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Entanglement of Australian sea lions and New Zealand fur seals in lost fishing gear and other marine debris before and after Government and industry attempts to reduce the problem

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Abstract

In recent years, Australian governments and fishing industry associations have developed guiding principles aimed at reducing the impact of fishing on non-target species and the benthos and increasing community awareness of their efforts. To determine whether they reduced seal entanglement in lost fishing gear and other marine debris, we analysed Australian sea lion and New Zealand fur seal entanglement data collected from Kangaroo Island, South Australia. Contrary to our expectations, we found that entanglement rates did not decrease in recent years. The Australian sea lion entanglement rate (1.3% in 2002) and the New Zealand fur seal entanglement rate (0.9% in 2002) are the third and fourth highest reported for any seal species. Australian sea lions were most frequently entangled in monofilament gillnet that most likely originated from the shark fishery, which operates in the region where sea lions forage—south and east of Kangaroo Island. In contrast, New Zealand fur seals were most commonly entangled in loops of packing tape and trawl net fragments suspected to be from regional rock lobster and trawl fisheries. Based on recent entanglement studies, we estimate that 1478 seals die from entanglement each year in Australia. We discuss remedies such as education programs and government incentives that may reduce entanglements.

Keywords: Entanglement; Fishing; Plastic; Marine debris; *Arctocephalus forsteri*; *Neophoca cinerea*

1. Introduction

The problem of plastic in the marine environment is of increasing concern because millions of tons of plastic enters the ocean each year (Pruter, 1987; Slip and Burton, 1991; Derraik, 2002). Fishing gear, packaging materials, convenience items and raw plastics comprise most of the plastic in the ocean (Pruter, 1987; Derraik, 2002). Major sources of plastic in the ocean are from fishing vessels, ship waste, drains, rivers and litter from people at beaches. Marine debris is concentrated by currents and waves at oceanic convergence fronts and in coastal waters around cities (Carr, 1987; Day and Shaw, 1987; Derraik, 2002). As oceanic convergence fronts are up- or down-welling regions and coastal waters are often estuaries, these very productive ecosystems often combine high densities of marine life and debris (Carr, 1987).

Plastic has replaced natural fibres in the fishing industry over the past 35 years due to its light weight, low production cost and physical and biological durability (Henderson, 2001). The use of durable plastic nets and ropes has increased efficiency of fishing operations as less time is spent repairing equipment made from natural fibres. However, the widespread use of plastic in the fishing industry has resulted in considerable quantities of fishing debris in oceans and on beaches (Henderson, 2001).

The impact of debris on marine wildlife populations is difficult to document because animal populations fluctuate significantly through time in response to

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natural factors such as climate variation and prey availability (Fowler, 1987). However, the physical effects that plastic debris has on wildlife are well documented and a growing body of evidence suggests plastic debris is a significant threat to some turtle and seal populations (Carr, 1987; Fowler, 1987). The few studies that quantified the effects of floating net fragments concluded they are possibly as effective at entangling and killing marine wildlife as operational nets (DeGrange and Newby, 1980; Jones and Ferrero, 1985; Fowler et al., 1990). A wide diversity of marine animals become entangled in plastic debris, including fish (Stewart and Yochem, 1987; Jones, 1995; Cliff et al., 2002), turtles (Carr, 1987), seabirds (Schrey and Vauk, 1987; Piatt and Nettleship, 1987), whales (Volgenau et al., 1995) and seals (Shaughnessy, 1980; Hofmeyr et al., 2002; Arnould and Croxall, 1995). Fur seals and sea lions provide a means of examining the types of debris present in their foraging range as many seals become entangled in debris and carry it back to land around their necks. When entangled seals haul out on land they can be observed, captured and the material removed for analysis.

The disposal of all plastics in Australian waters is prohibited by the *Protection of the Sea* (*Prevention of Pollution from Ships*) *Act, 1983*. This Act implements the provisions of Annex 5 of the International Convention for the Prevention of Pollution from Ships (MARPOL), which was ratified in 1989, prohibiting the disposal of plastic in international waters. Since ratification, entanglement rates of northern fur seals, *Callorhinus ursinus*, have decreased (Fowler et al., 1994) but entanglement rates of Hawaiian monk seals, *Monachus schlauinslandi*, have not changed (Henderson, 2001). In the early 1990s, the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) successfully educated commercial fishers about the effects of their plastic debris, resulting in most bait box packing tape being cut before disposal around South Georgia (Arnould and Croxall, 1995). However, following the education campaign there was also a coincident reduction in fishing effort in the region. As such, subsequent decreases in the entanglement rates of Antarctic fur seals (*Arctocephalus gazella*) were not solely attributed to improved waste management by fishers (Arnould and Croxall, 1995). No studies were conducted in Australia to determine whether these laws were effective in reducing the impact of fishing gear on marine animals.

In response to public concern regarding the impact of commercial fisheries on marine ecosystems the Commonwealth Government developed two policies: the National Policy on Fisheries Bycatch in late 1999 and the Commonwealth Policy on Fisheries Bycatch in 2000. The first policy did not include fishery-specific actions, but the latter policy was implemented as Bycatch Action Plans for each fishery in early 2001. The Bycatch Action Plans included aims, strategies and actions to ensure bycatch species were not adversely affected by fisheries (AFMA, 2001b). "For the purpose of the Bycatch Action Plan and this Background Paper, bycatch refers to that part of the catch which is discarded or which interacts with the fishing gear but does not reach the deck. This is consistent with the Commonwealth Policy on Fisheries Bycatch, which defines bycatch as: bycatch = discards + interactions with gear... Discards and interactions with fishing gear have been defined in the Commonwealth Policy on Fisheries Bycatch as: (1) that part of a fisher's catch which is returned to the sea either because it has no commercial value or because regulations preclude it being retained, (2) that part of the catch that does not reach the deck of the fishing vessel but is killed as a result of interaction with the fishing gear (including lost fishing gear). This can be described as unaccounted mortality resulting from fishing" (AFMA, 2001a). The sentiments of the Bycatch Action Plans are mirrored in state government policies and fishing industry codes of conduct. Clearly, there is a need for research to document levels of unaccounted mortality.

This study presents data from observations of entangled New Zealand fur seals (*Arctocephalus forsteri*) and Australian sea lions (*Neophoca cinerea*) ashore at Kangaroo Island (36°04′ S 137°28′ E). Fur seals and sea lions from these islands forage in regions that overlap with several fisheries managed by the Commonwealth Government (Great Australian Bight trawl, gillnet hook and trap, south east trawl and southern tuna and billfish fisheries) as well as fisheries managed by state governments (rock lobster, abalone and other marine fishes) (Page unpublished data, Costa personal communication). We describe the nature of the seal entanglements, determine their source where possible and estimate entanglement-related mortality for each species. Results are discussed in the context of the effectiveness of government and industry attempts to reduce unaccounted mortality.

2. Methods

2.1. Species

In Australia, fur seals and sea lions were intensively hunted for their pelts in the early 19th century (Gales et al., 1994; Ling, 1999). Very small populations survived on inaccessible islands and since the end of commercial sealing, numbers have increased (summarised in Goldsworthy et al., 2003). New Zealand fur seals are recolonising islands throughout their former range (Shaughnessy et al., 2002), however, this appears not to be the case for Australian sea lions (Gales et al., 1994). Fur seals and sea lions are protected in Australia under the *Environment Protection and Biodiversity Conserva-*

tion Act, 1999 and under State and Territory legislation. Although seals are known to compete for commercial fish species and sometimes damage fishing nets, it is illegal to take, kill, injure or move seals. Entangled Australian sea lions and New Zealand fur seals have been reported from South Australia by Robinson and Dennis (1988) and entanglement in man-made marine debris was identified as a threatening process for seals in Australian waters in Environment Australia's "Action Plan for Australian Seals" (Shaughnessy, 1999).

2.2. Study sites

Seals were observed at Seal Bay (Australian sea lions) and in the Cape Gantheaume Conservation Park (New Zealand fur seals), both on the south coast of Kangaroo Island, South Australia. The Australian sea lion population at Seal Bay has been stable since the study began in 1987 (approximately 700 individuals, Shaughnessy unpublished data, Goldsworthy et al., 2003), while the New Zealand fur seal population in the Cape Gantheaume Conservation Park (20 km east of Seal Bay, including Berris Point) has been increasing by about 16% per annum since 1987 and currently numbers about 8900 individuals (Shaughnessy and Dennis, 2002; Goldsworthy et al., 2003).

2.3. Data collection and analyses

Search effort for entangled seals varied between years and sites. At Cape Gantheaume, New Zealand fur seals were monitored between 2.3 and 6.5 months per year (mean 4.6 months, SD 48 days) from 1989 to 1991 and 2000 to 2002. For New Zealand fur seals we estimated the number of entangled seals that hauled out when the colony was not monitored, from 1989 to 1991 and 2000 to 2002, following the model developed by Henderson (2001), because both males and females of all ages have been shown to haul out throughout the year (Goldsworthy and Shaughnessy, 1994). For example, 40 entangled seals were observed at Cape Gantheaume in 2002 during 6 months (0.5 years) of monitoring, so the estimate for the number of entangled seals for the entire year is 80 (i.e. 40/0.50). The colony was not monitored from 1992 to 1999 so we did not estimate the number of entanglements for this period. We did not extrapolate numbers for Australian sea lions as approximately 80% of the colony at Seal Bay was observed daily (and the remainder monthly) since 1988.

For each observation of an entangled seal the location, date and sex of the seal was recorded. The age of entangled seals was estimated as one of five categories; pups, juveniles, sub adult males, adult males or adult females (as described in Goldsworthy and Shaughnessy, 1994; Gales et al., 1994). When an entangled seal was captured or found dead the entangling material was removed and either identified and discarded or retained for subsequent identification by commercial fishers and net manufacturers. If an entangled seal was not captured the nature of the material was determined, using spotting scopes or binoculars. Entanglements were classified as life-threatening if they had worn through the skin and become embedded in the neck, as such entanglements are unlikely to become detached (Fowler et al., 1990; Pemberton et al., 1992). Entanglement-related mortality was calculated based on the proportion of life-threatening entanglements observed. To avoid overestimation of entanglement rates, seals with scars caused by entanglements were not included in this study unless entangling material could be seen. Similarly, if entangled seals evaded capture and were subsequently observed they were not double-counted.

Some seals were found entangled after possible direct interactions with fishing gear such as tuna longlines and shark gillnets. Two entanglement studies excluded these interactions as they assumed seals were cut free from active fisheries, rather than entangled in net fragments (Stewart and Yochem, 1987; Henderson, 2001). We include all such cases in this study because all entangling materials, including longline hooks, were also found washed ashore (Page unpublished data).

Annual entanglement rates were calculated as proportions of the number of seals in the resident population. Population sizes were estimated using models from Goldsworthy et al. (2003), which multiply pup production by 3.93 for Australian sea lions and 3.95 for New Zealand fur seals. Mann–Whitney U-tests (two-tailed) were used to examine differences between entanglement rates before and after the implementation of Bycatch Action Plans, to assess whether they reduced the impact of lost fishing gear from Commonwealth fisheries. Some of the entangling material is most likely from state fisheries so we analyse interactions for the same period to enable comparison. Around this time state fisheries (such as the rock lobster fishery) implemented codes of practice to reduce the impact on the marine environment (Braund, 2000). The level of exact significance was set at 0.05 for Mann–Whitney U-tests. For New Zealand fur seals, our sample size of four years before and two years after the introduction of the Bycatch Action Plans was too small to determine exact significance of $p < 0.133$. However, levels of significance are given to provide insight into observed trends.

3. Results

A trend of increasing numbers of entanglements in recent years was apparent for New Zealand fur seals and Australian sea lions around Kangaroo Island (Tables 1 and 2, Figs. 1 and 2). Packing tape, netting and rope accounted for most of the material entangling seals. At

Table 1
The debris observed entangling Australian sea lions at Seal Bay, Kangaroo Island, between 1988 and 2002

Debris	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total	
																No.	(%)
Packing tape	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	4	11
Monofilament netting	0	1	0	1	1	0	1	0	2	0	1	3	1	6	2	19	55
Trawl netting	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	4	11
Fishing line and hook	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6
Other rope	0	0	0	1	0	0	0	1	1	0	0	0	0	0	2	5	14
Tyre tube	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3
Total (%)	1 (3)	2 (5)	0 (0)	2 (5)	1 (3)	0 (0)	1 (3)	1 (3)	3 (9)	0 (0)	3 (9)	3 (9)	3 (9)	6 (16)	9 (26)	35	

Table 2
The debris observed entangling New Zealand fur seals at Cape Gantheaume, Kangaroo Island, from 1989 to 1991 and 2000 to 2002

Debris	1989	1990	1991	2000	2001	2002	Total	
							No.	(%)
Packing tape	1	2	1	6	11	7	28	30
Monofilament netting	0	0	0	0	0	1	1	1
Trawl netting	0	1	0	2	10	12	25	28
Fishing line & hook	0	0	0	1	1	1	3	3
Lobster float rope	0	0	0	0	6	6	12	13
Other rope	0	2	0	1	1	5	9	10
Plastic bag	0	0	0	1	2	3	6	7
Other (see text)	0	0	0	0	2	5	7	8
Total (%)	1 (1)	5 (6)	1 (1)	11 (12)	33 (36)	40 (44)	91	

The category *other* includes rubber o-rings (two seals), a string of burst balloons (one seal) and a rock lobster pot (four seals).

the two colonies studied a total of 126 entangled seals were observed (Tables 1 and 2), 61 (48%) of which were suffering life-threatening injuries and five (4%) of which were dead. Sixty-five (52%) of the 126 seals were captured and the material removed. Of the 61 seals that avoided capture 59 (97%) were not resighted again, suggesting they died or the material became detached or perhaps they went elsewhere.

3.1. Australian sea lions

Thirty-five entangled sea lions were observed at Seal Bay during the 15 year study (Table 1, Fig. 1). Contrary to our expectations, entangled sea lions were significantly more common at Seal Bay from 2001 to 2002 ($n_1 = 13$, $n_2 = 2$, $p = 0.019$), increasing from an average of 1.5 (SD = 1.20, $n = 20$) per year before 2001 to 7.5 (SD = 2.12, $n = 15$) per year (Table 1). This represents an increase in the annual entanglement rate (% of the total population per year) at Seal Bay, from 0.2% before 2001 to 1.0% for 2001 and 1.3% for 2002.

Pups were the most frequently entangled age class (54% of entanglements), with their incidence of entanglement increasing significantly from an average of 1.0 (SD = 0.73) pups per year between 1988 and 2000 to 4.5 (SD = 2.12) pups per year from 2001 to 2002 ($n_1 = 13$, $n_2 = 2$, $p = 0.019$, Fig. 1). Cases of entangled juveniles, subadult males and adult females did not decrease in 2001–2002 (juveniles: $n_1 = 13$, $n_2 = 2$, $p = 0.114$; subadult males: $n_1 = 13$, $n_2 = 2$, $p = 0.571$; adult females: $n_1 = 13$, $n_2 = 2$, $p = 0.476$, Fig. 1). Only two (5% of total) adult males were observed with entanglements during the study, one in 1989 and one in 2002 (Fig. 1).

Interpretive Officers from the Department for Environment and Heritage conducted daily checks of the Main Beach at the Seal Bay colony and removed most

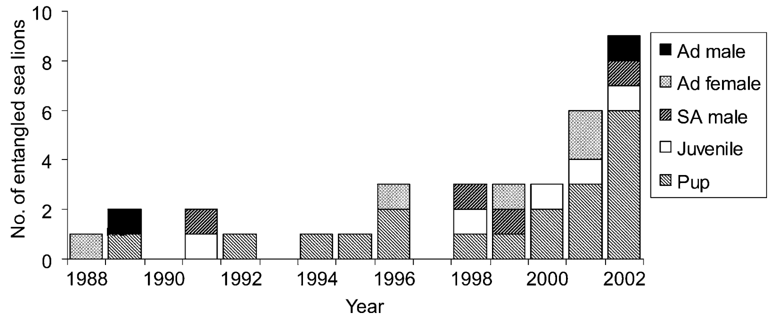

Fig. 1. The number, sex and age class of entangled Australian sea lions observed at Seal Bay, Kangaroo Island, between 1988 and 2002.

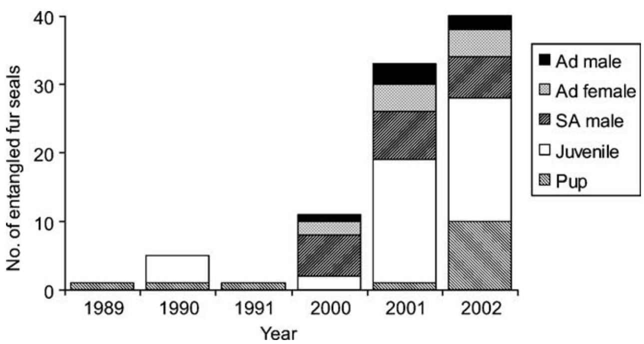

Fig. 2. The number, sex and age class of entangled New Zealand fur seals observed at Cape Gantheaume, Kangaroo Island, from 1989 to 1991 and 2000 to 2002.

entanglements (74%) from sea lions, ensuring entanglement-related mortality was minimal. We expect at least 15 (43%) of the entangled sea lions would have died as they were suffering life-threatening injuries when observed.

Entangling material observed on sea lions included monofilament netting, trawl netting, packing tape, rope, fishing line with hooks and a strip of car tyre inner-tube (Table 1). Monofilament netting, of >15 cm diameter mesh, was recorded on 19 (55%) sea lions and was the most common item in five of the 12 years when entanglements were observed (Table 1). The incidence of monofilament netting entanglements increased significantly following the introduction of the Bycatch Action Plans ($n_1 = 13$, $n_2 = 2$, $p = 0.038$, Table 1). South and southeast of Kangaroo Island, bottom set gillnets are used to catch school sharks (*Galeorhinus galeus*) and gummy sharks (*Mustelus antarcticus*) in the gillnet, hook and trap fishery (Jones, 1995; AFMA, 2001a). The relatively high incidence of monofilament netting on Australian sea lions contrasts with the low incidence of entanglement reported by the fishery to the Australian Fisheries Management Authority, ofone dead and two live seals in 14,243 shots in 1998, and one dead seal in 12,696 shots in 1999 (Shaughnessy et al., 2003). This suggests a low rate of reporting of entangled sea lions in logbooks by shark fishers or a high rate of net loss in the fishery. Industry representatives believe lost gear stops fishing within a short period of time because nets and lines become tangled on the bottom, covered in algae and coral (AFMA, 2001a), in contrast with studies of lost nets (DeGrange and Newby, 1980; Jones and Ferrero, 1985; Fowler et al., 1990).

Packing tape and trawl net entanglements were not observed at Seal Bay until 1998 and 2000, respectively (Table 1). At Seal Bay just four packing tape loops and four trawl net fragments (each 11% of total) were observed during the 15 year study (Table 1). The incidence of packing tape and trawl netting entanglements did not decrease in 2001–2002 (packing: $n_1 = 13$, $n_2 = 2$, $p = 0.381$, trawl: $n_1 = 13$, $n_2 = 2$, $p = 0.381$). Around Kangaroo Island packing tape is commonly used to bundle frozen bait, which is used to lure rock lobster, sharks, and tuna (Jones, 1995). The five rope entanglements (14% of total) at Seal Bay were most likely from regional fisheries, however, only one of the entanglements was identified to a fishery—a loop of rope commonly attached to floats on rock lobster pots.

3.2. New Zealand fur seals

Ninety-one entangled New Zealand fur seals were observed at Cape Gantheaume and a further 104 were estimated to have come ashore when the colony was not monitored in the six years from 1989 to 1991 and 2000 to 2002 (Table 2, Fig. 2). The highest number of entanglements observed was during 2002 when 40 were recorded in six months of monitoring (50% of the year). Despite the large increase in population size (from about 1800 in 1989 to about 8900 in 2002: Shaughnessy and Dennis, 2002, Goldsworthy et al., 2003) the annual entanglement rate (% of the total population per year) increased from an average of 0.4% (SD = 0.2%) per year prior to 2001 to 0.9% (SD = 0.1%) per year from 2001 to 2002, although the difference was not significant ($n_1 = 4$, $n_2 = 2$, $p = 0.133$). The entanglement rate in both 2001 and 2002 was 0.9%.

New Zealand fur seals of all ages were observed entangled at Cape Gantheaume during the study (Fig. 2). Entanglement rates increased for adult males (1989–2000: 0.01 to 2001–2002: 0.06%), females (0.02–0.10%), subadult males (0.07–0.16%), juveniles (0.23–0.45%) and pups (0.03–0.12%), although not significantly (adult males: $n_1 = 4$, $n_2 = 2$, $p = 0.133$, females: $n_1 = 4$, $n_2 = 2$, $p = 0.133$, subadult males: $n_1 = 4$, $n_2 = 2$, $p = 1.00$, juveniles: $n_1 = 4$, $n_2 = 2$, $p = 0.267$, pups: $n_1 = 4$, $n_2 = 2$, $p = 0.267$) (Fig. 2). Entangling material was removed from 39 (45%) of the 86 New Zealand fur seals observed alive. Five (5%) entangled seals were found dead in the colony and 46 (53%) of the 86 live seals had injuries classified as life-threatening.

The entangling material observed on New Zealand fur seals included packing tape, trawl netting, rope from rock lobster floats, other rope, plastic bags, a beach-washed rock lobster pot, fishing line, a string of burst balloons and a rubber o-ring (Table 2). Packing tape, most likely from rock lobster vessels and/or shark or tuna longliners, was the most common entanglement and its relative incidence did not decrease in 2001 to 2002 ($n_1 = 4$, $n_2 = 2$, $p = 1.000$) (Table 2). Trawl netting entanglements increased from 0.05% prior to 2001 to 0.27% during 2001–2002, although not significantly ($n_1 = 4$, $n_2 = 2$, $p = 0.133$) (Table 2). Around Kangaroo Island trawling is conducted on the shelf and shelf break, targeting mainly deep water flathead (*Neoplatycephalus conatus*) and Bight redfish (*Centroberyx gerrardi*). Rope from rock lobster floats entangled 12 seals in 2001–2002. A rock lobster pot set just off the colony washed ashore during high seas in May 2002. Four pups became trapped in the pot while it was ashore and drowned during the next high tide. Pieces of plastic bag entangled six seals but they could not be definitively sourced (Table 2). Monofilament netting was removed from one seal and three seals had fragments of fishing line with hooks attached (Table 2). One of the hooks was from a tuna longline and two were from recreational fisheries.

4. Discussion

The results of this study suggest most entangling material found on Australian sea lions and New Zealand fur seals originates from nearby fishing activity. Similarly, entangling material found on Australian fur seals (*A. pusillus doriferus*) around Tasmania included material from regional fisheries (Pemberton et al., 1992). Our data suggest that by 2001–2002 government and industry initiatives had not reduced the incidence of these interactions.

An important consideration regarding entanglement rates is that entangled seals are less likely to be observed on land than other seals, for three reasons (Fowler, 1987). First, observations of northern fur seals suggest an unknown number become entangled in material large enough to prevent them returning to shore, so they die at sea (Fowler et al., 1990). In the Bering Sea, 10–17% of trawl net fragments contained at least one entangled seal (Fowler, 1987). Second, while non-entangled seals may be counted many times throughout their lives, entangled seals will be counted less often as a result of their lower survival rates (Fowler et al., 1990). This is supported by our finding that only two of the entangled seals that avoided capture were seen again and because few fur seals are thought to dislodge entanglements (Fowler, 1987; Fowler et al., 1990). This suggests there is a relatively fast turnover of short-lived entangled seals that are replaced by recently entangled seals within a fur seal population. Finally, entangled seals spend longer periods at sea foraging than other seals, as a consequence of the additional drag (Fowler et al., 1990; Bengtson et al., 1989). Although the relative amount of time entangled seals spend on land between foraging trips has not been determined, it is unlikely that they spend longer on land than non-entangled seals, reducing the probability of observing entangled seals (Bengtson et al., 1989; Fowler et al., 1990). The effect of the above factors on young northern fur seals was estimated because they suffer significant mortality from entanglement. Fowler et al. (1990) suggested the entanglement-related mortality for young northern fur seals may be as high as 14% per year—35 times the observed entanglement rate of juvenile male seals. Entanglement rates and the subsequent mortality estimated in this study may be similarly underestimated.

Although we have shown an increase in seal entanglement in recent years, our comparisons may not reflect the efforts of fishers to reduce these interactions. For example, some of the packing tape, pieces of rope and other rubbish may have originated from fishers or cargo ships operating outside Australian waters. Similarly, plastic can persist in the environment for many years, so the entangling material we observed may have been lost by fishers several years prior. As a result, we may have underestimated the positive effect of government and industry attempts to reduce the impact of fishing on the marine environment. Continued monitoring of entanglement rates may resolve these issues.

We compare population entanglement rates from this study to those from other studies with an understanding that two different methods have been used to estimate rates: (1) the proportion of entangled seals at a colony from a series of surveys (e.g. Pemberton et al., 1992), and (2) the minimum annual incidence of entanglement for a population of known size (e.g. this study). If the minimum annual incidence of entanglement is not extrapolated to include months of the year when seal colonies are not monitored, the two methods would produce different results. However adequate sampling and estimating numbers of entangled seals ashore when colonies are not monitored (e.g. Henderson, 2001 and this study) minimises such errors.

The nature and amount of entangling material on fur seals in the Southern Ocean and around Australia has been shown to reflect the type and scale of regional fisheries (Arnould and Croxall, 1995; Pemberton et al., 1992). At South Georgia the most common fur seal entanglement was packing tape (suspected to be from longline vessels) and trawl net fragments used for mid-water trawls (Arnould and Croxall, 1995). Interestingly, when fishing activity diminished around South Georgia entanglement rates also decreased. At Marion Island in the Southern Ocean, the incidence of entanglement of pinnipeds nearly doubled after 1996, in association with the arrival of long-line fisheries (Hofmeyr et al., 2002). Finally, a four year study of entangled Australian fur seals around Tasmania coincided with the peak of the orange roughy (*Hoplostethus atlanticus*) fishery, when many net fragments were lost (Pemberton et al., 1992). As the authors expected, trawl netting was the most common fur seal entanglement (33%) followed by packing tape (23%) derived from the rock lobster fishery and tuna longline vessels (Pemberton et al., 1992).

We examined whether recent trends of increasing sea lion entanglement in monofilament netting and New Zealand fur seal entanglement in rock lobster fishery material and trawl netting, were matched by trends of increased fishing effort around Kangaroo Island (Fig. 3). Such a relationship did not exist between the southern shark fishery and the number of sea lion entanglements. Annual gillnetting effort almost halved during the study (from ~80,000 km of gillnet per annum at the beginning of the study to ~45,000 km in 2000 and 2001) (McLoughlin and Walker, 2002, Bureau of Rural Services unpublished data), while the number of entanglements increased (Fig. 3, Table 1). In the South Australian rock lobster fishery (around Kangaroo Island), effort (pot lifts) also decreased during this study (Fig. 3) (South Australian Research and Development Institute unpublished data). Increased sea lion/fur seal entanglement during periods of decreased gillnetting/pot lift effort suggests these interactions require further research. Trawl fishery data indicates that effort (measured in trawl hours) increased in both the entire south east fishery and the entire Great Australian Bight trawl fishery during the study (Fig. 3) (Tilzey, 2002; Tilzey and Wise, 2002). These fisheries span SW Australia to southern NSW, covering the regions where seals from Kangaroo Island forage. From 1989 to 1991 effort in the south east fishery and the Great Australian Bight trawl fishery was relatively constant (Fig. 3) at ~65,000 trawl hours and ~7000 trawl hours, respectively. Between 2000 and 2002 the effort in these fisheries averaged ~108,000 trawl hours and ~11,500 trawl hours, respectively (Tilzey, 2002; Tilzey and Wise, 2002, Bureau of Rural Services unpublished data). In light of an approximate doubling in trawl effort (Fig. 3) around Kangaroo Island during the study, more entanglements in trawl netting from 2000 to 2002 are not unexpected.

4.1. Australian sea lions

The entanglement rate observed at Seal Bay (1.3%) in 2002 is the third highest recorded for any seal species. Nearly all published seal entanglement rates are less than 0.5% (Fowler, 1987; Stewart and Yochem, 1987; Arnould and Croxall, 1995; Hofmeyr et al., 2002), with the exception of Australian fur seals (1.3–1.9%) and California sea lions (*Zalophus californianus*) in the Sea of Cortez, Mexico (3.9–7.9%) (Pemberton et al., 1992; Harcourt et al., 1994). Entanglements are thought to be partially responsible for northern fur seal population declines, where the entanglement rate is just 0.4% (Fowler, 1987). As the entanglement rate at Seal Bay is three times that of northern fur seals, it is possible that entanglements may be significantly affecting population recovery. Based on the Australian sea lion population of 11,231 (Goldsworthy et al., 2003) and the 2002 entanglement rate (1.3%), we expect 146 Australian sea lions become entangled each year and at least 64 die as a

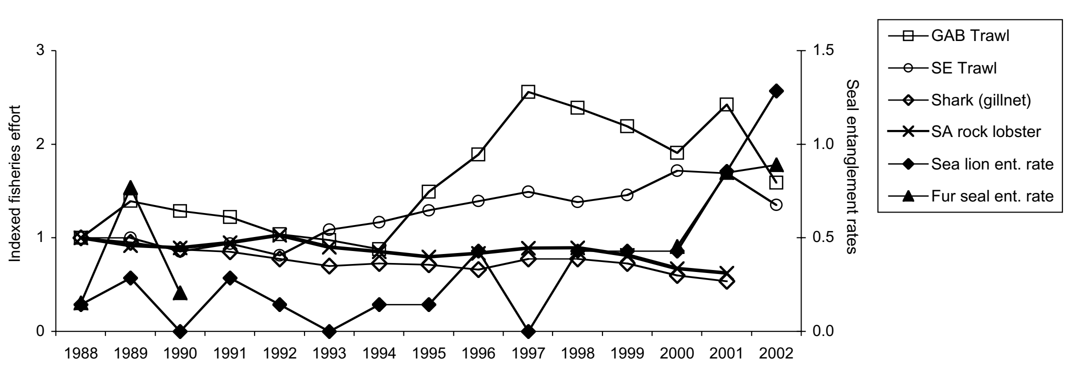

Fig. 3. New Zealand fur seal and Australian sea lion entanglement rates and annual fisheries efforts (indexed against 1988 values) in the Great Australian Bight Trawl Fishery (trawl hours), South East Trawl Fishery (trawl hours), Southern Shark Fishery (kilometres of gillnet) and the South Australian rock lobster fishery (pot lifts).

result (0.6% of the population, based on the minimum mortality rate: 44%).

One of the goals of the southern shark fishery Bycatch Action Plan is to identify whether fishing practices are having significant and detrimental interactions on Australian sea lions (AFMA, 2001b). Monofilament gillnetting is responsible for more sea lion entanglements (55%) than all other items combined, so its significance can not be understated. Australian fur seals in Tasmania also interact with gillnet fisheries (thought to be both recreational and commercial), accounting for 11.5% of entanglements (Pemberton et al., 1992). It is unlikely monofilament netting could fall off seals naturally because its mesh is designed to stretch and catch on fish as they struggle. As a result most sea lions entangled in monofilament netting would die. Under the Bycatch Action Plan requirements, research should be conducted to explicitly determine the nature and extent of interactions between sea lions and the southern shark fishery. This research should include satellite tracking and dietary studies of sea lions to determine the extent of spatial overlap in sea lion foraging effort with commercial fisheries and which gender and age classes of seals are more likely to interact with fishing activities. It should also include population modelling to determine the demographic impacts of entanglement-related mortality and the implications for Australian sea lion populations and their conservation status.

The effect of entanglements at the population level can only be assessed once basic demographic parameters are determined. Despite the current lack of demographic knowledge, the life history of Australian sea lions suggests the species is vulnerable to low levels of entanglement-related mortality. Female Australian sea lions breed every 18 months and as a result they have fewer reproductive opportunities relative to other seal species. To sustain sea lion populations, relatively large energy investments in pups must be compensated by high survival rates, not just among pups but also for juveniles and breeding females (Goldsworthy et al., 2003). The increasing number of entangled pups and juveniles observed since 2001 (Fig. 1) could be compounding the species' slow recovery from 19th century sealing. Furthermore, entanglement-related mortality at other sea lion colonies may be higher than at Seal Bay because seals at other sites are not released from entanglements and debris is not collected.

It is worth speculating why a large proportion of sea lions become entangled in monofilament nets when New Zealand fur seals from nearby colonies do not. Adult male and juvenile New Zealand fur seals would rarely encounter monofilament nets/debris because they forage in deeper waters than those used by the southern shark fishery (Page unpublished data, McLoughlin and Walker, 2002). Likewise, adult male Australian sea lions are thought to feed off the shelf (Costa personal communication) and would not fit their heads through the 15–16 cm diameter mesh of monofilament netting. Australian sea lion adult females, juveniles and pups and New Zealand fur seal adult females are thought to forage in regions where the southern shark fishery operates—on the shelf, south of Kangaroo Island (Costa and Gales, 2003, Page unpublished data). However, information on diving behaviour suggests Australian sea lions would encounter monofilament shark nets/debris more frequently than New Zealand fur seal females feeding in the same region. Australian sea lions are benthic foragers that search out cryptic prey such as rock lobster, octopus and benthic fish (Gales and Cheal, 1992; Costa and Gales, 2003), whereas New Zealand fur seal females mainly feed on schooling fish and squid in mid water (Page unpublished data). As monofilament shark nets are set close the seafloor, New Zealand fur seal foraging behaviour reduces the chance of them being caught in this material. However, Australian sea lions may frequently come across monofilament shark nets and may be attracted to them by struggling sharks. Young sea lions would be expected to be particularly prone to entanglement in monofilament netting as their inquisitive nature may attract them to netting, as is the case for northern fur seals (Fowler, 1987). Satellite tracking pups and juveniles may identify practical distances for shark fishers to operate around sea lion colonies and hence reduce the number of entanglements and also benefit commercial fishers.

The unique opportunity to walk amongst breeding Australian sea lions at Seal Bay is the cornerstone of Kangaroo Island's $72 million annual tourism industry (TOMM, 2002). During 2001, 138,000 tourists visited Kangaroo Island, 110,000 of who were guided through the sea lion colony (TOMM, 2002 and NPWSA unpublished data). As there are approximately 700 sea lions in the Seal Bay population (Shaughnessy unpublished data), each individual could be valued as an asset that attracts over $100,000 in tourist revenue annually ($72M—700 seals). If sea lions became extinct from the island the tourist industry would be considerably smaller. Research focussed on population trends of these valuable assets and threats to them is essential to protect the island's tourist industry.

4.2. New Zealand fur seals

The entanglement rate of New Zealand fur seals at Cape Gantheaume in 2002 (0.9%) is only exceeded by those of Australian sea lions (1.3%, this study), Australian fur seals (1.3–1.9%, Pemberton et al., 1992) and California sea lions in Mexico (3.9–7.9%, Harcourt et al., 1994). Based on the New Zealand fur seal entanglement rate in 2002 for the Australian population of 57,443 (Goldsworthy et al., 2003), we estimate 517 New Zealand fur seals become entangled each year and at least 295 of these die as a result (based on the minimum mortality rate: 57%). New Zealand fur seal populations are currently increasing (Shaughnessy and McKeown, 2002), suggesting that the current level of entanglement-related mortality is unlikely to be greatly affecting the species' recovery. However, given that New Zealand fur seals are protected species under Commonwealth, State and Territory Acts, reduction in entanglement rates should be pursued.

To reduce the impact of fishing on New Zealand fur seals, Commonwealth and State Governments should provide incentives to companies that use biodegradable packing tape or phase it out altogether. In the 1990s the Tasmanian rock lobster industry tried to reduce the use of packing tape. Cheaper, plastic-free bait boxes were developed to eliminate packing tape from this fishery. However these bait boxes were not mandatory and were taken up by few bait-packing companies (Jones, 1994). In South Australia some bait boxes used by commercial fishers are bundled in biodegradable packing tape, however its use is not mandatory. Seals that become entangled in biodegradable packing tape have a better chance of the material breaking before it cuts through their skin.

The rock lobster industry is a major source of marine debris in southern and Western Australia (Dalgetty and Hone, 1993; Edwards et al., 1992). Sixteen New Zealand fur seals were entangled in rock lobster fishery material, in addition to some packing tape entanglements that may have originated from the fishery. Because the code of best practice developed in 2000 by the rock lobster industry in South Australia recommended removing packing tape from bait boxes and leaving it in port before departure (Braund, 2000), it is surprising to see this material is still prevalent on fur seals and sea lions. The rope found on seals suggests fishers occasionally lose pots and/or floats, as the rope attaches floats to haul-in lines. New Zealand fur seals are also affected by trawl netting from the Great Australian Bight fishery and/or the south east trawl fishery, which is responsible for about 28% of entanglements.

The three seal species that breed in Australia have some of the highest entanglement rates reported for any seal species (Pemberton et al., 1992, this study). Based on the most recently reported entanglement rates and conservative estimates of subsequent mortality, approximately 1478 entangled fur seals and sea lions die in southern Australia each year [~64 Australian sea lions and ~295 New Zealand fur seals (this study) and ~1119 Australian fur seals (87% injured when sighted, Pemberton et al., 1992; Goldsworthy et al., 2003)]. Entanglement-related mortality is most likely slowing the recovery of Australian seal populations, particularly Australian sea lions. The nature and amount of entangling material in the marine environment highlights the need for further education campaigns to demonstrate the effect of plastic on marine animals. Governments should provide incentives to the fishing industry to implement simple remedies that could decrease seal entanglement rates, particularly with regard packing tape. To further assess whether government policies, industry initiatives and education campaigns reduce the impact of fisheries on the marine environment it is essential that monitoring of seal colonies and key fisheries is continued.

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