Measurement, Management and Mitigation of Operational Interactions Between Common Dolphins (*Delphinus delphis*) and the South Australian Sardine Fishery

D.J. Hamer, T.M. Ward, S.D. Goldsworthy,
R. McGarvey, and P.J. Rogers.

January 2007
SARDI Aquatic Sciences

Publication No. F2006/000212
SARDI Report Series No. 174

Report to PIRSA Fisheries

Measurement, Management and Mitigation of Operational Interactions Between Common Dolphins and the South Australian Sardine Fishery

South Australian Research and Development Institute (SARDI)
Aquatic Sciences Division
2 Hamra Avenue
West Beach
South Australia 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
Email: http://www.sardi.sa.gov.au

SARDI Aquatic Sciences Publication No. F2006/000212

SARDI Research Report Series No. 174

Printed in Adelaide, January 2007

Authors: D.J. Hamer, T.M. Ward, S.D. Goldsworthy, R. McGarvey, and P.J. Rogers

Reviewers: Dr Tony Fowler and Dr Stephen Mayfield

Approved by: Dr John Carragher

Signed:

Date: 25 October 2006

Distribution: Primary Industries Resources South Australia (PIRSA) Fisheries + SARDI Aquatic Sciences + South Australian Sardine Fishery (SASF).

Circulation: Public Domain

EXECUTIVE SUMMARY

1. This study was initiated in response to recommendations arising from an ecological assessment of the South Australian Sardine Fishery (SASF), undertaken pursuant to the Commonwealth *Environment Protection Biodiversity Conservation Act 1999*.
2. The ecological assessment report provided the SASF with a 5-year exemption from further assessment and recommended that:
   - mechanisms be established to allow fishers to record interactions with Threatened, Endangered and Protected Species (TEPS) at a species level and at an appropriate level of accuracy; and
   - if information became available to indicate that the SASF was having significant interactions with any TEPS, that measures to mitigate those interactions should be implemented within 12 months.
3. Logbook data collected between 1999 and 2004 suggested that the rates of dolphin interactions within the SASF were low and did not identify the species involved.
4. An observer program conducted between November 2004 and June 2005 revealed high rates of encirclement (1.78 per net-set) and mortality (0.39 dolphins per net-set) of common dolphins (*Delphinus delphis*).
5. The SASF was subsequently closed during August and September 2005 to prevent further interactions with common dolphins.
6. A TEPS Working Group, that had been established prior to the closure, finalised a Code of Practice (CoP) to mitigate operational interactions with TEPS, especially dolphins.
7. The key guidelines of the CoP were:
   - that fishing operations would be delayed or relocated if when dolphins were observed near the vessel;
   - that crews would take swift action to release encircled dolphins; and
   - that a net-set would be aborted if other methods for releasing dolphins were not successful.
8. The observer program conducted after the implementation of the CoP showed that rates of dolphin encirclement and mortality were reduced to 0.22 and 0.01 dolphins per net-set respectively, suggesting that the CoP had reduced encirclement rates by 87.34% and mortality rates by 97.11%.
9. The success of the CoP in reducing the operational interactions between the SASF and common dolphins is attributable to both the practicality and effectiveness of the guidelines and the industry's strong commitment to resolving the problem.

ACKNOWLEDGEMENTS

We sincerely thank the following organisations and individuals for there assistance with this study: licence holders, skippers and crews of the South Australian Sardine Fishery (SASF) who provided access to vessels and volunteered information; Angelo Tsolos and Emily Thompson (SARDI Statistics Unit) for providing access to historical SASF data; Steve Shanks (PIRSA Fisheries, former SASF Manager) for providing assistance and advice in relation to implementing the CoP; Justine Kenyon-Benson (PIRSA Compliance) for assistance with determining vessel movements and fishing effort; Keith Rowling, Alex Ivey, Matt Hoare and Shane Roberts (SARDI Aquatic Sciences) for collecting observer data during the second observer program; Stephen Mayfield, Tony Fowler (SARDI Aquatic Sciences) and Peter Shaughnessy (South Australian Museum) for reviewing drafts.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Dolphin interactions with purse-seine fisheries

Many commercial fisheries throughout the world have operational interactions with dolphins, although these have rarely been quantified or described (Northridge, 1984; Northridge, 1991; Alverson et al., 1994; Silva and Best, 1996; Kemper and Gibbs, 1997; Stone et al., 1997; Gosliner, 1999; Hale et al., 1999; Northridge and Hofman, 1999; Trippell et al., 1999; Kemper and Gibbs, 2000; Staunton-Smith and Ward, 2000; Bearzi, 2002; Barlow and Cameron, 2003). The few studies that have been conducted suggest that dolphins mainly have operational interactions with trawl, gill-net and purse-seine fisheries (Northridge, 1984; Northridge, 1991; Alverson et al., 1994).

Encirclements and mortalities of dolphins have been documented for several purse-seine fisheries (e.g. Di Natali and di Sciara, 1994; Gosliner, 1999; Hale et al., 1999; Staunton-Smith and Ward, 2000). The most thoroughly documented example of dolphin interactions with a purse-seine fishery is the eastern tropical Pacific tuna fishery, where millions of dolphins were incidentally killed between the 1960s and 1980s, peaking at 133,174 mortalities in 1986 (Wade, 1995; Gosliner, 1999; Archer et al., 2001; Archer et al., 2004). The high encirclement and mortality rates were due to the association between dolphins and tuna schools; fishers often used dolphin pods as an indicator of the presence of tuna and targeted them accordingly. An observer program was implemented in the early 1990s and the practice of deliberately setting the net around dolphin pods was prohibited. A 'back-down procedure' was also introduced to facilitate the escape of encircled dolphins, whereby the vessel was reversed to create an escape route between the top of the net and the surface of the water. These two changes in the fishing practice were responsible for the subsequent reduction in dolphin mortalities to about 2,600 in 1996, equating to a ~98% reduction (Gosliner, 1999). The positive result demonstrated that the establishment of avoidance and release practices could significantly reduce the impacts of purse seine fisheries on dolphin populations, while allowing fishing activities to continue relatively unhindered.

In contrast, the closure of a developmental purse-seine fishery in Queensland demonstrates a 'worst case' scenario, with regard to interactions between dolphins and a commercial fishery. An independent observer program conducted between 1997 and 1999 revealed that 77 dolphins were encircled and 9 were killed during a total of 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). A working group was established to address the issue and recommended that changes to fishing practices, including improvements to avoidance and release procedures, should be introduced (Hale et al., 1999; Staunton-Smith and Ward, 2000). In particular, the working group suggested that encircled dolphins could be released by lowering a portion of the corkline to create an opening (Figure 1), or by aborting the fishing operation entirely. However, a prohibition on purse-seine fishing was declared in Queensland before the effectiveness of these measures could be tested (Staunton-Smith and Ward, 2000).

1.2 South Australian Sardine Fishery (SASF)

The South Australian Sardine Fishery (SASF) was established in 1991 to secure a domestic supply of feed for wild-caught southern bluefin tuna (*Thunnus maccoyii*), ranched in sea cages off Port Lincoln. Most of the sardine (*Sardinops sagax*) catch is taken from southern Spencer Gulf, although some fishing occurs off the Coffin Bay Peninsula and near Kangaroo Island (Figure 2). Catches in the fishery increased from 3,241 t in 1994 to 42,475 t in 2005. For a detailed description of the SASF see Rogers and Ward (2006).

The SASF is a typical modern purse-seine fishery. Most fishing activity occurs at night, or during twilight, vessels are typically between 18 and 38 metres in length, nets are approximately 500 to 700 m in length and are between 40 to 70 m deep, with a mesh size ranging from 14 to 22 mm. Sonar and depth sounders are used to determine the location, depth and size of fish schools. Once the target school is located, it is encircled by a curtain of purse-seine net, before the bottom is 'pursed' to prevent the escape of the catch (Figure 1). The bulk of the net is then hauled aboard, until the catch is brought alongside the vessel and pumped into onboard holding tanks with a hydraulic suction pump.

1.3 Statutory protection of marine mammals in South Australia

Marine mammals in waters off South Australia are protected under State and Commonwealth legislation (Bache, 2003). The SA *Fisheries Act 1982* and associated regulations, which are administered by Primary Industries and Resources South Australia (PIRSA), require the *"the protection of marine mammals"* through the "*conservation, enhancement and management of fisheries"*. In particular, Section 20 specifies *"through proper conservation, preservation and fisheries management measures, that the living resources of the waters to which this Act applies are not endangered or overexploited"*. The protection of marine mammals in SA is also specifically addressed under Section 51 and 51A of the SA *National Parks and Wildlife Act 1972*, and Sections 29 to 31 of the SA *Wilderness Protection Act 1992*, both of which prohibit the take or killing of dolphins. The Commonwealth *Environment*

Protection Biodiversity Conservation Act 1999 (EPBC Act), which is administered by the Commonwealth Department of the Environment and Heritage (Commonwealth DEH), prohibits the taking of any listed marine species, including dolphins, in all State and Commonwealth waters. In addition, the EPBC Act requires that all commercial fisheries undergo strategic 'ecological assessments' under Sections 146 to 148 to ensure the mitigation of any adverse effects that fishing activities may have on the wider marine ecosystem.

In 2004, an ecological assessment of the SASF was undertaken pursuant to the EPBC Act (Shanks, 2004). The SASF was given a 5-year exemption from further assessment by the Commonwealth DEH and was required to address ten recommendations for improvement to the management arrangements for the fishery. Two of those recommendations (4 and 5) specifically referred to threatened, endangered and protected species (TEPS):

- *That PIRSA provide a mechanism, which allows fishers to record interactions with protected/listed species at a species level. PIRSA to implement an education program to ensure that industry has the capacity to make these reports at an appropriate level of accuracy.*
- *Should new information determine that the fishery is having significant interactions with any endangered, threatened or protected species, PIRSA will develop appropriate measures to mitigate those interactions. Measures should be implemented within 12 months of the information becoming available.*

1.4 Development of a Code of Practice (CoP) for dolphin by-catch mitigation

A study to address the Commonwealth DEH recommendations regarding TEPS was implemented in November 2004. Historical logbook data were analysed and a program was initiated to assess the effectiveness of logbooks for recording interactions with TEPS. The initial program showed that rates of encirclement and mortality of dolphins recorded by observers were significantly higher than those recorded in logbooks. The SASF was closed during August and September 2005 to prevent further interactions with dolphins. A TEPS Working Group was established during the initial observer program that included industry representatives, licence holders, fishers policy makers and researchers. A Code of Practice (CoP) for mitigating interactions with TEPS was developed by the Working Group and finalised during the closure (SAPFA, 2005). The CoP was based on the following four principals:

1. it must significantly reduce interactions with TEPS;
2. ongoing development of the CoP must be based on information provided by licence holders, skippers, fisheries managers and researchers;
3. it must be sufficiently flexible to be safely and practically applied on all vessels under all conditions; and
4. the cost of implementation must be low.

In summary, the CoP aimed to mitigate operational interactions between the SASF and dolphins by ensuring that fishing operations adhered to the following guidelines:

1. *Early detection.* This was achieved by ensuring that at least one of the crew on each vessel would be made responsible for determining the presence/absence of dolphins before and during all fishing operations, and for reporting any sightings immediately to the skipper;
2. *Avoidance.* This was achieved by ensuring that the commencement of fishing operations would be delayed or relocated if dolphins were detected;
3. *Swift action.* This was achieved by ensuring that release procedures would be initiated without delay when encircled dolphins were detected;
4. *Fitting a 'dolphin gate' to the net.* This was achieved by ensuring that each net was fitted with a section of corkline that could be removed to allow a portion of the net to sink, thus creating an exit for encircled dolphins (Figure 1);
5. *Carrying purpose-built weights.* This was achieved by ensuring that all vessels carried purpose built lead weights that could be attached to the corkline to sink a section of the net, thus creating an exit for encircled dolphins; and
6. *Being prepared to abort fishing operations.* This was achieved by ensuring that the net-set would be aborted if all other attempts to release encircled dolphins failed.

The SASF was reopened in September 2005, with all subsequent fishing operations subject to the newly developed CoP. Before each vessel could recommence fishing, TEPS by-catch mitigation devices had to be installed and all crews were briefed about their responsibilities pursuant to the CoP. A trained observer then accompanied each vessel to sea for the first five trips after fishing recommenced, to ensure that the crew understood and complied with the conditions set out by the CoP. A second observer program was then conducted to assess the effectiveness of the CoP in mitigating operational interactions and mortalities with dolphins.

This study presents observer and logbook data from the SASF and compares the rate and nature of operational interactions with dolphins before and after the introduction of the CoP to assess its effectiveness in mitigating interactions with dolphins. Findings are used to identify options for future measurement, mitigation and management of interactions with dolphins.

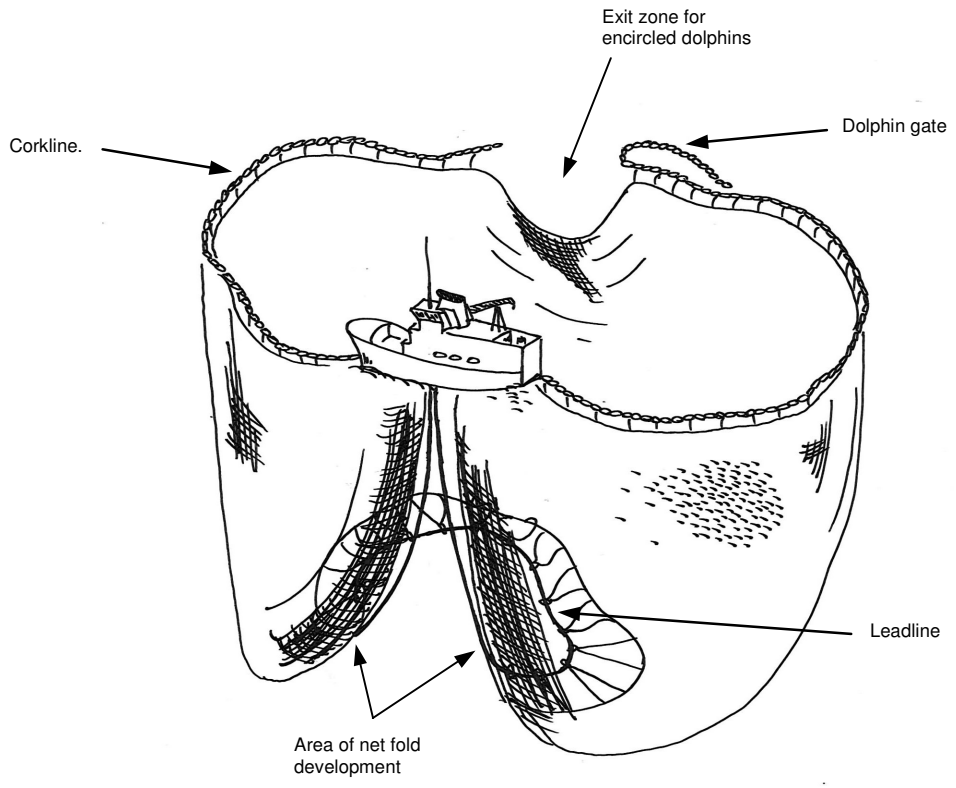

Figure 1. Schematic drawing of a purse-seine net, depicting the dolphin gate mentioned in the Code of Practice.

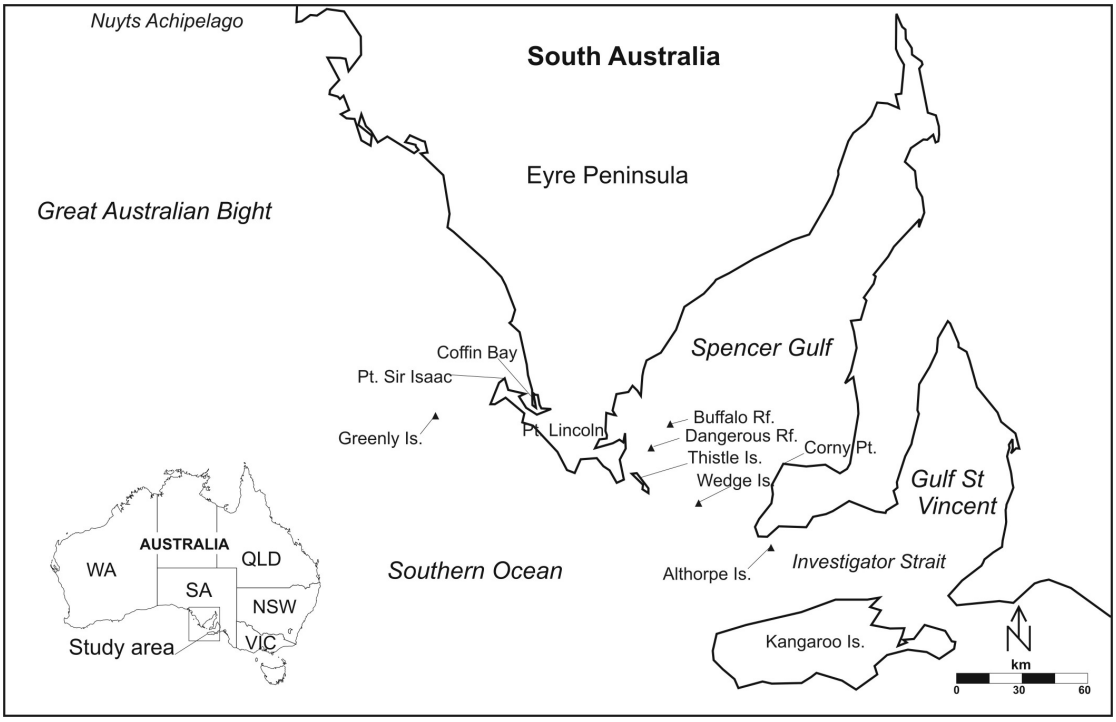

Figure 2. Location of the study and important sites.

2. METHODS

2.1 Historical data

Historical data relating to operational interactions with TEPS were obtained from daily logbooks lodged by licence holders with the South Australian Research and Development Institute (SARDI). Since April 1999, logbooks have included provisions for recording information on dolphin encirclements and mortalities. The levels of fishing effort, number and rate of dolphin encirclements and mortalities, plus spatial and temporal patterns in fishing effort were calculated for the period between April 1999 and May 2004.

2.2 Assessing the effect of the CoP

Observer programs were conducted before and after the introduction of the CoP, during November 2004 to June 2005 and November 2005 to June 2006, respectively. Logbook data for these periods were collated and summarised separately from the historical data.

During each observer program, SASF fishing vessels carried independent observers upon request. Observations were made from a high, unobstructed vantage point such as the wheelhouse, wheelhouse roof or bow, depending on the vessel and prevailing weather conditions and were concentrated within the circumference of the corkline of the net. As all fishing occurred at night, binoculars (Gerber® DLX/R 10x50) were used during moonlit periods and a night vision monocular (ITT® N160) was used during periods of reduced visibility.

The date, location and incidence of encirclements and mortalities were recorded for each observed net-set, during both observer programs. Other details of the nature of the interactions were recorded, including: the stage of the operation during which encircled dolphins were first detected; the time taken for crews to respond to the detection of encirclements; the nature and success of the procedures used to release dolphins; and swell height. Detailed notes were also made on the behaviour of encircled dolphins at different stages of the fishing operation.

2.3 Data analysis

The spatial and temporal (inter-annual and intra-annual) distribution of fishing effort was 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 fishing effort. For the 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, using a 1-tailed *t*-test (as only declines in encirclement and mortality rates were relevant). The observer and logbook data approximated a Poisson distribution. However, the pooled sample size was sufficiently large to be robust for non-normal data, meeting the condition that the number of observations (49 + 89) should be greater than 40 (Moore and McCabe, 2003).

The variance of data collected during the initial observer program (pre-CoP: *X*) was larger than during the second observer program (post-CoP: *Y*). The *t*-test was modified to account for these differences (Rice, 1988). The *t*-statistic for the observed difference in the mean rates of encirclements and mortalities was:

$$t = \frac{(\bar{Y} - \bar{X}) - (\mu_Y - \mu_X)}{s_{\bar{Y}-\bar{X}}}$$

The pooled variance (Rice, 1988) was calculated by:

$$s_{\bar{Y}-\bar{X}} = \sqrt{\frac{s_Y^{\,2}}{n_Y} + \frac{s_X^{\,2}}{n_X}}$$

where: n_X = sample size pre-CoP;
n_Y = sample size post-CoP;
s_X = sample variance pre-CoP; and
s_Y = sample variance post-CoP.

The *t*-test used the approximate formula for degrees of freedom modified to account for unequal variances (Rice, 1988; Moore and McCabe, 2003):

$$DF = \frac{\left[\frac{s_Y^{\,2}}{n_Y} + \frac{s_X^{\,2}}{n_X}\right]^2}{\frac{\left(\frac{s_Y^{\,2}}{n_Y}\right)^2}{n_Y - 1} + \frac{\left(\frac{s_X^{\,2}}{n_X}\right)^2}{n_X - 1}}$$

2.4 Required level of observer coverage

Power analysis was used to estimate the number of observations required to detect future changes in the encirclement and mortality rates, relative to the rates obtained in the second observer program. The power to detect rate increases or decreases depends on the significance level, sample variances, sample sizes and the magnitude of the change that occurs. In this study, standard levels of significance (α = 0.05) and power (ϕ= 80%) were used in the calculations. The required sample size was calculated for assumed levels of change, $\Delta_p = (\mu_Y - \mu_X)/\mu_X$. Power was written as a probability integral of the *t*-distribution over assumed changes in the observed rates, $(\bar{Y} - \bar{X})$ = $(\bar{Y} - \bar{X})_{crit}$, that were greater than the threshold or critical level beyond which a future t-test with the same sample variance would yield a significant difference.

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

This equation was solved numerically to calculate the future number of net-sets, n_Y , that need to be observed to achieve 80% power. The assumed proportions of actual change that were assessed in the power analysis were decreases of 10% to 90% and increases up to 700%. A 1-tailed *t*-test was applied in the power analysis because it was used to detect increases and decreases separately, relative to the current post-CoP encirclement and mortality rates.

3. RESULTS

3.1 Historical logbook data (April 1999 to May 2004)

Logbook data for the SASF from April 1999 to May 2004 suggested that the number of interactions with dolphins was low and variable between years (Figure 3a). From the 3917 net-sets conducted over the five-year period, only 69 encirclements and one mortality were recorded (Table 1). The overall encirclement and mortality rates were 0.0176 and 0.0003 dolphins per net-set respectively (Figure 4a). Only 1.5% of the encirclements that were recorded resulted in mortalities.

The number of encirclements was strongly and positively correlated with the location of fishing effort (Encirclement = 0.013.effort + 0.009; $P < 0.01$; $R^2 = 0.50$), with most occurring in areas of high fishing effort in southern Spencer Gulf (Figure 5a). No interactions were recorded along the north coast of Kangaroo Island and west of Point Sir Isaac, where the water is deeper than 60 metres. There was no relationship between the number of encirclements recorded per year and the 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 = 0.010.effort + 2.678; $P = 0.02$; $R^2 = 0.44$; Figure 3b). More encirclements were recorded between April and June than during other months and none were recorded in November. The only reported mortality occurred in April 2002.

3.2 Before the introduction of the CoP

Initial observer program

During the initial observer program, the mean level of observer coverage (% net sets monitored) was 6.5% and ranged from 12.9% in January to 0.9% in April (Figure 7a). Observers monitored fishing activity throughout most of the area historically fished within the southern Spencer Gulf (Figure 5b). Fishing did not occur near Coffin Bay and only a relatively small amount of effort was undertaken near Althorpe Island.

The only species of dolphin observed interacting with the SASF during the initial observer program was the common dolphin (*Delphinus delphis*). Dolphins were often observed bow riding and feeding on sardine schools prior to setting the net. Some dolphins were observed during pursing, but most were first detected soon after hauling commenced, when the deck lights were turned on (Figure 8). Some encircled dolphins were not detected until the bunt of the net was brought alongside the vessel and pumping had commenced.

A total of 87 encirclements and 19 mortalities were recorded from 49 net-sets over 89 nights (Table 1). The overall encirclement and mortality rates were 1.7755 and 0.3878 dolphins per net-set, respectively (Figure 4c). A total of 22% of all encircled dolphins died.

The number of encirclements recorded by observers was strongly and positively correlated with the location of fishing effort (Encirclement = 2.726.effort + 0.027; $P < 0.01$; $R^2 = 0.79$), and most encirclements occurred east of Thistle Island and northeast of Wedge Island (Figure 5b). No interactions occurred along the north coast of Kangaroo Island.

The number of interactions with dolphins varied between months (Figure 3c). 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 ($P = 0.30$; $R^2 = 0.18$).

Encircled dolphins exhibited a consistent behavioural pattern, moving as far away from the vessel as possible and swimming slowly back and forth along the corkline (Figure 1). As hauling progressed and the area inside the corkline diminished, animals tended to move toward the centre of the net. Once approximately half of the net had been hauled aboard, some animals became motionless and vertical with their head and blowhole just above the waterline. This latter behaviour was commonly associated with subsequent mortality.

Eleven of the 19 dolphins that were killed were initially observed alive. The average time taken for crews to respond and initiate a release procedure on occasions when mortalities occurred was 135.9 $\pm$ 3.7 minutes, compared with 62.5 $\pm$ 6.8 minutes when encircled dolphins were released successfully (Figure 6a).

The other 8 dead dolphins were initially observed dead and were detected within 5 minutes of the start of hauling, once the deck lights were turned on. It is likely these animals became entangled in sub-surface net folds and drowned during pursing (Figure 1). These incidents only occurred when the swell height was above 2.5 metres (Figure 9).

On no occasion during the initial observer program were fishing operations delayed or relocated in response to dolphins being observed near a target sardine school. 'No action' was the most

prevalent response to encirclements and only 16% of encircled dolphins escaped without action being taken (Table 2). A dolphin gate was opened twice and succeeded in releasing the dolphins on one occasion. The corkline was submerged using weights on 15 occasions, with a 53% success rate. The front of the net was partially opened to release dolphins 18 times, with 78% success. The physical removal of dolphins from the net was attempted on 18 occasions with 89% success. The net-set was aborted twice and was successful on each occasion.

Logbook data (during initial observer program)

Logbook data collected over the same period as the initial observer program included 63 reported dolphin encirclements and seven mortalities, from 973 net-sets (Table 1). The encirclement and mortality rates were 0.0647 and 0.0072 dolphins per net-set, respectively (Figure 4b). These figures equate to 3.6% of the encirclement rate and 18.6% of the mortality rate recorded by the observer program. Logbook data suggest that approximately 11.1% of encircled dolphins died, which is about half of the proportion calculated from observer data.

The number of encirclements recorded in logbooks was positively correlated with the spatial distribution of fishing effort (Encirclement = 0.031.effort + 0.012; $P < 0.01$; $R^2 = 0.22$). Encirclements occurred mainly in areas of high fishing effort, east of Thistle and Wedge Islands, east of Dangerous Reef and southeast of Althorpe Island (Figure 5d). Mortalities were reported from west of Corny Point, between Thistle and Wedge Islands and east of Buffalo Reef. There was a weak relationship between the number of encirclements recorded and monthly fishing effort (Encirclement = 0.035.effort + 2.624; $P = 0.04$; $R^2 = 0.11$). The greatest number of encirclements occurred in January 2005, with lower numbers recorded during the remainder of the study period (Figure 3e).

3.3 After the introduction of the CoP

Second observer program

A second observer program was conducted between November 2005 and June 2006 to assess the effect of the newly introduced CoP. During the second observer program, the mean level of observer coverage was 7.43%, and ranged from 24.36% in November to 0.98% in December (Figure 7b). Observations were concentrated in the southern Spencer Gulf region, although some fishing was monitored adjacent to Greenly Island and Coffin Bay and along the western Eyre Peninsula (Figure 5c).

The common dolphin was again the only species recorded by observers. The behaviour of encircled dolphins observed were similar to those recorded during the initial observer program. Encircled dolphins were typically observed after the deck lights were turned on to commence hauling, although some animals were observed earlier (Figure 8). No animals were first detected during pumping.

A total of 20 encirclements and one mortality were recorded from 89 monitored net-sets (Table 1). The overall encirclement and mortality rates were 0.2247 and 0.0112 dolphins per net-set respectively (Figure 4c). The encirclement and mortality rates recorded by observers before and after the introduction of the CoP were statistically significant (ANOVA: P = 0.001 and 0.002 respectively). Approximately 5.2% of animals encircled died after the CoP was introduced.

Encirclements predominantly occurred in areas of high fishing effort to the east of Thistle Island, east of Wedge Island, east of Dangerous Reef and southeast of Althorpe Island (Figure 5c). 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 (Figure 3d).

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). In addition, action was taken every time a dolphin was encircled. The release procedures were used more often during the second observer program than during the initial program, but levels of success achieved were similar in each program.

The response time during the second observer program was 16.3 $\pm$ 4.3 minutes. All encircled dolphins initially observed alive were successfully released (Figure 6b). The only mortality was first detected dead soon after hauling had commenced. This death was attributed to drowning by entanglement in sub-surface net folds.

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 SASF during this period (Table 1). The encirclement and mortality rates were 0.1301 and of 0.0066 dolphins per net-set respectively

(Figure 4b). These encirclement and mortality rates were 57.9% and 58.9% respectively of those recorded in the second observer program. Approximately 4.1% of encircled animals died.

Encirclements occurred mainly in areas of high fishing effort, northeast of Thistle and Wedge Islands, east of Dangerous Reef, southeast of Althorpe Island and north of American River on Kangaroo Island (Figure 5e). Mortalities occurred northwest and west of Thistle Island and near Althorpe Island.

Encirclements were recorded each month for the duration of the study period, with most occurring between February and March 2006 (Figure 3f).

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

At the standard levels of power and significance, it would not be possible to detect further declines in the encirclement or mortality rates recorded in the second observer program due to the low levels of interactions recorded following the introduction of the CoP (Figure 10a; Figure 10b). For encirclement rates, a doubling (100% increase) could be detected if 310 net-sets were observed and a tripling (200% increase) could be detected if 21 net-sets were observed. For mortality rates, a quadrupling (300% increase) could be detected if 198 net-sets were observed and a five-fold (400%) increase could be detected if 57 net-sets were observed.

Table 1. Summary of the number of net-sets, plus the number and rate of dolphin encirclements and mortalities in the SASF. Results derived from logbook and observer data.

		Encircled		***Mortality***	
Period	*# of records*	*Total*	*Rate*	*Total*	*Rate*
Logbook programs					
Historical (1999 – 2004)	3915	69	0.0176	1	0.0003
During initial program	973	63	0.0647	7	0.0072
During second program	753	98	0.1301	5	0.0066
Observer programs					
Initial observer program	49	87	1.7755	19	0.3878
Second observer program	89	20	0.2247	1	0.0112

Table 2. Summary of avoidance and release procedures used by fishers for dolphin by-catch mitigation, before and after the introduction of the CoP. Results derived from observer data.

	Initial program		***Second program***		***Combined***	
Mitigation method	*Success/# observations*	*Success rate (%)*	*Success /# observations*	*Success rate (%)*	*Success /# observations*	*Success rate (%)*
Avoidance						
Delay	0 / 0	–	6 / 6	100	6 / 6	100
Relocate	0 / 0	–	9 / 9	100	9 / 9	100
Release procedure						
No action	5 / 32	16	0 / 0	–	5 / 32	16
Corkline weights	8 / 15	53	2 / 4	50	10 / 19	53
Physical removal	16 / 18	89	3 / 3	100	19 / 21	90
Open net front	14 / 18	78	6 / 7	85	20 / 25	80
Open gate	1 / 2	50	3 / 7	43	4 / 9	44
Abort fishing	2 / 2	100	6 / 6	100	8 / 8	100

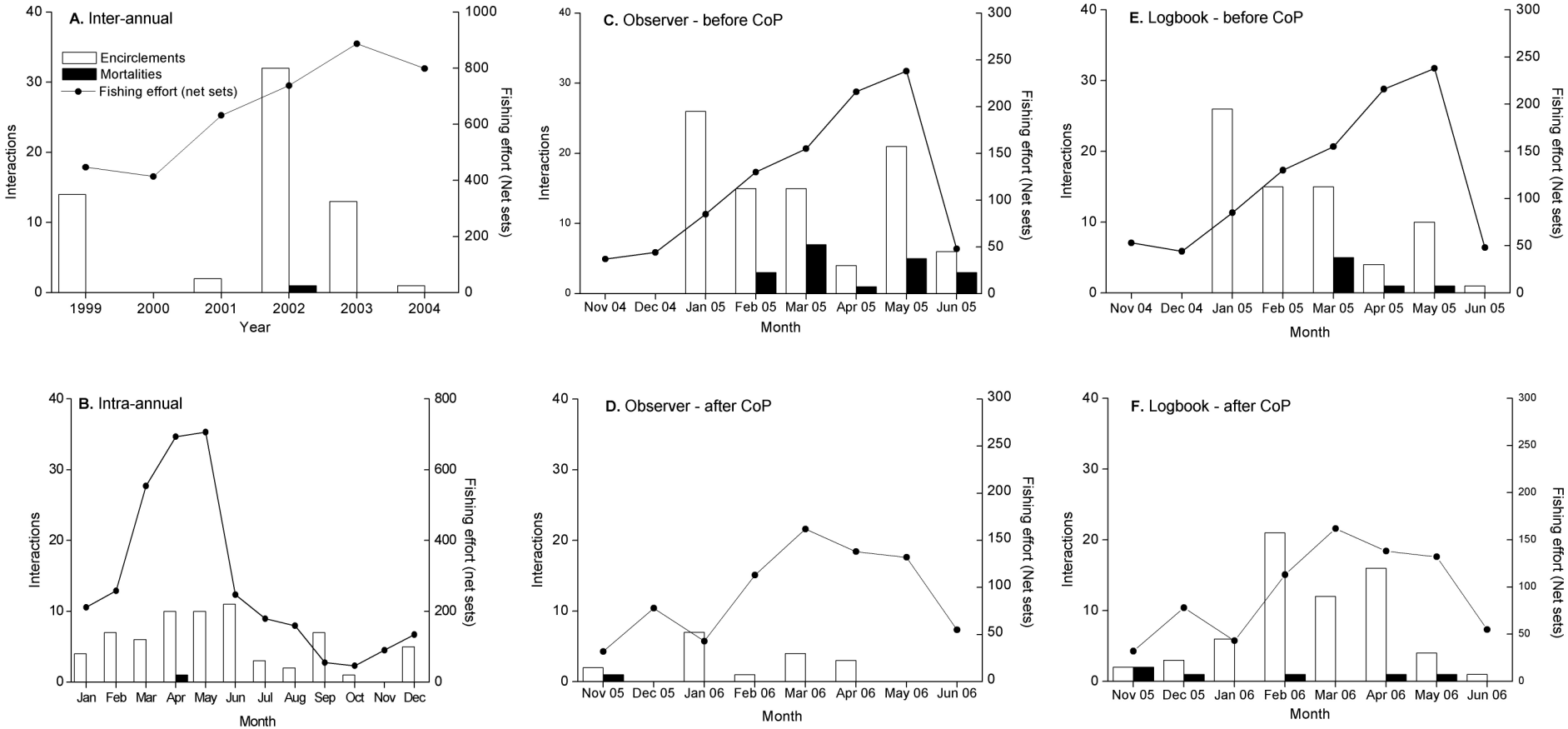

Figure 3. Inter-annual and intra-annual patterns in fishing effort and number of encirclements and mortalities. Results derived from logbook and observer data.

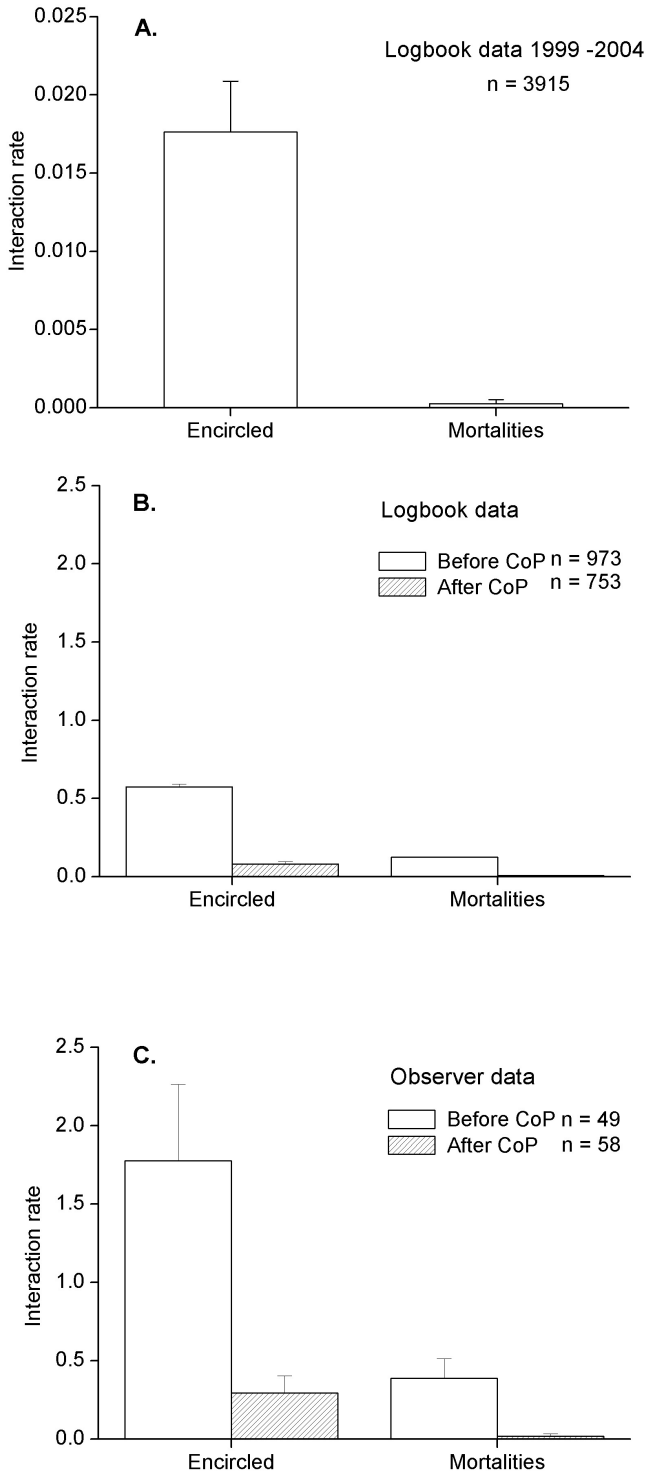

Figure 4. Dolphin encirclement and mortality rates. Results derived from logbook and observer data.

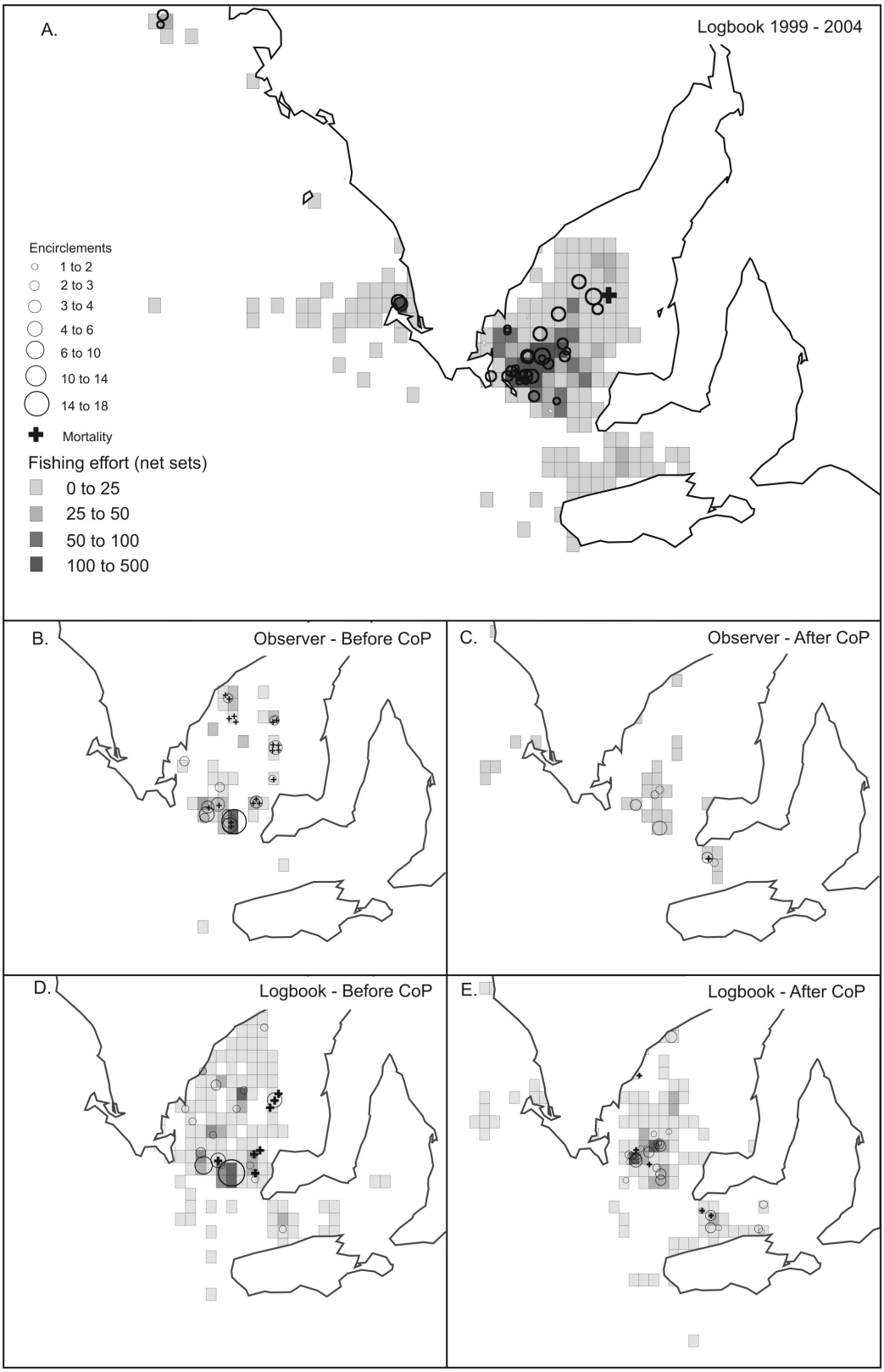

Figure 5. Spatial distribution of fishing effort and dolphin encirclements and mortalities. Results derived from logbook and observer data.

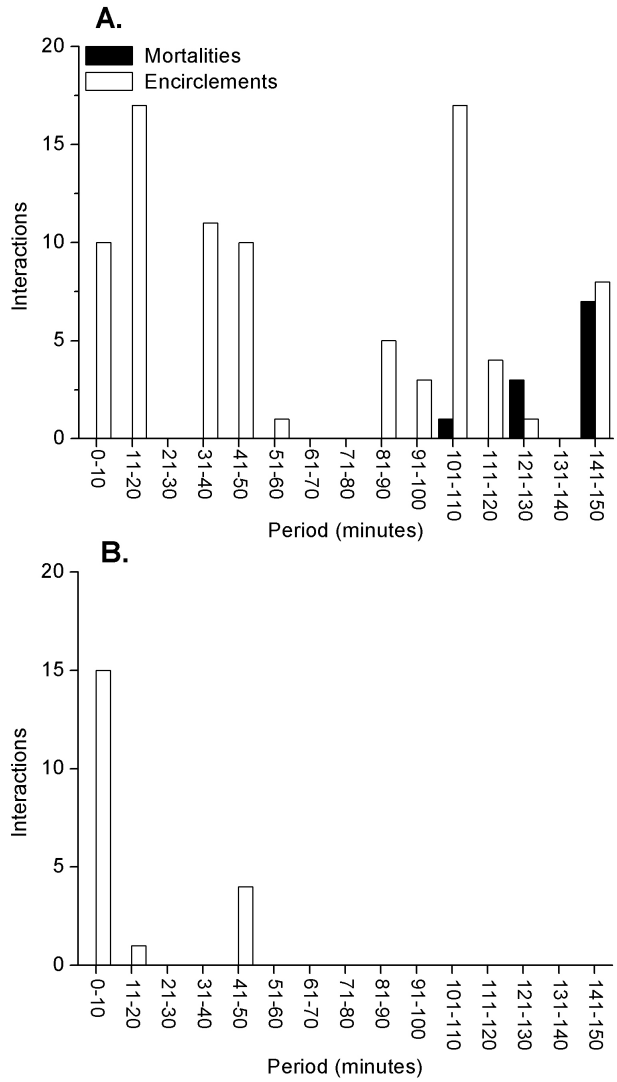

Figure 6. Crew response times after detecting an encircled dolphin, before and after the introduction of the CoP. Results derived from observer data.

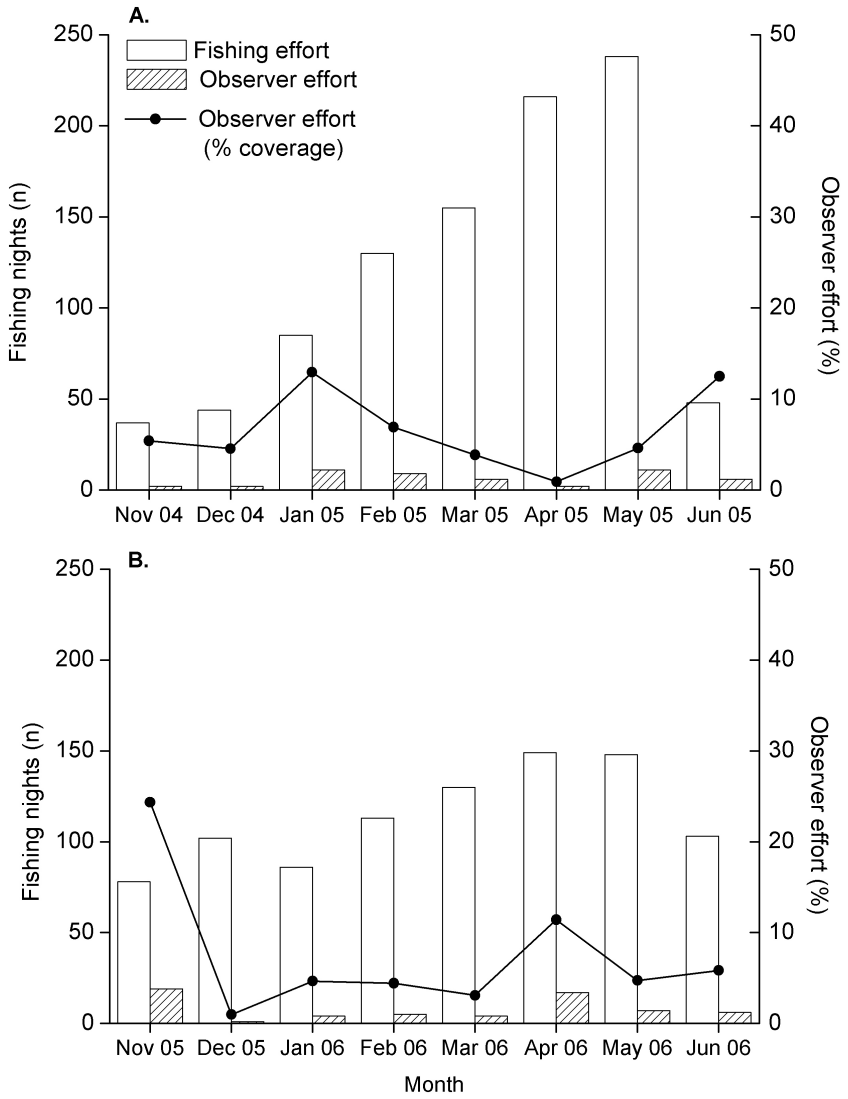

Figure 7. Fishing effort, observer effort and observer coverage (%) during the initial and second observer programs.

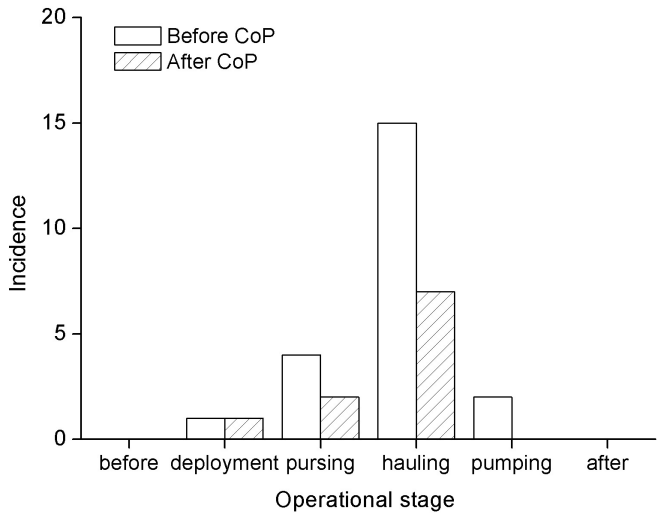

Figure 8. The stage that encircled dolphins were first detected, before and after the introduction of the CoP. Results derived from logbook and observer data.

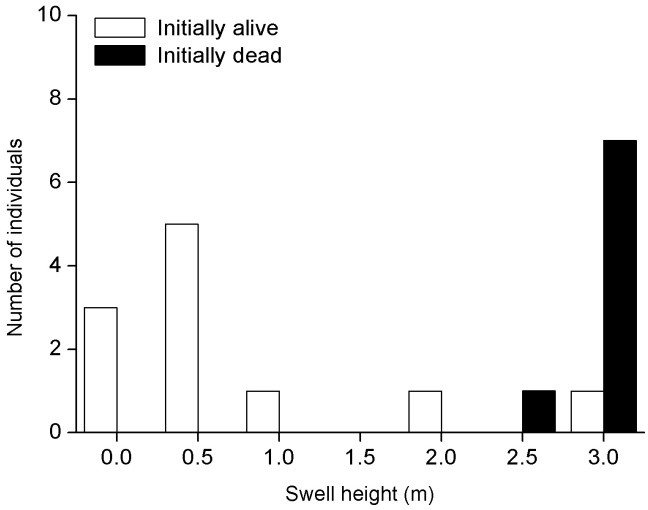

Figure 9. The relationship between swell height and dolphin mortalities, possibly caused by sub-surface entanglement in net folds.

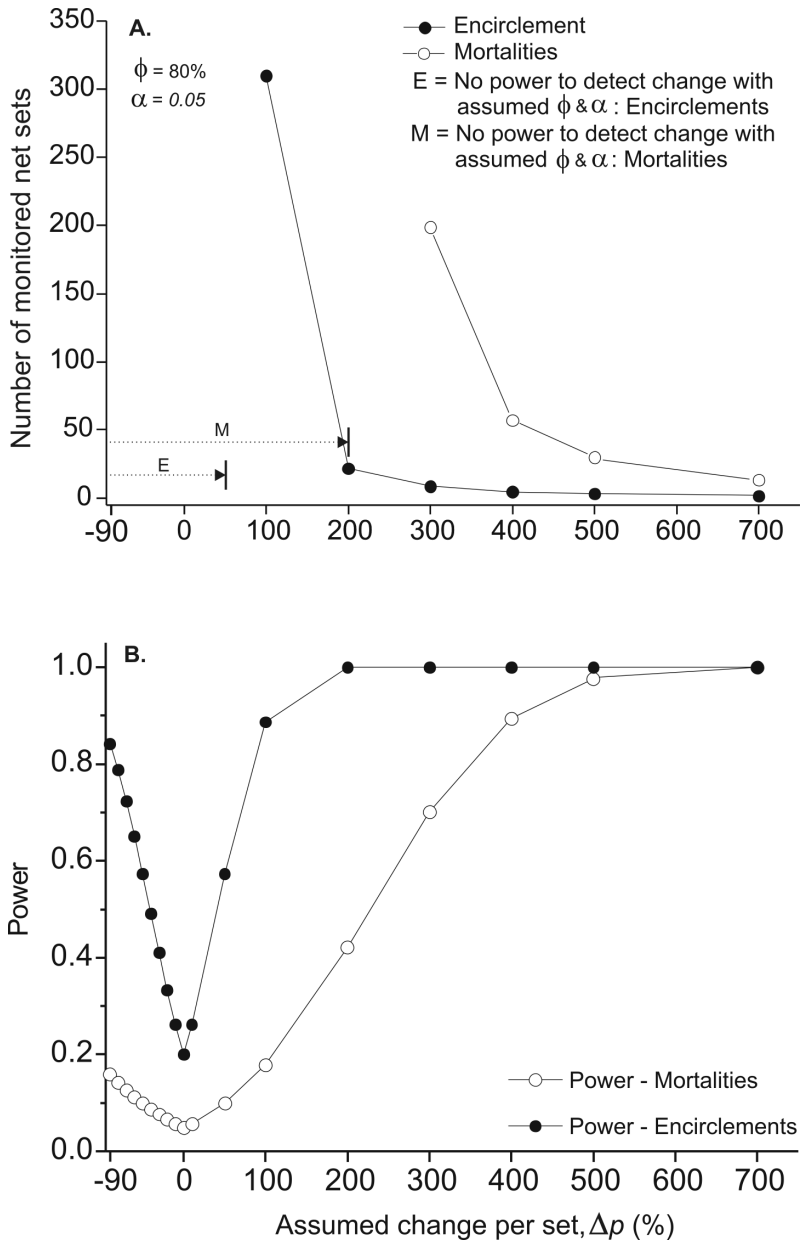

Figure 10. Power analysis for determining the sample size needed to detect various levels of change in dolphin encirclement and mortality rates in the SASF. Internationally accepted standards of power (ϕ = 80%) and significance (α = 0.05) applied.

4. DISCUSSION

The introduction of the TEPS CoP for the SASF resulted in large reductions in the numbers and rates of dolphin encirclement and mortality. The encirclement rate recorded in the second observer program (after the CoP was introduced) was 86.4% lower than the rate recorded in the initial program. The mortality rate was reduced by 97.1%. Comparable changes to fisher behaviour and fishing gear resulted in similar reductions in dolphin mortality rates in the eastern tropical Pacific tuna purse seine fishery (Gosliner, 1999). The success of the CoP in reducing rates of encirclement and mortality of dolphins ensured that the SASF effectively addressed the Commonwealth DEH recommendation to mitigate significant interactions with TEPS.

As the CoP relied on changes in fisher behaviour and modifications to fishing gear, it success in achieving its primary goal of reducing interactions with TEPS (Principle 1) was critically dependent on its acceptance and implementation by licence holders and crews. The CoP was strongly supported by industry because it was developed by a working group that included all stakeholders (Principle 2), only included guidelines that did not unduly reduce the efficiency of fishing operations or jeopardise the safety of the crew (Principle 3), and was cost-effective to implement (Principle 4).

Several changes in fisher behaviour and fishing gear were critical to the success of the CoP. Delaying or relocating fishing operations when dolphins were observed near the target school (Guideline 2) was particularly important for reducing encirclement rates. During the second observer program, a member of the crew was delegated responsibility for searching for dolphins prior to deploying the net and fishing operations were delayed or relocated every time a dolphin was observed near the target school. As a result of this practice being followed during the second observer program, no dolphin that was observed near a target school prior to fishing was subsequently encircled. The large reduction in encirclement rates during the second observer program can largely be attributed to inclusion of this guideline in the CoP.

The guidelines that required fishers to continually search for encircled dolphins (Guideline 1) and to implement release procedures as soon as they were detected (Guideline 3) were also critically important to the success of the CoP. As a result of these guidelines, encircled dolphins were more likely to be detected early in the fishing operation and response times were reduced markedly. These guidelines ensured that encircled dolphins were released before the circumference of the net was reduced to a size where dolphins typically began to display the

behaviours that were commonly associated with mortality events (i.e. becoming motionless and vertical with their head and blowhole just above the waterline).

Another important component of the CoP was the requirement to abort the net-set if all other attempts to release encircled dolphins were unsuccessful (Guideline 6). In the initial observer program, some fishers were reluctant to abort fishing operations to release encircled dolphins, which led to extended encirclement times and subsequent mortalities. However, the willingness of fishers to abort net-sets during the second observer program contributed significantly to the reductions in encirclement times and mortality rates.

The only dolphin that died during the second observer program was first observed dead soon after hauling commenced. The eight mortalities that occurred under similar circumstance during the initial observer program, all occurred when swell heights were >2.0 m, suggesting that large swells may have reduced the capacity of the observer and crew to see encircled dolphins and/or increased the likelihood of sub-surface mortalities. The reliance of the CoP on the visual detection of dolphins and the possible effect of swell height on the capacity of crewmembers to detect dolphins and/or the likelihood of sub-surface mortalities are issues that need to be considered as the CoP is further refined.

Several previous studies suggest that fishery logbook data are unsuitable for measuring the number or rate of operational interactions with TEPS (Bache, 2002; Romanov, 2002; Walsh et al., 2002; Baum et al., 2003; Dans et al., 2003). The findings of the present study support this suggestion; encirclement rates calculated from logbook data for the period April 1999 to May 2004 were two orders of magnitude lower than the rate recorded in the initial observer program (Table 1). The difference in the mortality rates was even greater, with historical mortality rates being three orders of magnitude lower than those in the initial observer program.

There was a marked reduction in the discrepancy between logbook and observer data following the introduction of the CoP. Encirclement and mortality rates recorded in logbooks during the initial observer program were 3.6 and 18.6% respectively of those calculated for observed fishing activities (Table 1). Encirclement and mortality rates calculated from logbook data during the second observer program were 57.9% and 58.9%, respectively, of those calculated from observer data. Hence, as well as reducing the number and rate of interactions with dolphins, the CoP for the SASF had the additional benefit of improving the quality of the TEPS data recorded in logbooks. This result partially addresses the Commonwealth DEH recommendation for a

mechanism to be established which allows fishers to accurately record interactions with TEPS. The TEPS logbook and identification booklet that is scheduled to be introduced into South Australia's commercial fisheries in 2007/2008 will further address this recommendation and will include an education program that will help to ensure that reports are made with an appropriate level of accuracy. Future observer programs may provide an opportunity to validate the accuracy of information recorded in TEPS logbooks.

Logbook and observer data suggest that operational interactions with dolphins occurred across the geographic range of the SASF, with spatial patterns of encirclement being strongly correlated with the level of fishing effort. The absence of dolphin interactions in waters >60 m in depth was the apparent exception to this link with fishing effort, and is notable because this species is known to occur across a wide range of depths (Cowardine and Camm, 1995). The positive relationship between encirclement rates and the spatial patterns of fishing effort precluded the use of spatial closures to mitigate interactions between the SASF and dolphins. This finding was critical for justifying the introduction of a CoP that focused on modifications to fishing gear and fisher behaviour, rather than establishing additional spatial closures in the fishery.

Historical logbook data suggested that there were marked intra-annual variations in the number of interactions between the SASF and dolphins, with many encirclements occurring in late summer and autumn. However, this pattern appears to be primarily related seasonal differences in the level of fishing effort, rather than intra-annual variations in the numbers of dolphins on the fishing grounds. Observer data were unsuitable for examining intra- or inter-annual patterns in the rates of encirclement and mortality of dolphins in the SASF because they were only collected over eight months during two years in which fishing practices differed significantly.

The low rates of encirclement and mortality that were achieved after the introduction of the CoP have implications for future monitoring of the operational interactions between the SASF and dolphins. Importantly, power analyses show that an observer program of the scale of that 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. However, an observer program of this scale would have the capacity to detect a tripling (200% increase) of the encirclement rate and/or a five-fold (400%) increase in the mortality rate. Hence, an observer program could identify major reductions in the level of adherence to the CoP, but could not reliably measure the success of future refinements to the existing CoP.

If observer programs are used to monitor future interactions between the SASF and dolphins, it is important that the goals of each program are clearly defined from the outset and that the capacity of the program to detect relevant changes in the parameters of interest is determined before it is initiated. The relative benefits and costs of alternative methods for monitoring interactions between the SASF and dolphins should also be assessed in this context.

REFERENCES

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G. (1994). A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper, **339**. 233pp.

Archer, F., Gerodette, T., Dizon, A., Abella, K., Southern, S. (2001). Unobserved kill of nursing dolphin calves in an tuna purse-seine fishery. *Marine Mammal Science*, **17**(3): 540-554.

Archer, F., Gerrodette, T., Chivers, S., Jackson, A. (2004). Annual estimates of the unobserved incidental kill of pantropical spotted dolphin (*Stenella attenuata attenuata*) calves in the tuna purse-seine fishery of the eastern tropical Pacific. *Fishery Bulletin*, **102(2)**: 233-244.

Bache, S.J. (2003). *Marine wildlife bycatch mitigation: global trends, international action and the challenges for Australia.* Ocean Publications, Wollongong.

Barlow, J., Cameron, G.A (2003). Field experiments show that pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science*, **19**(2): 265-283.

Baum, J.K, Myers, R.A., Kehler, D.G. Worm, B., Harley, S.J., Doherty, P.A. (2003). Collapse and conservation of shark populations in the Northwest Atlantic. *Science*, **299**: 389-392.

Bearzi, G., Politi, E., Agazzi, S., Bruno, S., Costa, M., Bonizzoni S. (2005). Occurrence and present status of coastal dolphins (Delphinus delphis and Tursiops truncatus) in the eastern Ionian Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **15**: 243-257.

Cowardine, M., Camm, M. (1995). *Whales, dolphins and porpoises: identification guide.* Smithsonian handbook. Dorling Kindersley Handbooks.

Dans, S.L., Alonso, M.K., Pedraza, S.N., Crespo, E.A. (2003). Incidental catch of dolphins in trawling fisheries off Patagonia, Argentina: Can populations persist? *Ecological Applications*, **15**: 189-202.

Di Natale, A., Notarbartolo di Sciara, G. (1994). A review of the passive fishing nets and trap fisheries in the Mediterranean Sea and of cetacean bycatch. Rep. Int. Whal. Commn., Special Issue **15**:189-202.

Gosliner, M.L. (1999). The tuna-dolphin controversy. In: Twiss, J.R., Reeves, R.R. (Eds.). *Conservation and management of marine mammals*. Melbourne University Press, Melbourne.

Hale, P.T., Hill, B., Limpus, C., McPhee, D., Staunton-Smith, J., Ward, T. (1999). Ways in which dolphin mortalities might be minimised or avoided in the conduct of a purse-seine net fishing operation for pilchards in south-east Queensland. Report to the Queensland Fisheries Management Authority (QFMA). 20pp.

Kemper, C. M. and Gibbs, S. E. (1997). A study of life history parameters of dolphins and seals entangled in tuna farms near Port Lincoln, and comparisons with information from other South Australian dolphin carcasses. Report to Environment Australia. 47 pp.

Kemper, C.M., Gibbs, S.E. (2000). Dolphin mortalities in the tuna feedlots near Port Lincoln, South Australia: an update. Newsletter of the Marine and Coastal Community Network. *Waves*, **7**(3):

Moore, D.S., McCabe, G.P. (2003). Introduction to the Practice of Statistics, 4th ed. Freeman, New York.

Northridge, S.P. (1984). World review of interactions between marine mammals and fisheries. FAO Fisheries Technical Paper, **251**. 190pp.

Northridge, S.P. (1991). An updated world review of interactions between marine mammals and fisheries. FAO Fisheries Technical Paper, **251** (Supplement 1)**.** 58pp.

Northridge, S.P., Hofman, R.J. (1999). Marine mammal interactions with fisheries. In: Twiss, J.R., Reeves, R.R. (Eds.). *Conservation and management of marine mammals*. Melbourne University Press, Melbourne. 99-119.

Rice, J.A. (1995). *Mathematical statistics and data analysis. 2nd Edition*. Duxbury Press, Belmont, California.

Rogers, P. J., and Ward, T. M. (2006). Sardine (*Sardinops sagax*). Fishery Assessment Report. Report to Primary Industries and Resources South Australia. South Australian Research and Development Institute (Aquatic Sciences). SARDI Publication No. RD03/0198-3. Report Series No. 139.

Romanov, E.V. (2002). By-catch in the tuna purse-seine fishery of the western Indian Ocean. *Fishery Bulletin*, **100**: 90-105.

SAPFA (2005). Code of practice for threatened, endangered and protected species in the South Australian Sardine Fishery. South Australian Pilchard Fisherman's Association (SAPFA). September 2005. Port Lincoln. 14pp.

Shanks, S. (2004). Ecological assessment of the South Australian pilchard fishery. South Australian fisheries management series. Report to Primary Industries and Resources South Australia (PIRSA). June 2004. Adelaide. 51pp.

Silva, V.M.F., Best, R.C. (1996). Freshwater dolphin/fisheries interaction in the central Amazon (Brazil). *Amazoniana-Limnologia*, **14**(1-2): 165-175.

Staunton-Smith, J., and Ward, T. (2000). Stock assessment of pelagic bait fishes in southern Queensland, with special reference to pilchards (*Sardinops sagax*). Report to the Fisheries Research and Development Corporation (FR&DC). 126pp.

Stone, C.D. (1997). Too many fishing boats, too few fish: Can trade laws trim subsidies and restore the balance in global fisheries? Ecology Law Quarterly, **24**(3): 505-544.

Wade, P.R. (1995). Revised estimates of incidental kill of dolphins (Delphinidae) by the purse-seine tuna fishery in the eastern tropical Pacific, 1959-1972. *Fishery Bulletin*, **93**(2): 345-357.

Walsh, W.A., Kleiber, P., McCracken, M. (2002). Comparison of logbook reports of incidental catch rates by Hawaii-based longline vessels to fishery observer data application of a generalized linear model. *Fisheries Research*, **58**(1): 79-94.