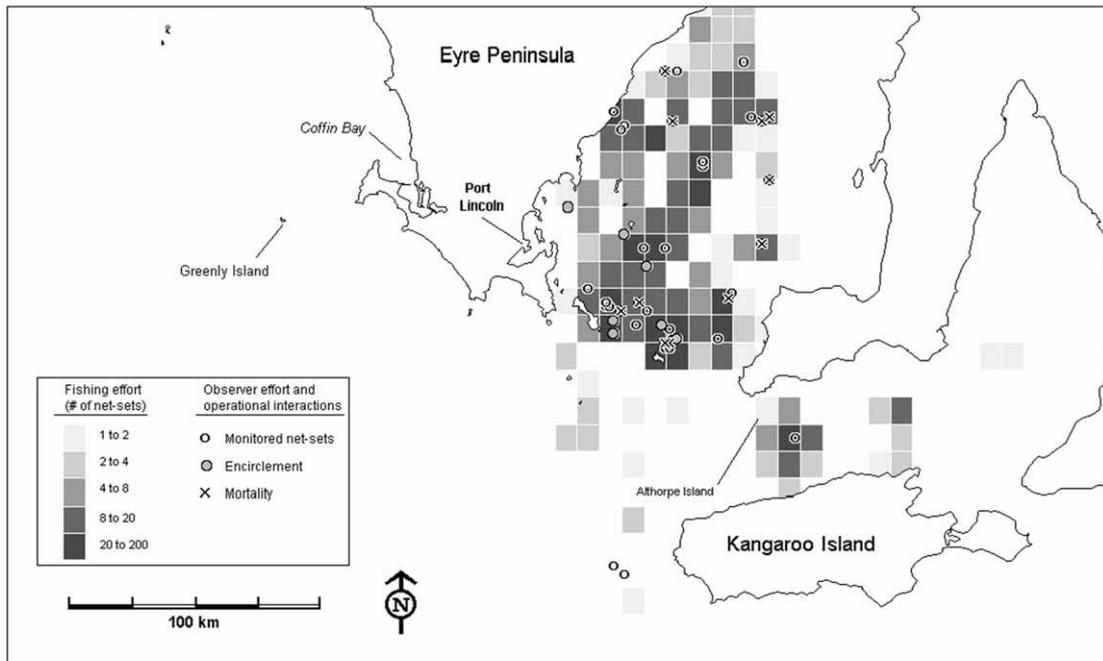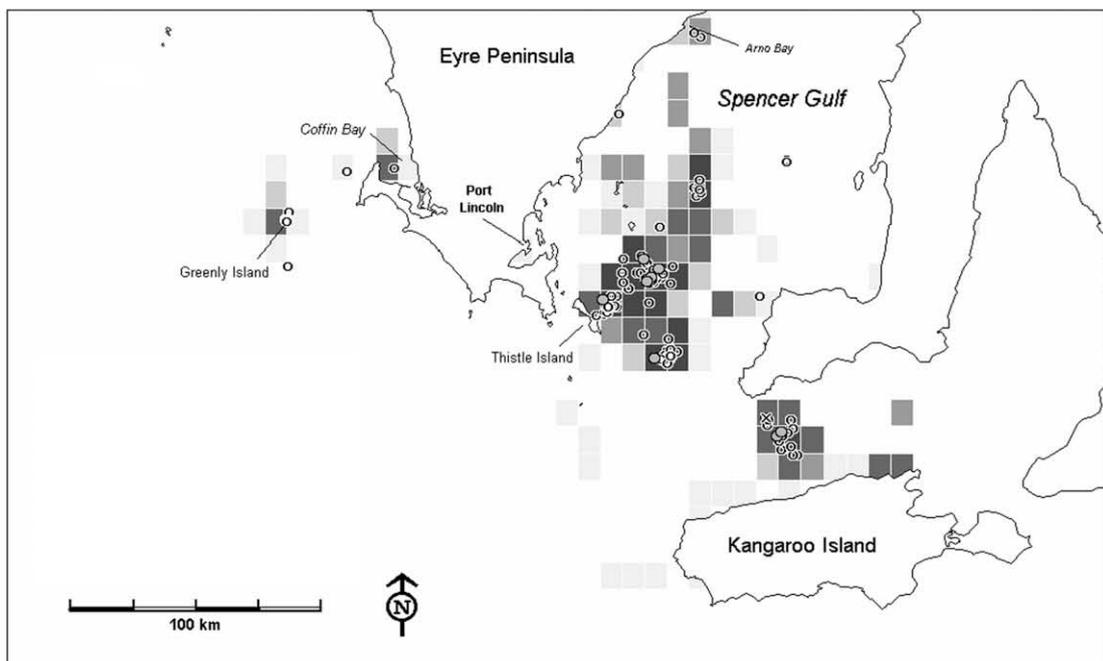

Fig. 3 – Spatial distribution of fishing effort and dolphin encirclements and mortalities, before (a) and after (b) the introduction of a CoP.

monitored throughout most of the area historically fished within the southern Spencer Gulf (Fig. 3a). Fishing did not occur near Coffin Bay and only a relatively small amount of effort was undertaken near Althorpe Island. The number of encirclements recorded by observers was strongly and positively associated with the location of fishing effort (Encirclement $= 2.73 \cdot$ location of effort $+ 0.03$; $P < 0.01$; $R^2 = 0.79$), with most encirclements occurring east of Thistle Island and northeast of Wedge Island. No interactions occurred along the north coast of Kangaroo Island.

The number of interactions with dolphins varied between months, with most occurring in January and May (Fig. 4a). No interactions were recorded in November and December 2004, but low numbers of mortalities occurred between February and June 2005. The greatest numbers of encirclements occurred in January and May 2005. There was no relationship between the number of dolphin encirclements and monthly fishing effort ($P = 0.30$; $R^2 = 0.18$).

Seventy nine of the 87 encircled dolphins were initially observed alive. Most (62) of these were first detected soon after hauling had begun, once the deck lights were turned on, although some were detected earlier during pursing (14). Some (three) encircled dolphins were not detected until the net was brought alongside the vessel, prior to commencing pumping, although this only occurred during rough weather conditions.

Eleven of the 19 dolphins that died were initially observed alive, swimming at the surface, within the corkline. The average time taken for crews to respond to the presence of encircled animals and to initiate a release procedure was 135.9 ± 23.7 min on occasions when one of the 11 mortalities occurred, compared with 62.5 ± 6.8 min when encircled dolphins were released successfully (Fig. 5a). The remaining eight dolphins that died were already dead when they were first sighted and were detected within five minutes from the start of hauling, once the deck lights were turned on.
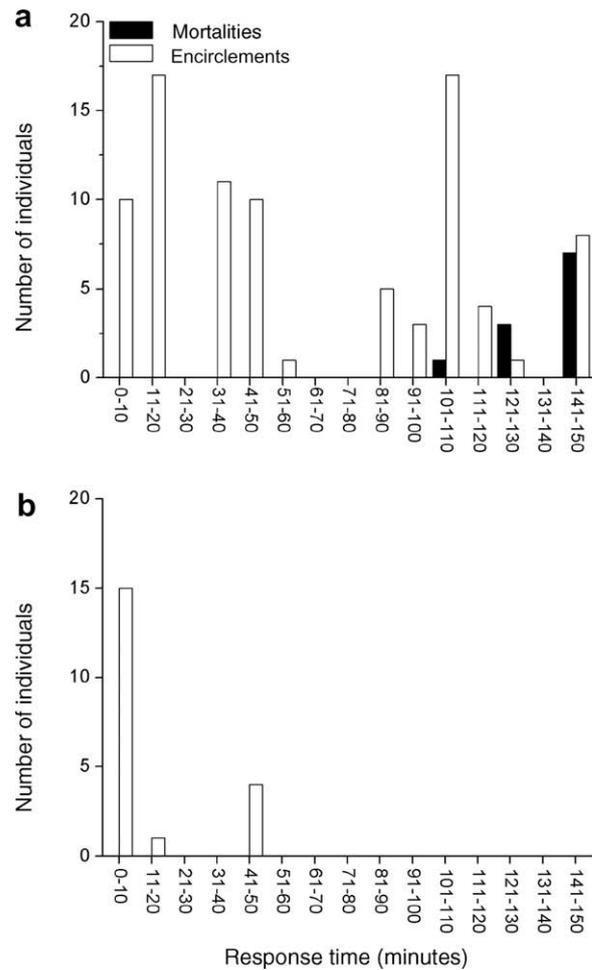

Fig. 5 – The times taken for crews to implement dolphin release procedures after detecting encircled dolphins, before (a) and after (b) the introduction of the CoP.
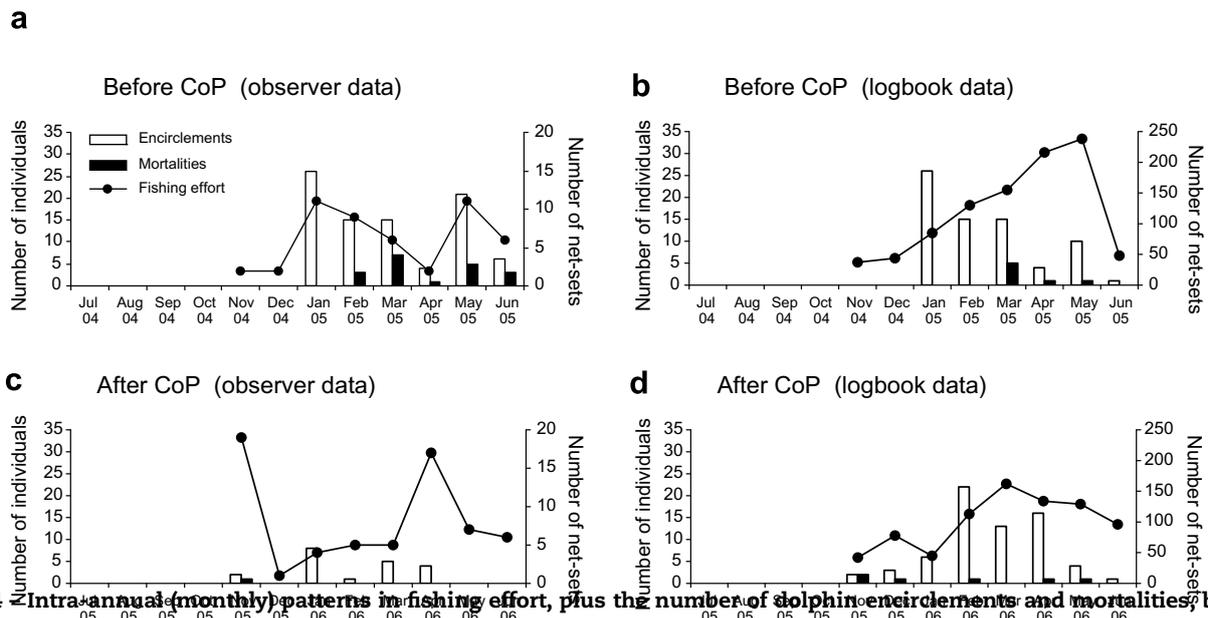

Fig. 4 – Intra-annual (monthly) patterns in fishing effort, plus the number of dolphin encirclements and mortalities, before (a, b) and after (c, d) the introduction of a CoP.

Although fishing generally occurred in good weather when swell height was typically 1 m or less, these mortalities occurred when the swell height was above 2.5 m (Fig. 6). It is likely these eight animals became entangled in sub-surface net folds directly under the vessel during pursing and subsequently drowned (Fig. 2). In contrast, encircled animals that were initially observed alive but then later died occurred across all swell heights (Fig. 6).

Consistent behavioural patterns were observed in the 79 encircled dolphins that were initially observed alive and swimming freely inside the corkline (excluding the eight that were already dead), during the 18 encirclement events. Of particular note was the behaviour classified as 'erratic swimming', which provided the first clear indication that an encircled dolphin was becoming stressed. This behaviour was typified by frequent bursts of rapid swimming in no particular direction, with numerous bouts of tail fluke slapping on the surface of the water. Soon after this initial stress behaviour was observed, some individuals stopped swimming and became motionless in the water in a 'vertical floating' position, with beak, head and blowhole above the waterline. All of these animals exhibited 'passive sinking' soon after, whereby they began to float belly-up and then sink beneath the surface.

This sequence of behaviours was typically associated with imminent mortality, because the animals displaying them did not return to the surface of their own accord and subsequently drowned. Divers attempted to assist animals that exhibited these behaviours on a number of occasions by physically moving them toward the surface, but without success. The duration of the encirclement and the area within the corkline appeared to be associated with the behavioural sequence described above, although the two were probably confounded, making it difficult to determine the individual effect of each on dolphin behaviour.

During the initial observer program, fishing operations were not delayed or relocated on any occasion when dolphins were observed near a target sardine school. 'No action' was the most prevalent response when dolphins were detected prior to commencing fishing and during encirclements (Table 2). Only
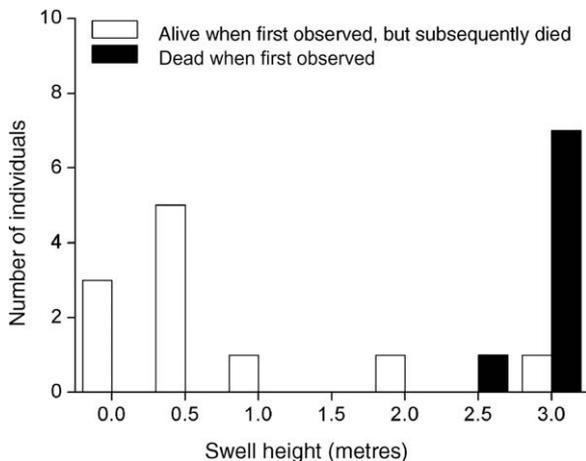

Fig. 6 – The relationship between swell height and dolphin mortalities, derived form data collected before the introduction of the CoP.

Table 2 – Summary of the success of avoidance and release procedures used by fishers to mitigate dolphin by-catch

Guideline	Before CoP			After CoP (CoP assessment)			Combined		
	# Records	# Successful	% Successful	# Records	# Successful	% Successful	# Records	# Successful	% Successful
Avoidance measures									
Delay/relocate	0	–	–	15	15	100.0	15	15	100.0
Release procedures									
No action	32	5	15.6	0	0	–	32	5	15.6
Attach corkline weights	15	8	53.3	4	2	50.0	19	10	52.6
Open dolphin gate	2	1	50.0	7	3	42.9	9	4	44.4
Open net front	18	14	77.8	7	6	85.7	25	20	80.0
Physical removal	18	16	88.9	3	3	100.0	21	19	90.1
Abort net-set	2	2	100.0	6	6	100.0	8	8	100.0

Values are derived from: historical records (1999–2004), plus data collected before (2004–2005) and after (2005–2006) the introduction of the CoP.

15.6% of encircled dolphins escaped form the net without action being taken, although these almost always occurred when the corkline was pulled below the surface by an excessively large school of sardines exerting downward pressure. Other actions taken in order to release encircled dolphins were: opening the dolphin gate (Fig. 1), submerging the corkline by using weights, opening the front of the net, physical removal and aborting the net-set (Table 2). Interestingly, the gear modifications (ie. dolphin gate and weights) did not appear to be reliable tools for releasing dolphins, while opening the net front and aborting the net-set were very successful (Table 2).

3.2.2. Logbook data: during initial observer program

Fishery logbook data was collected from all active vessels over the same period as the initial observer program and they reported 63 dolphin encirclements and seven mortalities, from 973 net-sets (Table 1). The encirclement and mortality rates were 0.0648 and 0.0072 dolphins per net-set, respectively. From these figures, it is estimated they represent only 3.6% of the encirclement rate and 1.9% of the mortality rate recorded by independent observers during the initial observer program.

The number of encirclements recorded in logbooks was positively associated with the spatial distribution of fishing effort (Encirclement $= 0.031 \cdot$ location of effort $+ 0.012$; $P < 0.01$; $R^2 = 0.22$), as was the case with the observer data. Encirclements occurred east of Thistle and Wedge Islands, east of Dangerous Reef and southeast of Althorpe Island. Mortalities were reported from west of Corny Point, between Thistle and Wedge Islands and east of Buffalo Reef. Although there was no temporal relationship with the recorded number of dolphin encirclements found in the observer data, a weak relationship was calculated from SASF logbooks (Encirclement $= 0.035 \cdot$ effort $+ 2.624$; $P = 0.04$; $R^2 = 0.11$). The greatest number of encirclements occurred in January 2005, as was the case in the logbook data (Fig. 4b).

3.3. After the introduction of the CoP (2005–2006)

3.3.1. Second observer program

The second observer program was conducted between November 2005 and June 2006. Once again, the short-beaked common dolphin was the only dolphin species involved in operational interactions with the fishery. After the introduction of the CoP, 20 dolphins were encircled and 1 mortality was recorded from 89 monitored net-sets (Table 1). This equates to a significant reduction in the observed rate of encirclement by 87.3% to 0.2247 per net-set ($F = 5.36$; df $= 2$; $P < 0.01$) and mortality by 97.1% to 0.0112 per net-set ($F = 5.82$; df $= 2$; $P < 0.01$). The number of encircled animals that subsequently died after becoming caught in the net reduced from 21.8% to 5.0%. A total of 753 net-sets were recorded in SASF logbooks across the fishery over the same time period, indicating 11.8% of net-sets were monitored. Therefore, an estimated 169 encirclements and 8 mortalities occurred across the entire fishery and over the same period, assuming the rates were constant.

All 12 vessels operating in the fishery during the second observer program, which included the eight that participated in the initial observer program, carried an observer at least once during the second observer program. Observations were concentrated in the southern Spencer Gulf region, although some fishing was monitored adjacent to Greenly Island, Coffin Bay and along southwestern coast of the Eyre Peninsula (Fig. 3b). Encirclements predominantly occurred in areas of high fishing effort to the east of Thistle Island, Wedge Island and Dangerous Reef, and southeast of Althorpe Island. There were no interactions along the north coast of Kangaroo Island. The only mortality occurred near Althorpe Island in November 2005, soon after the program commenced (Fig. 4c).

The behaviours of encircled dolphins during the second observer program were similar to that described during the initial observer program. Encircled dolphins were detected earlier after the CoP was introduced due to crewmembers being assigned to searching for them, resulting in some encircled animals being detected before the deck lights were turned on and no animals being first detected during pumping. The average response time of fishers to encirclement events during the second observer program reduced by approximately 88.0% to 16.3 ± 4.4 min, compared with the initial observer program (Fig. 5b). All encircled dolphins that were initially observed alive and swimming at the surface within the corkline were successfully released. The only mortality that occurred was first detected dead soon after hauling had commenced. This death was attributed to drowning by entanglement in sub-surface net folds directly beneath the vessel (Fig. 2).

During the second observer program, fishing operations were delayed or relocated every time a dolphin was observed near the target school. No dolphin encirclements occurred when this avoidance guideline was followed (Table 2). Nonetheless, some dolphins were still encircled, because they were not detected prior to commencing fishing operations, meaning that delay and relocation strategies were not carried out. On these occasions, release procedures were used much more often than during the initial program, although the levels of success were similar in both programs (Table 2).

3.3.2. Logbook data: during second observer program

Logbook data collected during the second observer program indicated that 98 dolphins were encircled and five were killed from 753 net-sets across the fishery (Table 1). The encirclement and mortality rates were 0.1302 and of 0.0066 dolphins per net-set, respectively. Agreement between industry and observer data increased after the introduction of the CoP, with the encirclement and mortality rates recorded in logbooks increasing to 57.9% and 58.9%, respectively, of those recorded during the second observer program.

Encirclements occurred mainly in areas of high fishing effort, northeast of Thistle and Wedge Islands, east of Dangerous Reef and southeast of Althorpe Island and occurred in each month for the duration of the study period, with most occurring between February and March 2006 (Fig. 4d). Mortalities occurred northwest and west of Thistle Island and near Althorpe Island and were also temporally spread throughout the study period.

3.4. Power of future observer programs to detect changes in interaction rates

At the standard levels of power ($\varphi = 80\%$) and significance ($\alpha = 0.05$), it would not be possible to detect declines in the
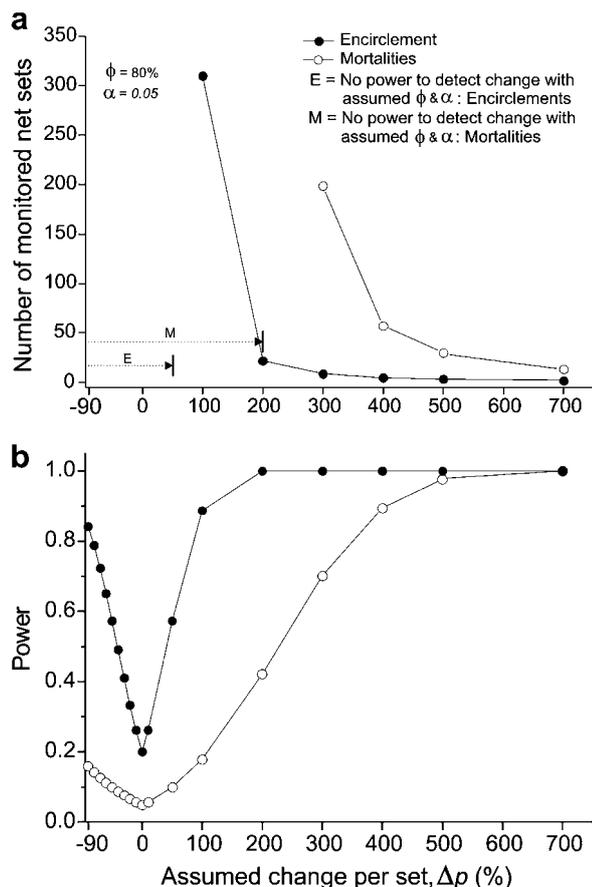
Fig. 7 – Results of analysis for the number of net-sets required to detect a prescribed level of change in encirclements and mortalities (a), plus the corresponding level significance and power (b).

encirclement or mortality rates beyond those recorded in the second observer program, due to the low levels of interactions recorded following the introduction of the CoP (Fig. 7). Conversely, a tripling (200% increase) in the encirclement rate could be detected from as few as 21 observed net-sets, but 310 net-sets would be needed to detect a doubling (100% increase) in the encirclement rate. Similarly, a fivefold (400%) increase in the mortality rate could be detected if 57 net-sets were observed and a quadrupling (300% increase) could be detected if 198 net-sets were observed.

4. Discussion

4.1. The CoP as the preferred dolphin by-catch mitigation tool

Logbook and observer data suggest operational interactions with dolphins occur across the geographic range of the SASF, with spatial patterns of encirclement strongly associated with the level of fishing effort. Although there were areas where operational interactions did not occur, the majority occurred in fishing hotspots, suggesting dolphins were attracted either by the aggregation of large schools of sardines, or by the activity of the fishing vessels that converged upon them. In addi-

tion, historical and observer logbook records from the first observer program suggest there was a marked intra-annual correlation in the number of operational interactions between the sardine fishery and dolphins, with most encirclements occurring when fishing effort was greatest. Once again, this suggests the dolphins are attracted either directly by the fish aggregations, or the fishing effort by proxy.

The fact this pattern did not exist during the second observer program is likely the result of increased efforts by fishers to prevent encirclements and mortalities, rather than a departure from this behaviour by the dolphins. Historical data indicate these results are unlikely to be confounded by the movement of dolphins in and out of the fishing grounds, because encirclements occurred the year round. This suggests either the possibility of a resident population (although its size and range remain unknown), or year round visitation by a larger and more transient population. As such, the incidence of encirclements of dolphins by the SASF follow seasonal fluctuations in fishing effort, rather than intra-annual variations in the numbers of dolphins in the fishing grounds. Therefore, spatial and temporal closures would not be suitable for mitigating operational interactions of common dolphins with this fishery, thus justifying the introduction of a CoP focused on modifying fisher behaviour and fishing gear.

4.2. Success of the CoP at mitigating dolphin by-catch

The high rates of operational interactions with short-beaked common dolphins recorded during the initial observer program were of the same magnitude as those reported in the developmental pilchard fishery in Queensland, although mortality rates in this study were almost three times as high (Hale et al., 1999; Staunton-Smith and Ward, 2000). The CoP that was subsequently introduced to the fishery was similar to that proposed for the Queensland fishery and resulted in large reductions in the observed rates of encirclements (87.3%) and mortalities (97.1%). By-catch estimates for the entire fleet during each of the two seven month observer programs suggest the number of encirclements declined from 1728 to 169 and the number of mortalities declined from 377 to 8, after the introduction of the CoP. These results demonstrate that changes in fisher behaviour and fishing gear modification can mitigate the impacts of commercial fisheries on marine mammals. Similar changes to fisher behaviour and fishing gear resulted in comparable reductions in dolphin by-catch in the eastern tropical Pacific tuna purse-seine fleet (Gosliner, 1999).

A marked cultural change occurred in the fishery during this study, with fishers becoming more aware of their need to mitigate the impacts of their activities on dolphins. A similar evolution was reported as the principal driving force behind the reduction in dolphin by-catches by the US tuna fleet in the ETP (Gosliner, 1999). The improvements in SASF operations are due in part to the philosophy of inclusion of all stakeholders in the development of the CoP, plus the adoption of realistic changes to fishing practices that could be thoroughly and rapidly implemented. During the second observer program in particular, it was mandatory under the CoP for at least one member of the crew to actively search for dolphins prior to deploying the net and for fishing opera-

tions to be delayed or relocated if a dolphin was observed near the target school. These guidelines are likely to have been responsible for the significant reduction in encirclement rates subsequently recorded.

It also became mandatory under the guidelines of the CoP for fishers to continue searching for encircled dolphins during the entire fishing event and to implement release procedures immediately upon detecting dolphins inside the net. As a result, encircled dolphins were more likely to be detected earlier and this was reflected in the marked reduction in response times by 76.9% to about 16 min. This guideline helped to ensure that encircled dolphins were released before they began to display behaviours commonly associated with mortality events.

Stress behaviours typically occurred immediately before a mortality event, after a considerable amount of time had elapsed. Although not quantified, the eleven mortalities that occurred under these circumstances also took place at a time when the circumference of the net had diminished considerably, suggesting the elapsed time and the area within the pursed net were confounded, making it impossible to distinguish their individual effect. Nonetheless, the CoP could be modified to encourage fishers to release dolphins as soon as they are detected, but no later than when one of these behaviours is observed. This would abolish the need for data relating to the response time of fishers and the space available within the net. The association of stress behaviours with mortality events was first described in the ETP tuna purse-seine fishery (Norris et al., 1978; Coe and Stuntz 1980; Gosliner, 1999). The suitability of using behavioural indicators of stress was a key element of the proposed response to the encirclement of dolphins in the southern Queensland pilchard fishery (Staunton-Smith and Ward, 2000). A detailed investigation of the behaviour of encircled dolphins would assist in further refining the CoP and mitigating dolphin mortalities in this and similar fisheries.

An important part of the CoP was that fishers were required to abort the net-set if all other attempts to release encircled dolphins were unsuccessful. During the initial observer program, some fishers were reluctant to abort fishing operations to release encircled dolphins, which lead to protracted response times and subsequent mortalities. However, after the introduction of the CoP, fishers aborted the net-set if other attempts to release encircled dolphins were unsuccessful and this change was associated with the marked reduction in dolphin mortality rates. It is also notable that fishers became better at interpreting dolphin behaviour after the introduction of the CoP and that some fishers aborted net-sets as soon as rafting behaviour was observed, or sooner.

The gear modifications trialled during the CoP were surprisingly unsuccessful when compared with other alternatives. This result was surprising given the apparent success of analogous apparatus in the ETP (Gosliner, 1999). One explanation for this difference between the two fisheries may be subtle differences in the installation and use of these devices. Some observers in the sardine fishery commented that the weight of the sinking net tended to draw the corkline together and close the dolphin gate, thus preventing the escape of dolphins. These gear modifications will need to be refined if they are to become an effective tool for releasing encircled dolphins in the SASF.

4.3. Improvement of fishery logbook reporting

Several previous studies have suggested that fishery logbook data are unsuitable for measuring the number or rate of operational interactions with marine mammals (Bache, 2003; Romanov, 2002; Walsh et al., 2002; Baum et al., 2003; Dans et al., 2003). A similar conclusion could be drawn in this study from the comparison of logbook and observer data for the fishery both prior to and after the introduction of the CoP. Nonetheless, there was an increase in the level of agreement in encirclement and mortality rates sourced from logbooks during the second observer program when compared with observer data, rising from 3.6% to 57.9% and from 1.9% to 58.9%, respectively. However, the current level of reporting of dolphin by-catch by the SASF still requires improvement, due to the large proportion that remained unreported.

In addition to ongoing underreporting, fishers may have modified their behaviour in the presence of observers to reduce the probability of operational interactions with dolphins. The 'observer effect' was reported in the ETP tuna purse-seine fishery, where a significantly higher number of dolphins were killed on vessels carrying an observer monitoring the compliance of dolphin release procedures than in the presence of observer specifically monitoring the number of dolphins killed (Wahlen and Smith, 1985). While it would be impossible to quantify this categorically (ie. presence and absence of observers), this behaviour among fishers is likely to result in the observer data providing an underestimate of the actual numbers and rates of dolphin by-catch. This is not an uncommon problem when monitoring the ecological effects of fisheries, with recent analysis of fishery logbook data in a New Zealand fishery indicating it only reported about half of its by-catch when compared with observer data (Burns and Kerr, 2008).

4.4. Power to detect change

The low rates of encirclement and mortality that were achieved after the introduction of the CoP have implications for future monitoring. Power analyses showed that an observer program of the scale conducted in this study (i.e. 100–200 monitored net-sets per year) would not have the capacity to detect further reductions in interaction rates. This presents a problem for measuring future proposed improvements to the CoP, but also indicates that observed interaction rates were at a low level during the second observer program. A similar situation occurred in the eastern tropical Pacific tuna fishery, where the large reductions in dolphin mortality made it difficult to assess the effectiveness of further improvements in fisher behaviour and fishing gear (Gosliner, 1999).

The ability to detect increases in interaction rates is also related to the level of observer coverage. A total of 89 net-sets were monitored during the second observer program, although the power analyses indicate that approximately 310 observed net-sets would be needed to detect a 100% increase (doubling) in the encirclement rate, while 198 observed net-sets would be required to detect a 300% (fourfold) increase in the mortality rate. Therefore, under the 11.8% observer coverage achieved during the second observer program, only large increases in interaction rates could be detected,

by which time major departures from the CoP are likely to have occurred.

4.5. Potential impacts on the short-beaked common dolphin population in SA

In general, very little is known about the potential impacts of fishery induced by-catch mortalities on common dolphin populations. Prior to this study, the extent and nature of their operational interactions with commercial fisheries has only been studied in one other similar fishery in Australian waters, thus the overall impact that the SASF and other fisheries may have had on their health remains unclear. In the absence of reliable common dolphin population estimates it is impossible to establish a quantitative link between the losses of common dolphins during operational interactions with fisheries and the impact it has on their health.

In spite of these uncertainties, some life history parameters provide insights into the potential impacts of by-catch mortality, especially if the population is already small. Females typically become sexually mature at between 7.9 and 9.5 years of age and live for up to 25 years (Danil and Chivers, 2007; Westgate and Read, 2007). Gestation lasts for between 11 and 12 months, a calf is produced every 2.1 years and they exhibit a fecundity rate of between 25% and 33%, resulting in the production of 7–8 calves in their lifetime (Danil and Chivers, 2007; Westgate and Read, 2007). These figures suggest the reproductive capacity of common dolphins is very low. However, they are a best estimate of production, because they do not account for calves that do not reach sexual maturity due to disease and predation, nor those who die when they are killed or orphaned by fishing activities (Archer et al., 2001, 2004; Noren and Edwards, 2007). Therefore, the removal of even low numbers of animals from a population may have large and deleterious impacts.

In Australia, the little amount of research that has been conducted has focused on diet and population genetics. Common dolphin carcasses collected in South Australia revealed they ate squid (two species) and at least seven families of teleost fish (at least 16 species; Kemper and Gibbs, 2001). These findings suggesting they are opportunistic foragers that commonly feed on small pelagic schooling fishes, including sardines, which explains their frequent encounters with SASF fishing activity. Although a highly mobile and apparently ubiquitous species, a recent population genetics study demonstrated that animals from South Australia were genetically distinct from animals in Tasmanian waters, some 1400 km to the southeast (Bilgmann, 2007). This suggests a genetic boundary between the two populations and the subsequent limitations to immigration from adjacent populations. In contrast, very little genetic differentiation was found to exist between short-beaked common dolphin populations in the eastern tropical Pacific, northwest, northeast and southwest Atlantic, and the southwest Indian Oceans, which are separated by 4000–17,000 km (Natoli et al., 2006; Amaral et al., 2007).

In summary, there is little known about the status and size of the common dolphin population in South Australian waters. Notwithstanding, their limited reproductive capacity and the apparent restrictions to immigration in the South Australian population suggest the population is vulnerable to adverse impacts under relatively low levels of fishery induced by-catch mortality.

4.6. Recommendations

Given the limited understanding of the impacts of the by-catch mortality sustained by the South Australian short-beaked common dolphin population in recent times, there is a need to obtain information on the abundance and boundaries of the population. Tools that could assist in obtaining such information include aerial surveys and population genetic studies, respectively. This information would improve our understanding of the effect operational interactions have on their populations.

Further refinement of the CoP should include a requirement for fishers to monitor the behaviour of encircled dolphins, not just their presence or absence. As such, fishers would need to become familiar with behaviours associated with stress and imminent mortality. These behaviours could then be used to help categorically identify when a net-set should be aborted, in preference to the more complicated and time consuming approach which involves removing encircled animals while saving the catch. Even though the latter is the preferred option for the fisher who is following an economic imperative, this study has shown that encircled dolphins are at greater risk of dying when stress behaviours are observed. In addition, the current gear modifications should be reviewed in light of their poor performance and consideration given to alternative strategies, including opening the front of the net, which has already been employed with a high degree of success by some fishers.

The apparent association between swell height and mortality events warrants further investigation also, especially as eight of the animals that died probably becoming caught in net folds under the vessel and died before reaching the surface. The CoP was not applicable in these cases, because these animals were dead when first observed. These incidents only occurred when the swell height was above 2.5 m, indicating the need to include additional guidelines in the CoP that address this potential cause of dolphin mortality. Finally, even though the discrepancy between the rates of operational interactions recorded by fishers and by observers diminished in the second observer program, there is a need to address continued underreporting by fishers. Fishers may be encouraged to improve their reporting with the introduction of tougher penalties, or increased observer coverage, both of which cold result in a financial durden to individual fishers and the SASF in general. Until this is achieved, partial or full self management of marine mammal by-catch by the SASF should not be considered.

5. Conclusions

Our results indicated the CoP is the most appropriate tool for managing operational interactions of perse-seiners with short-beaked common dolphins in the SASF, whereas spatial and temporal management options would not be as effective. The CoP significantly reduced the fishery's operational interactions with dolphins, with the avoidance and release strategies

likely responsible for reducing the number of encirclements and mortalities. In contrast, the gear modifications outlined in the CoP appeared to have little effect. In general though, the CoP as it currently stands has met its four underpinning principals, suggesting it should remain as the tool for mitigating dolphin by-catch. Nonetheless, when considering the shortfalls to the CoP that were highlighted during this study, it would benefit from being refined to include clear references to: (i) when and how fishers should search for dolphins; (ii) the kind of behaviours that indicate stress in encircled animals; (iii) the most effective methods for avoiding and releasing them; and (iv) weather conditions, such as swell height. Such improvements to the CoP for dolphin by-catch mitigation, in addition to ongoing observer coverage and improved logbook reporting, could result in the SASF becoming a 'best practice' example of this important issue.

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