Dolphin interactions with tuna feedlots at Port Lincoln, South Australia and recommendations for minimising entanglements

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ABSTRACT

Cetacean carcasses near Port Lincoln and entanglements in southern blue-fin tuna feedlots were monitored between 1990 and 1999. Dolphins became entangled and died in large-mesh (usually > 15cm) anti-predator nets around the cages, from surface to seafloor (18m). The carcasses were retrieved and studied with respect to diet and life history. During the period of study, 29 dolphins (15 bottlenose, 9 common, 5 unidentified) were confirmed entanglement deaths and an additional eight unconfirmed reports of dead dolphins were made between 1993 and 1996. Beach-washed or floating carcasses of an additional 38 dolphins were found in the Port Lincoln region during 1990-1999, four of which were suspected entanglements. The carcasses of 23 entangled and four suspected entangled dolphins were studied for diet, and reproductive and relative age characteristics. At least 24 of the 33 entangled animals were juveniles or sexually mature animals, of which most of the females were pregnant or lactating. Three calves and no neonates were entangled. Gastrointestinal contents of 57 bottlenose and common dolphins from elsewhere along the coast of South Australia were also studied. Cephalopods were more abundant in bottlenose dolphins than common dolphins, including those entangled in tuna feedlots. Carangidae were the main identified fish prey of dolphins entangled in tuna nets. The study concluded that dolphins were being attracted to, and feeding in, the area of the cages. Recommendations for minimising entanglements include removing anti-predator nets or reducing mesh size to less than 8cm, reducing tuna food wastes and thereby the food source for other fish in the vicinity, and rigorous monitoring of both entanglements and dolphin populations in the Port Lincoln region.

KEYWORDS: BOTTLENOSE DOLPHIN; COMMON DOLPHIN; INCIDENTAL CATCHES; FOOD/PREY; FISH; CEPHALOPODS; REPRODUCTION; RELATIVE AGE; AUSTRALASIA

INTRODUCTION

Fisheries-marine mammal interactions have been the subject of much debate and concern worldwide for many years (Beddington *et al.*, 1985). There have been a growing number of publications on attempts to reduce cetacean bycatch in passive fishing nets, particularly gillnets and traps (see reviews in Perrin *et al.*, 1994). In several cases entanglements have been reduced by modifying gear or adding acoustic deterrent devices. Recent use of small, low-intensity acoustic deterrent devices ('pingers') has shown promising results in reducing particularly harbour porpoise (*Phocoena phocoena*) bycatches as well as some other species (e.g. Reeves *et al.*, 1996; IWC, 2000; Cox *et al.*, 2001). However, acoustic pingers cannot be considered a panacea for all species and areas and it may be that a combination of methods is optimal (Rossman, 2000; see also IWC, 2001b). Very loud deterrent devices (acoustic harassment devices) are often used to reduce predation on caged fish by pinnipeds (Reeves *et al.*, 1996) but the effect may be so great as to keep cetaceans away from a very large area around the nets, perhaps many square kilometres (Morton, 2000). The precise causes of cetacean entanglements remain unclear (IWC, 1994; IWC, 2001a, p.52) but in some cases it may be that dolphins simply 'switch off' to the obstruction because they are engrossed in other activities such as feeding (Cockcroft and Ross, 1991; IWC, 1994). As noted in IWC (1994), it is important to try to determine the factors influencing entanglements (e.g. location, type of net, attraction to the net) when attempting to devise ways to deter animals. In order to achieve this, more information is needed on the natural history of species prone to entanglement (Reeves *et al.*, 1996).

There have been few studies on cetacean entanglements in Australian waters (Bannister *et al.*, 1996). Bycatch in the protective shark nets along the Queensland coast and New South Wales beaches has included several species of dolphins (Paterson, 1990; Krogh and Reid, 1996). The highest recorded rates of entanglement (estimated at 4,662 in two years) were found in the Taiwanese pelagic gillnet industry off northern Australia in the 1980s (Harwood *et al.*, 1984; Hembree and Harwood, 1987). Kemper and Gibbs (1997) noted that at least 13% of all dolphin carcasses collected in South Australia (mostly from 1985-1996) died as a result of entanglement.

Throughout the world, studies on interactions between fish farming and marine mammals have focussed on pinnipeds (e.g. Wickens, 1995). Farming a potential or realised marine mammal prey species usually attracts predators, especially seals, as experienced by the marine salmon farming industry in Tasmania, Australia (Pemberton, 1989; Pemberton and Shaughnessy, 1993). However, little has been reported on interactions between cetaceans and fish farming operations. An unknown number of dolphin entanglements has occurred in the Chilean salmon cage fishery, which uses large-meshed anti-predator nets (Oporto and Gavilán, 1990; Perrin *et al.*, 1994). Baleen whale incidents include a gray whale (*Eschrichtius robustus*) dying in a herring net pen in British Columbia (Baird *et al.*, In press), a large baleen whale (probably a southern right whale, *Eubalaena australis* or a humpback whale, *Megaptera novaeangliae*) colliding with a salmon cage in Tasmania (Pemberton *et al.*, 1991) and a humpback whale breaking through the net of a tuna feedlot at Port Lincoln (Kemper and Gibbs, 1997). Fatal dolphin entanglements in the anti-predator nets of the salmon farms in Tasmania have been reported (Pemberton, 1996) but few entanglements have occurred in the farming of northern blue-fin tuna in Japan (Kasuya, pers. comm.). Experience in Australia suggests that the best way of reducing interactions between marine mammals and fish farming is by appropriate net design and feeding regimes, constant vigilance, site placement and gear maintenance (Pemberton, 1989; 1996; Pemberton and Shaughnessy, 1993; Schotte and Pemberton, 2001). On a worldwide scale, the number of cases of cetacean interactions with fish farming operations is certain to rise because of the rapid increase in aquaculture (Newton, 2000). It is important that these be monitored.

In South Australia, both a small 'inshore' (cf *Tursiops aduncus*) and large 'offshore' (cf *T. truncatus*) bottlenose dolphin have been described on morphological (Kemper and Gibbs, 1997) and genetic grounds (P. Hale, pers. comm.). The bottlenose dolphins entangled in Port Lincoln tuna feedlots were of the 'inshore' type, measuring less than 260cm. Morphological (Bell, 2001) and genetic (White, 1999) studies of the common dolphin in southern Australia (including those entangled in tuna feedlots) concluded that they were *Delphinus delphis*.

The aims of this study were to determine the diet, relative age, gender and reproductive status of dolphin carcasses from tuna feedlots and make recommendations to minimise entanglements. Carcasses found washed ashore in the vicinity of Port Lincoln were also examined to assess the probability of some being unreported entanglements. Gastrointestinal contents of bottlenose and common dolphins collected from other parts of South Australia were compared with those entangled in tuna feedlots.

MATERIALS AND METHODS

Study area and details of tuna feedlots

Tuna feedlotting has been practised in the Port Lincoln (Fig. 1) region since 1992 (ASIC, 1996), when a small number of research and development cages were set up. Leases, containing multiple cages, are licenced under agreement with the South Australian government. The number of cages[1] operating each year has varied but is generally increasing: 1993 (unknown), 1994 (33), 1995 (43), 1996 (65), 1997 (67), 1998 (unknown), 1999 (unknown), 2000 (110). Until April 1996, when a large number of tuna died[2], most of the cages were close to Boston Island with many on its protected western side in Boston Bay. Subsequently, most have been located in deeper (17-18m vs 15m) and less protected waters to the east of the Island and in Louth Bay (Fig. 1).

Boston Bay is a shallow (5-15m), protected bay with a sandy/silty bottom and slow water flow rates of 2.5cm/s (Aquaculture Group (Primary Industries), 1996). Particularly as a result of industry feeding practices, these characteristics have exacerbated environmental changes around the tuna feedlots (Cheshire *et al.*, 1996). Caged tuna are fed primarily pilchards (*Sardinops neopilchardus*) but other food such as squid and other fish (blue mackerel, *Scomber australasicus* and horse mackerel, *Trachurus declivis*) have also been used (ASIC, 1996). Tuna are fed once or twice a day, usually by shovelling dead pilchards from feeding boats into the cages. Industry practice is to overfeed the caged tuna and maximise growth rates. Considerable quantities of food are not consumed and either fall to the bottom or are consumed by a variety of fish and other species. For example, both the fish white trevally (*Pseudocaranx dentex*) and horse mackerel (both in the family Carangidae) have been found to feed around and within the tuna cages (ASIC, 1996; Smart, pers. comm.). Divers check the cages for dead tuna and entangled vertebrates every 1-3 days.

Tuna cages have generally been in place from about January-October each year but this has varied between feedlots and seasons. Cages are made of heavy-duty flexible nets with a drop from 12-20m hung from 30-50m diameter pontoons and anchored to the sea floor.

Initially, it was a condition of the licence agreement between operators and the South Australian Government that feedlots had anti-predator nets, presumably to protect tuna from sharks and pinnipeds. These were hung either 'on the bar' (square) or 'on the point' (diamond) at least 1m from the main net and were not enclosed at the bottom. Billowing sometimes occurred when the anti-predator net touched the sea floor at low tide. Stretched mesh size of the anti-predator nets ranged from about 8-30cm, with most being >15cm.

Statistics on anti-predator nets (number and characteristics) were not made available to the authors but anecdotal evidence suggested that there was some decrease in their use after recommendations to remove them were made in 1997 (Kemper and Gibbs, 1997). A formal reporting procedure for entangled marine mammals was not established until 1997 but prior to that, the South Australian Museum (SAM) was informed of some entanglements, particularly from one feedlot located to the southwest of Boston Island (Fig. 1; see Discussion).

Carcasses and samples

A total of 15 bottlenose and nine common dolphins were entangled in tuna feedlots (between January 1994 and June 1999) and were collected for study at the South Australian Museum (SAM). In addition, five entangled dolphins were reported to SAM but not collected for study. Thirty-eight other dolphin carcasses (31 examined by SAM) have been found washed up or floating in the vicinity of Port Lincoln between 1990 and 1999 (Figs 1 and 2). Carcasses of entangled animals were collected by tuna feedlot employees and those found washed up in the Port Lincoln vicinity were collected by government officers or members of the public. Dead dolphins from other parts of South Australia and of various causes of death (see below) were studied by SAM to compare their diet with animals entangled in tuna feedlots.

Carcasses were assigned to the following categories:

(ET) entangled in tuna feedlots = animals that died in the Port Lincoln tuna anti-predator nets;

(EP) entanglement probable = animals for which there was strong indirect evidence (e.g. partially digested food in oesophagus and found floating/flukes cut off/net wounds on flippers, peduncle or flukes) that entanglement was the cause of death;

(O) other = live-stranded, diseased, human-related death and unknown.

At the time of dissection, ET dolphins were usually relatively fresh (code 2 or 3, Geraci and Lounsbury, 1993), although one code 4 carcass (a common dolphin) could have been dead in an unattended anti-predator net on the seafloor for up to a month. Dolphins not entangled in tuna feedlots ranged from fresh to mummified (codes 2 to 5). Carcasses were usually frozen before being dissected. After fixation in formalin, large testes were weighed on an electronic pan balance to the nearest 10g and small testes were weighed on a Mettler balance to the nearest 0.01g. The sexual maturity of males was assessed by comparing testis weight with published studies on bottlenose (Harrison *et al.*, 1972; Mead and Potter, 1990) and common dolphins (Collet and Saint Girons, 1984). Based on these studies, testes of both species were considered mature when >50g (see Kemper and Gibbs, 1997).

The number of corpora lutea, corpora albicantia and follicles was noted after macroscopic examination of the

[1] Incomplete records supplied by the Tuna Boat Owners Association of Australasia and Department of Primary Industries South Australia.

[2] Possibly as a result of a toxic algal bloom (Paxinos, pers. comm.).

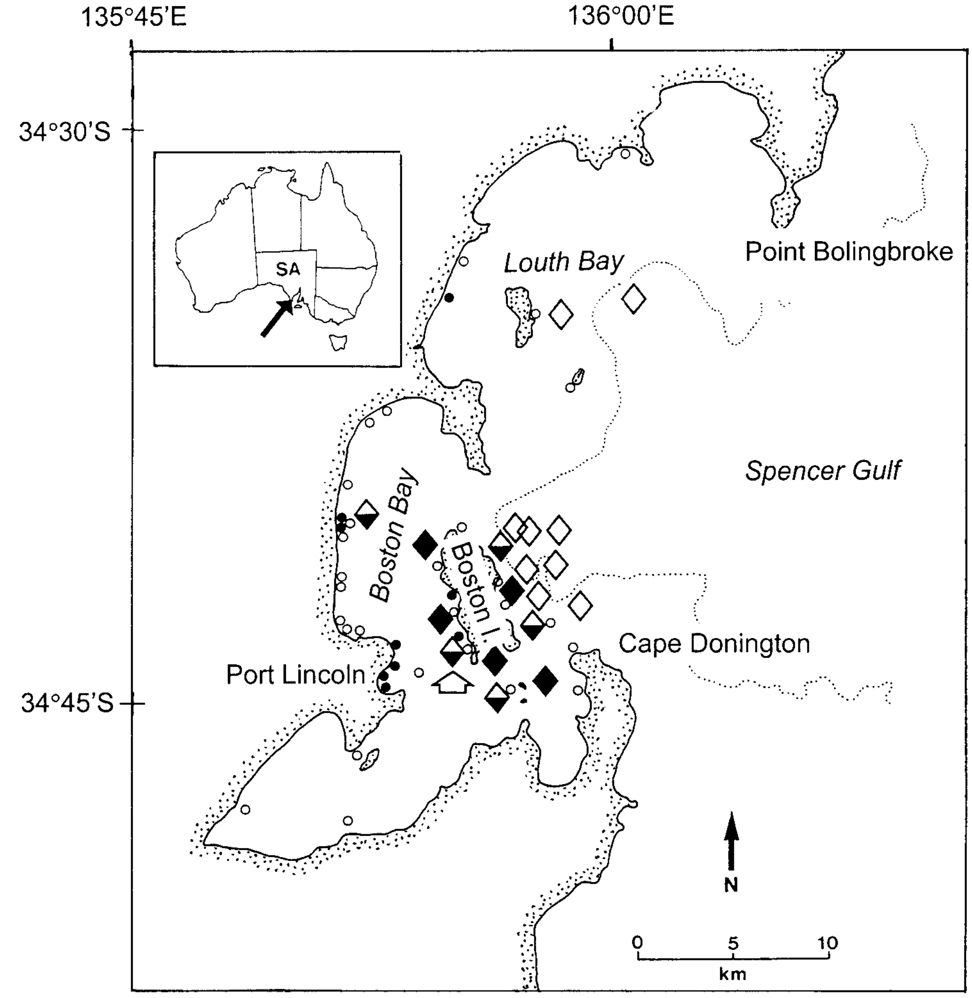

Fig. 1. Port Lincoln region, southwestern Spencer Gulf, South Australia. Diamonds are locations of tuna feedlot companies (solid = before May 1996; open = after April 1996; solid/open = both before and after). Arrow to south west of Boston Island shows farm where most dolphins were entangled up to 1996. Small circles are beach-washed and floating carcasses found during 1990-early 1996 (solid) and 1997-1999 (open). Dotted line is 18m water depth contour.

ovaries using the methods of Ivashin (1984) and Harrison *et al.* (1972). Females were assigned to the following classes:

(1) immature = no sign of past or present activity in ovaries or uterus;
(2) pregnant = visible foetus present;
(3) lactating = milk exuded when mammary gland cut during dissection;
(4) pregnant and lactating = simultaneously pregnant and lactating; and
(5) resting = presence of corpus albicans or corpus luteum with no observed foetus and not lactating.

Measures of relative age

Full skeletons were prepared for all animals entangled in the tuna feedlots and most of the others collected from the Port Lincoln area. The degree of epiphyseal fusion along the vertebral column was assessed and animals assigned to 'physically mature' if all vertebral epiphyses were well fused to the corresponding centra.

Animals were divided into relative age classes based on external developmental features, size and sexual and/or physical maturity:

(N) neonate = neonatal folds present and/or dorsal fin folded and/or trailing edge of fluke scalloped;
(C) calf = hairs on rostrum visible and/or tongue scalloped and/or milk present in stomach, body length < 150cm, the approximate length at weaning for *Delphinus* and 'inshore' *Tursiops* (Ross, 1984);
(J) juvenile = post-weaning (i.e. > 150cm body length) but not sexually or physically mature;
(S) sub-adult = sexually mature but not physically mature; and
(A) adult = both sexually and physically mature.

If no information on reproduction was available then animals were assumed to be sexually mature if they were physically mature (see Kemper and Gibbs, 1997).

Diet

There were 80 dolphin gastrointestinal tracts available for study, of which, almost 30% (15 bottlenose and 8 common) were from ET dolphins. Twenty of the ET dolphins were collected before 1997 and their contents have been identified and counted. The beaks and otoliths in the remaining three, collected in 1998 and 1999, have been counted only.

Gastrointestinal tracts were removed from the abdomen entire and either frozen for later examination or their contents removed immediately. If present, oesophageal contents were removed at dissection and treated separately. The stomach and intestines were flushed separately with water. Intestines were usually cut along parts of their length to aid in removing all material. Washings were screened through a 0.5mm Endocell Sieve. Prior to 1995, the contents of at least six ET and 10 other dolphins were preserved in 10% formalin but this practice was abandoned when it was realised that formalin erodes otoliths (Fitch and Brownell, 1968). These were unidentifiable and were used only for minimum counts.

Stomach contents were treated according to the methods of Treacy and Crawford (1981), except that the volume and weight of the contents were not determined due to the variable state of decomposition of carcasses. Identifiable items (fish parts but not otoliths, cephalopod parts, crustaceans, isopods and assorted other items) were removed and stored in 70% ethanol. Otolith pairs were removed from the heads of intact fish. Any remaining otoliths were removed from the loose contents with the aid of a magnifying ring lamp, after being screened through a 0.5mm sieve. All otoliths were dried and, using a binocular microscope, were identified to the lowest taxonomic level by comparison with an otolith reference collection of 70 South Australian fish species at SAM, and descriptions and photographs of otoliths in Smale *et al.* (1995). Otoliths that were not worn but could not be identified were sorted into forms and these given an identifying number for each animal. Eroded otoliths were labelled 'unidentifiable'. To obtain counts of minimum number of fish consumed, otoliths were first divided into left and right, then the maximum (whichever side was greater) was added to half of those unable to be assigned to side.

Cephalopod beaks were removed and immediately placed in 70% ethanol to prevent drying. With the aid of a magnifying ring lamp, they were then sorted into 'forms' and within these, upper and lower beaks. Beaks still in the buccal mass were removed and stored as a pair. To obtain counts of minimum cephalopods consumed, upper or lower beak numbers (whichever was the greater for each form) were totalled for each GIT and added to the counts of pairs removed from buccal masses. Beaks were compared with a reference collection of four inshore South Australian species at SAM, and descriptions and photographs of beaks in Clarke (1986).

RESULTS

Incidence of entanglements and other carcasses

A summary of available carcasses is given in Table 1. The reporting and collecting effort of dead dolphins from the Port Lincoln area was believed to have been relatively uniform throughout the study. However, publicity of the entanglements and the introduction of a formal reporting procedure may have influenced the number of reports.

Of the 29 reported entanglements from seven leases, the majority (19) came from one lease southwest of Boston Island (see Fig. 1). At this lease there was good cooperation from the manager. In addition, anti-predator net characteristics and feedlot location may have contributed to high rates of entanglement. The total number of ET dolphins collected for SAM was 24 (15 bottlenose, 9 common dolphins), all between January 1994 and June 1999 (Fig. 2). The remaining five unidentified dolphins were reported as entangled but not made available to SAM.

Between 1990 and 1999, 38 beach-cast or floating dolphin carcasses were reported from the Port Lincoln area, mostly near the feedlots or along the shores of Boston Bay (Fig. 1). Thirty-one were examined by SAM. There is strong evidence that four of these were unreported entanglements (see EP defined in 'Materials and Methods'), possibly from the tuna feedlots. Of the remaining 34 carcasses, 10 died as a result of other sorts of accidental or intentional acts by humans (shot, speared etc.) and 24, some very decomposed,

Table 1

A summary of causes of death of the 67 carcasses from the Port Lincoln region (see Fig.1). In addition, stomach contents from 24 other common and 19 other bottlenose dolphins from South Australian animals were examined. The key to the categories is given in the text.

Category	Common dolphin	Bottlenose dolphin	Unidentified	Total
ET	15	9	5	29
EP	2	2	0	4
O	19	11	4	34
Total	36	22	9	67

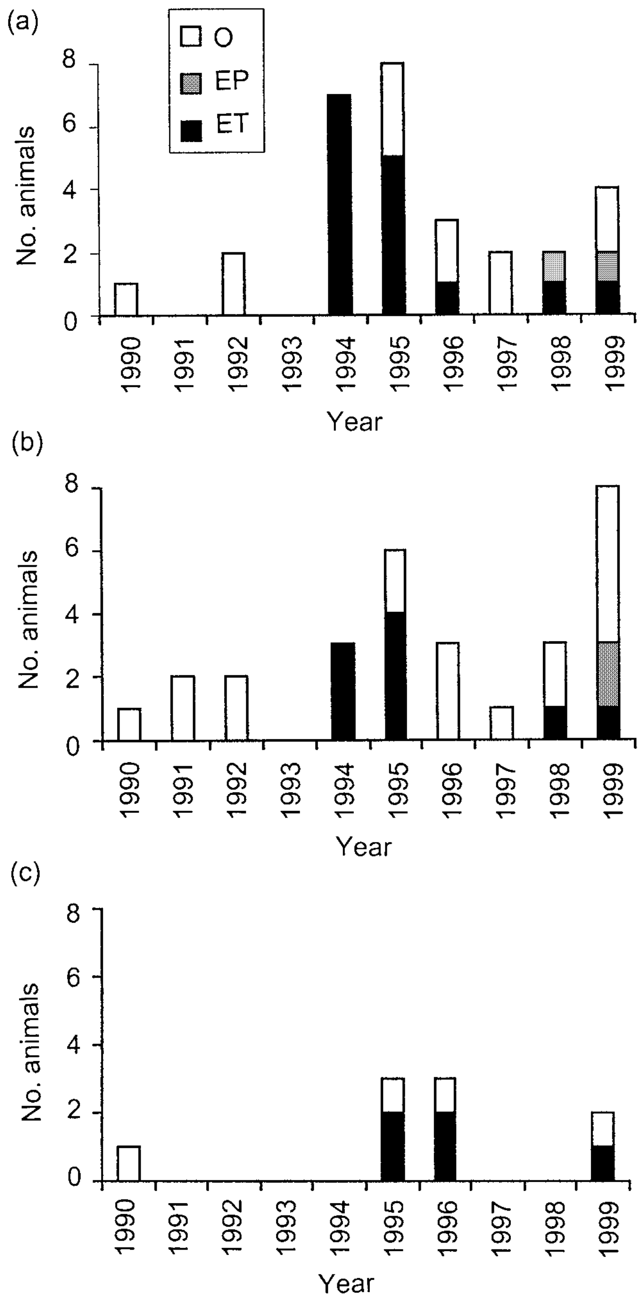

Fig. 2. Number of confirmed reports of dead (a) bottlenose, (b) common and (c) unidentified dolphins found in the Port Lincoln region during 1990-1999. Bars are divided into dolphins entangled in tuna feedlots (ET), suspected entangled in tuna feedlots (EP) and other circumstances of death (O).

died of unknown causes. Excluding ET dolphins, there were more (29 vs 9) dead dolphins found in the region during 1994-1999, after tuna feedlotting was well underway, compared with 1990-1993 (Fig. 2).

Entanglement characteristics

All reported entanglements during 1994-1996 were in anti-predator nets but due to the lack of a reporting procedure, no specific details were available on the characteristics of those nets, where the dolphins were found in them or how they were entangled. Anti-predator nets of the farm at which 19 of the 24 dolphin entanglements were reported during the 1994-1996 period were orange, thin, multiply-nylon, with a stretched mesh of at least 20cm and often loose and billowing.

Five datasheets, each for an individual dolphin entanglement (completed by farm operators), were submitted to SAM for entanglements during 1998, 1999 and early 2000. All entanglements were in anti-predator nets of cages 30-40m diameter with drops of 12-20m. Anti-predator nets were made of 4-5mm twisted nylon, were green or black in colour and had stretched mesh sizes of 8-23cm (all but one were > 15cm). Some were fouled by weed growth. The five entangled dolphins were found at a variety of depths (0, 3, 4, 4 and 18m) and with various parts of the body caught in the anti-predator net (head, rostrum, flippers, tail and whole body). One animal was found floating dead in the middle of the cage and had net marks on the head.

Reproductive status and relative age

Eighteen of the ET and EP bottlenose dolphins (from the Port Lincoln area) examined by SAM were juveniles and sub-adults (Table 2). Of the three subadult and four adult females, two were lactating and one had a large corpus luteum, was not lactating and had no obvious foetus. No neonates and only one calf was entangled. A neonate and calf were recorded in the other carcasses found in the region.

Of the four sexually mature ET and EP (from the Port Lincoln area) female common dolphins, one was pregnant, two lactating and one had a large corpus luteum and was neither lactating nor had an obvious foetus. No neonatal common dolphins were entangled. Only one neonate and one calf was present in the other carcasses found in the region.

Diet

Of the non-ET dolphin stomachs, 39% (22/57) were empty, compared with 13% (3/23) of those entangled in tuna feedlots. No EP dolphin stomachs (from the Port Lincoln area) were examined. Of the 25 animals with empty stomachs, 10 were calves and 15 were other relative age classes. Given the small and uneven sample size, it is not possible to compare the diet results of the different age groups.

Fish and cephalopod remains made up most of the recognisable food items and the information by individuals is given in Appendix 1. Isopods and crustaceans were present in small amounts.

Four cephalopods species were present: octopus, probably *Octopus australis*; cuttlefish, *Sepia apama*; and two squid species, arrow squid *Nototodarus gouldi* and southern calamary *Sepioteuthis australis.* Of the 23 (out of 31 with food remains) bottlenose dolphins that had cephalopods, 1,350 cephalopod beaks were recovered, representing a minimum of 840 individuals. For individual bottlenose dolphins, the number of cephalopods present ranged from 1-187 (Appendix 1). In order of overall abundance (minimum prey consumed), bottlenose dolphins consumed octopus (415), cuttlefish (246) and southern calamary (191); no arrow squid were found. Of the 18 (out of 25 with food remains) common dolphins that had cephalopods, 231 cephalopod beaks were recovered, representing a minimum of 138 individuals. For individual common dolphins, the number of cephalopods present ranged from 1-88 (Appendix 1). In order of abundance (minimum prey consumed), common dolphins consumed southern calamary (128), arrow squid (8) and octopus (2). Arrow squid and octopus were found in only three common dolphins, all ET. No cuttlefish were found in common dolphin gastrointestinal tracts.

Fish remains were found in 44 dolphins. Eight dolphins that had food remains (3 bottlenose, 5 common) had no recognisable fish remains. A total of 20 otolith forms were identified to some taxonomic level (Appendix 1). From the 16 bottlenose dolphins containing otoliths, 315 were recovered (minimum fish consumed = 190). The main fish families, in order of presence/absence, were Carangidae, Gerreidae, Moridae, Clupeidae, Scombridae, Mugilidae and Pempherididae (Appendix 1). Other fish families occurred in only single dolphins. From the 13 common dolphins containing otoliths, 883 were recovered (minimum consumption = 427). The main fish families present, in order of presence/absence, were Clupeidae and Carangidae, with other families occurring in single individual dolphins.

Thirteen out of 23 ET dolphins had stomachs that contained intact fish and cephalopods, and therefore had eaten a short time before death. Seventeen contained cephalopod beaks, representing minimum consumptions per individual of 1-170 (bottlenose = 1-170, common = 1-15). More species/forms of fish were identified in ET dolphins than those dying by other means (Appendix 1). There was a significant difference (Mann-Whitney test, $p < 0.01$) in the minimum number of fish eaten by individual common, but not bottlenose dolphins, from the tuna feedlots when compared with other circumstances of death. The maximum

Table 2

Relative age classes of dolphins entangled (ET), probably entangled (EP) and other causes of death near Port Lincoln. Only animals examined at SAM included. Numbers in parentheses are male, female and unknowns. See 'Materials and methods' for definitions of classes.

Species	Neonates	Calves	Juveniles	Subadults	Adults
Bottlenose dolphin					
ET and EP	0	1 (0, 1)	7 (5, 2)	6 (4, 2)	2 (1, 1)
Other	1 (1, 0)	1 (1, 0)	1 (1, 0)	1 (1, 0)	4 (3, 1)
Common dolphin					
ET and EP	0	2 (1, 1)	2 (0, 2)	3 (2, 1)	4 (1, 3)
Other	1 (0, 1)	1 (0, 1)	7 (0, 7)	1 (0, 1)	5 (3, 1, 1)

number of otoliths in an individual ET bottlenose dolphin was 73 (minimum consumption = 60) which was the highest recorded consumption for a bottlenose dolphin in the study. The following families were recorded, in order of numerical importance: Carangidae, Gerreidae, Moridae, Clupeidae, Mugilidae, Sciaenidae and Sillaginidae. For common dolphins the following families were recorded, in order of numerical importance: Carangidae, Clupeidae, Hemiramphidae, Arripidae and Scorpaenidae. The highest minimum consumption of fish for an ET common dolphin was 104, also the highest for the study.

DISCUSSION

It is commonly thought that many species of dolphins are attracted to fishing nets and forage nearby (e.g. IWC, 1994) either on the target species of the fishery or others found in the same area. Two lines of evidence from the present study suggest that dolphins may be attracted to fish farms. The first is that fish species in the family Carangidae, known prey of bottlenose and common dolphins (e.g. Silva, 1999; Barros *et al.*, 2000), were the primary identified fish prey in both dolphin species entangled in tuna feedlots; these species were common around the feedlots. Interestingly, fish surveys of the bays in the Port Lincoln area in 1985, before tuna feedlotting began, did not record any carangid species (Jones, 1986). It is possible that tuna feedlotting created a new feeding ground for them. The second is that many of the entangled dolphins had relatively undigested stomach contents, indicating that they were feeding around the time of death.

Bottlenose dolphins would be expected to take advantage of the abundant prey in the vicinity of the tuna feedlots because they are known to do so in other fishing operations (e.g. Corkeron *et al.*, 1990) and have been observed foraging near fish farms in the Ionian Sea (Bearzi *et al.*, 2001). They are often found in near-shore waters (e.g. Corkeron, 1990; Scott *et al.*, 1990; Cockcroft and Ross, 1991) and have been seen frequently in Boston Bay. Their catholic diet (Cockcroft and Ross, 1990; Gales *et al.*, 1992; Hanson and Defran, 1993; Bannister *et al.*, 1996) would allow them to take advantage of a variety of prey species in the bay.

Prey distribution has been reported to strongly influence the movements of common dolphins (Evans, 1980; Young and Cockcroft, 1994) which feed on the most abundant and easily-captured species, usually pelagic shoaling fish and cephalopods (Evans, 1980; Young and Cockcroft, 1994; 1995; Ohizumi *et al.*, 1998; Silva, 1999). Common dolphins are known to interact with some fishing operations (e.g. IWC, 1994; Tregenza *et al.*, 1997).

Cockcroft and Ross (1991) noted that the proportions of age/sex classes of bottlenose dolphins captured in shark nets off South Africa were biased towards lactating females and weaned or weaning calves. They concluded that this was due to the preference by breeding females and calves (compared with adult males) for smaller fish in the inshore environment. The number of animals entangled at Port Lincoln was too small to confirm whether a similar trend was occurring, although 50% of the bottlenose dolphins were calves or juveniles. Perhaps these age groups are more prone to entanglement because they are inexperienced (e.g. IWC, 1994) and/or are more abundant than other age classes in the general population or in the vicinity of the tuna feedlots.

There are a number of potential factors involved in entanglements in the predator nets of the Port Lincoln tuna feedlots and these are discussed briefly below.

The nature of the anti-predator nets

These nets were often hung above the bottom at high tide and were not enclosed at their base. Dolphins may have been able to get between the anti-predator and internal nets but then not have been able to surface, which may have resulted in entanglements, possibly due to panic. Bottlenose dolphins may be particularly susceptible to this since they are known to feed on bottom-dwelling prey (Cockcroft and Ross, 1990). Unrepaired holes in the nets would also have allowed dolphins to get between the two nets. There have been several cases of dolphins becoming entangled after having entered the space between the anti-predator and main nets of salmon farms in Tasmania (D. Pemberton, pers. comm.).

Loose and billowing nets will entangle an animal much more easily than taut nets because the animal becomes enfolded in the net. Billowing probably occurs in some anti-predator nets at low tide because the weights at the bottom of the nets touch the substrate. Pemberton (1996) recommended solid-meshed anti-predator fences from the sea bed to 1.5m above the surface to reduce pinniped attacks on tuna. These might also stop cetacean entanglements.

The range of stretched mesh sizes for anti-predator nets was 8-30cm, with most being > 15cm. The recommended mesh size to avoid dolphin entanglements is 2-3 inches (5-7cm) (W. Perrin, pers. comm.). Hanging anti-predator nets ‘on the bar’ would give a narrower hole size and a more taut net.

Dolphin behaviour

Bottlenose dolphins have acute echolocation abilities and are able to detect the presence of nets (Murchison, 1980) so they must be able to detect anti-predator nets. When nets are heavily fouled they must be even easier to avoid because nets would almost appear as a ‘wall’. If dolphins were entangled from outside the net, they may have been oblivious to its presence, perhaps because they were preoccupied chasing fish (Cockcroft and Ross, 1991; Goodson *et al.*, 1994; Perrin *et al.*, 1994).

Impact of entanglements

The true number of entangled dolphins in the Port Lincoln tuna feedlots was probably higher than the 29 reported and four suspected cases documented here. For example, when questioned about entanglements, some feedlot managers in 1996 reported that another eight may have occurred between 1993 and 1996 (Kemper and Gibbs, 1997). An additional three dolphins are known to have died during entanglement in 2000. There was also a high number of beached-washed dolphin carcasses in the Port Lincoln region during 1990-1999 (38 = 12% of South Australia’s reported total during the same period, Kemper, unpublished data). The minimum number of dolphin mortalities in the region for that decade was 80 and in mid-2000 this showed no signs of easing. During 2000, 17 beach-washed or floating carcasses were reported, 14 of which were common dolphins. There have also been unconfirmed reports of dolphin (possibly common dolphin) mortalities associated with the pilchard fishery off Port Lincoln; some of the above-mentioned carcasses could have been associated with this. The effect of the total human-induced mortality on populations of bottlenose and common dolphins in the southwestern Spencer Gulf cannot be estimated given the absence of information on the stock structure, abundance and reproductive capacity of either species in the region. Future research should include these latter fields.

Recommendations

The study had many limitations (e.g. small number of reported entangled dolphins, eroded otoliths for stomachs collected during the early 1990s, limited otolith reference collection, insufficient data on the fish fauna, poor reporting procedure for entanglements). Notwithstanding these, we believe that the available information justifies the following recommendations in order to improve the environmental acceptability of the tuna feedlot industry.

(1) Intiate an observer programme to investigate the magnitude of bycatch of dolphins in tuna feedlots.
(2) Initiate a study to collect the necessary information on common and bottlenose dolphins in the Port Lincoln area in order to ascertain the impact of entanglement mortality on their long-term viability.
(3) Review the use of anti-predator nets. If they are not removed and some other means of repelling tuna predators installed, the mesh size should be reduced to <8cm (stretched), the nets should be hung so that billowing does not occur and the nets should be enclosed at the bottom. Any holes in the nets should be repaired immediately.
(4) The use of acoustic harassment devices (and possibly pingers) might detrimentally affect the movements of dolphins in the area. If their introduction is considered, a pilot study on their effects on cetaceans should be designed and monitored by qualified researchers and the results made available before widespread use is allowed.
(5) Feeding programmes should be developed which minimise waste food and a study undertaken on the behaviour and food preferences of marine mammals around tuna and other finfish farms.
(6) Reporting and collecting entangled vertebrates should be monitored by the government and the carcasses made available to those researching them. A system of rewarding operators who do report might encourage more to do so. A long-term marine mammal/fisheries interaction working group should be set up under South Australian Government direction.
(7) The impact of tuna feedlots on the marine invertebrate and fish faunas of the region should be monitored and the information made available.

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Appendix 1

Table 1

Bottlenose dolphin fish (otoliths) and cephalopod (beaks) consumption expressed as minimum numbers consumed (see 'Materials and methods'). Each column represents one animal (gastro-intestinal tracts that did not contain otoliths or beaks are not included). C = calf; J = juvenile; S = subadult; A = adult; ? = identification of fish species probable; + = unknown forms within individual stomach, e.g. unknown form 1 not necessarily same in each stomach; * = unidentifiable expressed as total otoliths, i.e. not minimum fish consumed because left and right indeterminable; ** = minimum number of fish or cephalopods consumed. Dolphins with no cephalopods in the gastro-intestinal tract not included.

	Entangled												Other															
Species	J	J	J	J	J	J	S	S	S	S	A	A	J	J	J	J	J	J	S	A	A	A	A	A	A	A	A	A
Octopus	7	9	-	16	42	14	94	2	33	-	8	12	28	5	4	2	-	-	2	1	111	1	10	3	10	-	-	1
Sepia apama	5	6	-	6	18	1	61	1	22	-	-	3	-	-	-	-	-	-	18	48	-	5	9	-	39	-	-	4
Sepioteuthis australis	1	8	2	5	2	4	15	1	3	-	9	11	1	1	-	2	-	-	21	12	76	2	4	2	5	-	1	3
Minimum cephalopods**	13	23	2	27	62	19	170	4	58	-	17	26	29	6	4	2	-	-	41	51	187	8	23	5	54	-	1	8
Carangidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudocaranx dentex	?3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trachurus novaezealandiae	3	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
T. declivis	7	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Gerreidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parequula melbournensis	-	-	-	-	-	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	3	-
Moridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Pseudophycis sp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Clupeidae	2	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sardinops neopilchardus	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scombridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scomber australasicus	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mugilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aldrichetta forsteri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-	-
Sciaenidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Argyrosomus hololepidus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	5	-	-
Pempherididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pempheris klunzingeri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
P. multiradiata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?1	-
Scorpaenidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?1	-
Maxillicosta scabriceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
Labridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Notolabrus tetricus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Sillaginidae	?3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mullidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Upeneichthys vlamingii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
Terapontidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pelates octolineatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?1	-	-	-	-	-	-	-	-	-	-
Platycephalidae	?1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranoscopidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?7	-	-	-	-	-	-
Unknown 1+	1	2	5	-	-	-	-	-	14	-	-	-	-	-	-	-	1	-	-	-	-	2	1	-	2	-	-	-
Unknown 2+	1	1	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-
Unknown 3+	3	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Unknown 4+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Unidentifiable*	12	5	5	-	-	-	-	-	23	-	-	-	-	-	-	-	3	3	-	-	-	4	3	1	2	-	3	-
Minimum fish**	32	5	14	4	-	-	-	-	60	4	-	-	-	-	-	-	4	2	-	-	-	28	12	5	6	5	9	-

Table 2

Common dolphin fish (otoliths) and cephalopod (beaks) consumption expressed as minimum numbers consumed (see 'Materials and methods'). Each column represents one animal (gastro-intestinal tracts that did not contain otoliths or beaks are not included). C = calf; J = juvenile; S = subadult; A = adult; ? = identification of fish species probable; + = unknown forms within individual stomach, e.g. unknown form 1 not necessarily same in each stomach; * = unidentifiable expressed as total otoliths, i.e. not minimum fish consumed because left and right indeterminable; ** = minimum number of fish or cephalopods consumed. Dolphins with no cephalopods in the gastro-intestinal tract not included.

	Entangled							Other															
Species	J	J	S	S	A	A	A	J	J	C	A	J	J	S	C	C	J	J	J	J	J	A	A
Octopus	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Seipioteuthis australis	7	2	8	1	2	2	-	1	1	3	4	88	1	1	1	2	-	-	2	1	-	-	1
Nototodarus gouldii	-	1	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Minimum cephalopods**	8	4	15	1	2	2	-	1	1	3	4	88	1	1	1	2	-	-	2	1	-	-	1
Carangidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-
Pseudocaranx dentex	-	-	1	-	?11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trachurus novaezealandiae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. declivis	-	16	?4	4	?6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clupeidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	1	-
Sardinops neopilchardus	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
Hemiramphidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyporhampus melanochir	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H. regularis	-	-	?1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arripidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arripis truttacea	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scombridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scomber australasicus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Scorpaenidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maxillicosta scabriceps	-	-	?6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinolestidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinolestes lewini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?1	-	-	-	-	-
Unknown 1+	-	38	1	5	1	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-
Unknown 2+	-	30	1	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown 3+	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown 4+	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown 5+	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown 6+	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentifiable*	-	18	10	15	-	-	-	-	-	-	-	-	-	-	-	9	-	11	-	24	2	8	18
Minimum fish**	-	93	67	45	28	-	104	-	-	-	-	-	-	-	-	6	29	14	1	12	1	6	21