Strandings of dolphins in the Adelaide Dolphin Sanctuary, South Australia

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ABSTRACT

The Adelaide Dolphin Sanctuary was gazetted in 2005 to protect a resident population of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) that lives in a heavily impacted urban environment. This study assesses the numbers and types of strandings before and after the creation of the sanctuary. Monitoring took place during 1987–2013, when 57 events were reported and 53 carcasses were examined by post-mortem. Events were assigned to a circumstance of death that combined post-mortem results and/or anecdotal information. The majority of records were Indo-Pacific bottlenose dolphins (n = 47, 82%) but a few common dolphins (*Delphinus delphis*, n = 7, 12%) were also documented. Many (n = 19/46, 41%) of the Indo-Pacific bottlenose dolphins were 1 year old or less. Strandings averaged 2.19 per annum for all dolphin species and 1.80 for Indo-Pacific bottlenose dolphins. When pre- (n = 20) and post-sanctuary (n = 27) data were compared for Indo-Pacific bottlenose dolphins, anthropogenic events decreased from 30% (n = 6/20) to 7% (n = 2/27) and no intentional (illegal) killings or entanglements were recorded after 2004. Unintentional anthropogenic mortalities were primarily boat collisions (n = 4 out of 5 cases). Disease was the most frequently recorded circumstance of death (n = 21) and although the number of cases increased after 2004, this may have been due to improved pathology investigations. Live strandings were rare during the study (n = 2). Despite a significant increase in overall dolphin mortalities pre- and post-sanctuary, the number of human-induced mortality events decreased significantly. Continued monitoring and post-mortems of carcasses is recommended for managing dolphins in the sanctuary.

KEYWORDS: AUSTRALASIA; INDO-PACIFIC BOTTLENOSE DOLPHIN; SANCTUARIES; REGULATIONS; CONSERVATION

INTRODUCTION

Cetaceans are iconic species that are protected by law in most western countries yet are still under threat due to human activities. Unintentional mortalities can result from entanglement in fishing and other gears and from vessel collisions, both of which are believed to be leading causes of cetacean mortality worldwide (e.g. Reeves *et al.*, 2013; Thomas *et al.,* 2016; Van Waerebeek *et al.*, 2007). In order to mitigate these interactions, some countries have introduced legislation to reduce vessel speeds (Read, 2000; ASCOBANS, 2015) and reduce and monitor bycatch through improved fisheries reporting (Read, 2000). The creation of marine protected areas in which there are effective mitigation measures can also assist cetacean conservation (Hoyt, 2005; Gormley *et al.*, 2012). Marine protected areas specifically designed to protect cetaceans have increased since the early 2000s (Hoyt, 2005).

Ecosystem-based management is the most effective strategy for marine protected areas, including those focused on cetaceans (Hoyt, 2005). This approach attempts to meet the needs of the environment while addressing the impacts of human activities (Hooker and Gerber, 2004). Cetaceans can benefit from these integrative strategies if the protected area is properly managed (Bearzi, 2012). Although cetaceans have not historically been the focus of protected areas, management plans have increasingly included them as important components of the ecosystem. Examples include the Moray Firth Special Area of Conservation in Scotland (Cheney *et al.*, 2014) and the Pelagos Sanctuary in the Mediterranean (Hoyt, 2005). In 2005, the Adelaide Dolphin Sanctuary Act (2005) was established to protect a resident population of Indo-Pacific bottlenose dolphins and its habitat, including Barker Inlet and adjacent waters of Gulf St. Vincent (DEWNR, 2007).

Management of the Adelaide Dolphin Sanctuary (ADS) adopts an integrative and passive management approach, meaning that the sanctuary is monitored but not heavily regulated as activities such as shipping and fishing are still allowed (DEWNR, 2008). Community engagement and education on the ADS raise awareness of conservation issues and well-trained volunteers act as wardens of the sanctuary. Wardens assist with boat patrols, perform land-based and boat-based surveys of dolphins and conduct surveys on human attitudes toward the sanctuary. Non-government organisations have also been actively involved in studying and protecting the dolphins. The lead agency in sanctuary management is the South Australian Department of Environment and Water, with support from other government departments (DEWNR, 2008).

The target species of the ADS is the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*). However, common bottlenose dolphins (*Tursiops truncatus*) and common dolphins (*Delphinus delphis*) are also frequently recorded in South Australia. Common bottlenose dolphins inhabit the open ocean coast outside Gulf St. Vincent and common dolphins occur within the gulf but away from the coast (Kemper *et al.*, 2008). About 30 resident Indo-Pacific bottlenose dolphins live in the sanctuary, with an additional 20 transients from nearby regions at any one time (Kemper *et al.,* 2008).

A South Australian stranding network began in the early 1990s and has resulted in a database that contains almost 2,000 records. These data have been summarised in several publications related to circumstance and cause of death (Kemper *et al.*, 2005; Tomo *et al.*, 2010; Segawa

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and Kemper, 2015). The most frequent anthropogenic circumstance/cause of death was entanglements in fishing and aquaculture nets and lines, which accounted for 17% of all cetacean mortalities examined by the South Australian Museum (SAM) (Kemper *et al.*, 2005). Common dolphin entanglement mortalities in the purse seine South Australian Sardine Fishery numbered 377 in one year, prior to the adoption of a code of practice (Hamer *et al.*, 2008). In addition, many entanglements have occurred as a result of the tuna feedlot industry (Kemper and Gibbs, 2001). Other types of unintentional anthropogenic mortalities, such as boat collisions, were much less frequent than entanglements in South Australia (Segawa and Kemper, 2015). Intentional (illegal) killings accounted for only 5% of mortality from 1881 to 2000 and some regions, including Adelaide, were noted as problematic (Kemper *et al.*, 2005). Non-anthropogenic mortalities made up 58% of records, with disease, live strandings and other natural causes being noted (Segawa and Kemper, 2015). Tomo *et al.* (2010) considered that lung nematode infections were an important cause of mortality in common dolphins, especially during 2005–2006. In 2013, an Unusual Mortality Event (UME) occurred in Gulf St. Vincent, which was linked to morbillivirus infection in bottlenose dolphins (Kemper *et al.*, 2016).

There has been no published assessment of dolphin mortalities focusing on the Adelaide region. The present study analyses patterns of live strandings and mortalities of Indo-Pacific bottlenose dolphins in the ADS. It provides a baseline for future comparison and a preliminary assessment of the efficacy of management by comparing circumstance of death before and after the sanctuary was created.

METHODS

The ADS is located on the eastern shore of Gulf St. Vincent and includes the lower reaches of the Port River, Barker Inlet and coastal waters to the north (Fig. 1; DEWNR, 2007). The 118km^2 sanctuary incorporates mangroves, tidal flats, salt marshes, seagrass beds and tidal creeks (DEWNR, 2007). The adjacent terrestrial environment is urbanised and industrial. The metropolitan centre of Adelaide (population 1.2 million) is nearby and the banks of the Port River contain important infrastructure, such as a wastewater treatment plant (Fig. 1). The port is the busiest in South Australia, with 2,000 large vessel (approximately 50 to 300m length overall) movements annually (DEWNR, 2008). Water depth ranges from 2 to 16m and the tidal range in the Gulf St. Vincent is approximately 3m (Kämpf *et al.*, 2009). A study conducted by Bossley *et al.* (2017) separated the estuary into two areas. The 'Outer Estuary' was designated as the portion of the estuary in contact with Gulf St. Vincent, which shared similar water quality and the 'Inner Estuary' was the area exposed to a high amount of anthropogenic inputs such as wastewater and heat effluent (Fig. 1; Bossley *et al.*, 2017).

Dolphin strandings, including live strandings and carcasses, were recorded from the sanctuary region during 1987–2013 by SAM. Of 57 documented events, 53 carcasses were collected for post-mortem examination. Species identifications were verified using photographs (in the case of dolphins not collected) and skulls of those collected. When insufficient information was available to identify species, the terms 'bottlenose dolphin' (*Tursiops* sp.) or 'dolphin' were applied.

The SAM and associates improved the pathology findings gained from post-mortems after 2004 when a wildlife pathologist (IT) joined the team. Routine procedures included external and internal examination and photographs, body measurements, gross and histopathology and bacteriological and virological testing. Reproductive organs were collected to determine sexual maturity status and stomach contents were examined for diet and ingested foreign bodies. In most cases, full skeletons were collected and prepared by warm-water maceration.

Relative age was determined for necropsied dolphins using developmental features, body length, sexual maturity and physical maturity of the skeleton (Kemper and Gibbs, 2001). For dolphins that were not collected, neonates could be identified when photographs showed foetal folds and calves could be identified if body length was available. Estimated age of Indo-Pacific bottlenose dolphins was determined by counting incremental layers in the dentine of decalcified, thin-sectioned and stained teeth (Evans *et al.*, 2011). Two teeth were examined for each dolphin and three sets of estimates were made by at least two readers. A mean was calculated to obtain an overall age estimate for each dolphin. The number of GLGs (growth layer group) deposited per annum was assumed to be one.

Strandings were assigned to one of eight categories relating to the reported circumstances surrounding them and results of post-mortem, if performed. These categories were:

(1) Intentional Killing: Intentional harm by humans causing death, such as shotgun or knife wounds.

(2) Other Unintentional: Unintentional/accidental anthropogenically-related deaths such as boat-strikes or propeller wounds.

(3) Entanglement: Dolphin removed from fishing or aquaculture gear or remains of gear found on carcass.

(4) Probable Entanglement: Evidence of entanglement (net marks and body slit or mutilated by human or physiological evidence of entanglement) but without the presence of gear.

(5) Disease: Deaths related to disease, such as pneumonia or infections.

(6) Other Natural: Natural deaths not related to disease, such as starvation, choking on shark and neonatal death.

(7) Live Stranding: Seen alive on the beach and either died there or was euthanised.

(8) Unknown: No cause of death could be identified.

The first four categories were considered anthropogenic circumstances because they were directly and demonstrably related to human activities. The Other Unintentional category is comprised of accidental mortalities resulting from human activities, such as injuries incurred from boats (Kemper *et al.*, 2005). The categories Disease, Other Natural and Live Stranding were treated as a natural circumstance of death, although the authors note that anthropogenic pollutants can lead to immunosuppression in cetaceans (Isobe *et al.*, 2011).

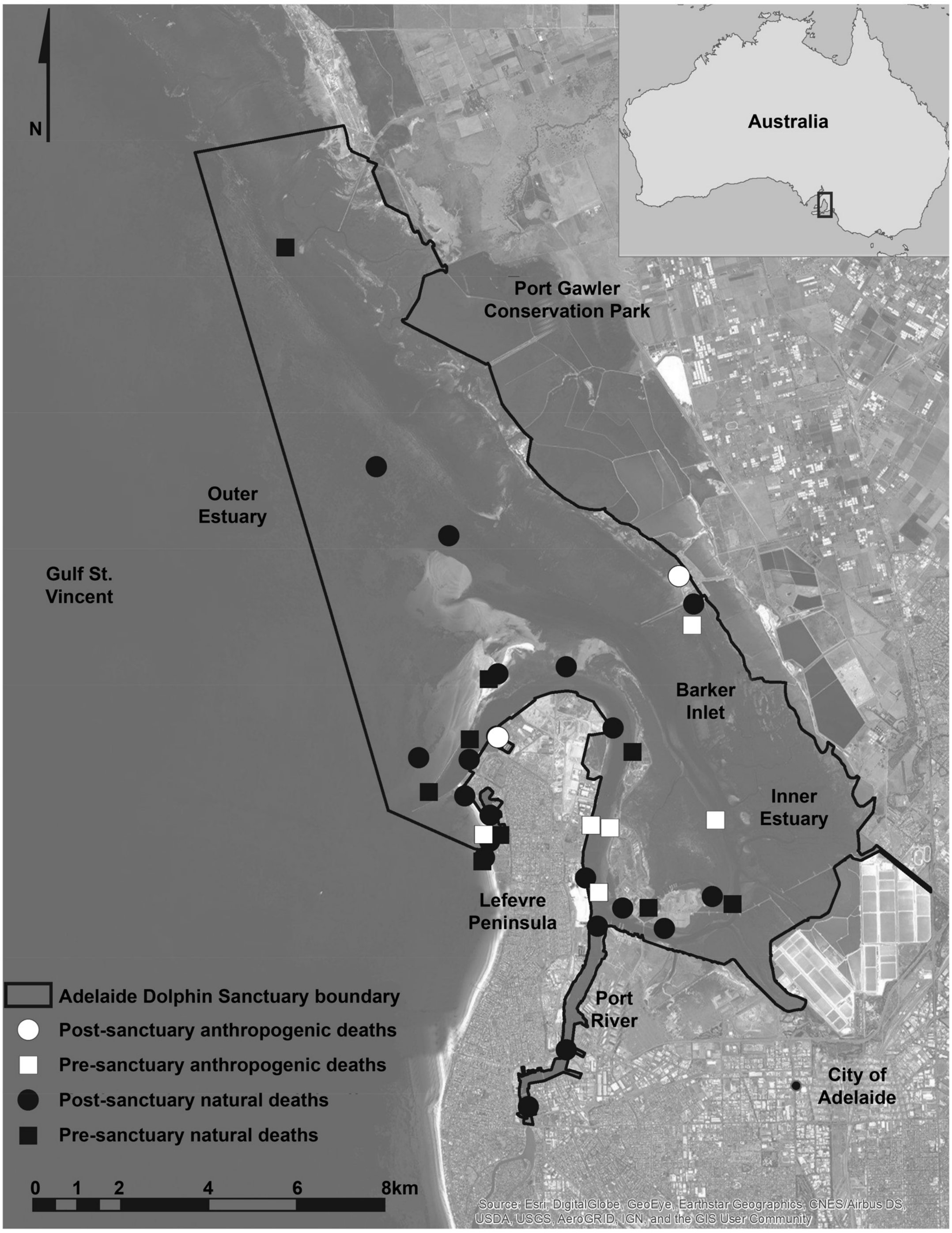

Fig. 1. Map of study area showing Indo-Pacific bottlenose dolphin strandings divided into non-anthropogenic mortalities (Stranding, Other Natural, Disease) pre-sanctuary (n = 9) and post-sanctuary (n = 20) and anthropogenic mortalities (Other Unintentional, Entanglement, Intentional Killing) pre-sanctuary (n = 6) and post-sanctuary (n = 2).

Statistical tests were computed using the default statistics package in R (R Development Core Team, 2016). Pearson's Chi-square test was used to compare sexes and anthropogenic versus non-anthropogenic strandings, both pre-and post-sanctuary. An F-test showed that there were unequal variances between pre- and post-sanctuary annual counts of events, therefore a non-parametric Wilcoxon signed rank test was used. Cases classified as unknown were not included in statistical analyses.

RESULTS

The total number of strandings recorded within the sanctuary during 1987–2013 was 57 (Table 1). Most individuals were bottlenose dolphins (n = 48), of which the majority (n = 47) were verified as Indo-Pacific bottlenose dolphins. Strandings were clustered around the Lefevre Peninsula and the western part of Barker Inlet (Fig.1), where there was considerable human activity. Six out of the seven common dolphins were outside Barker Inlet and the Port River. There appeared to be no clear geographic pattern of strandings related to pre- and post-sanctuary, nor anthropogenic and non-anthropogenic circumstances (Fig. 1), although sample size is small. The assumption made in this paper is that carcasses were found close to where the dolphins died.

Of the Indo-Pacific bottlenose dolphins aged by tooth preparations, the oldest was 23 years and individuals 1 year

Table 1

Strandings of dolphins in the Adelaide Dolphin Sanctuary before (1987–2004) and after (2005–13) its gazetting. Number of carcasses that were not collected are in parentheses and included in the number to the left.

Species	1987–2004	2005–3
T. aduncus	20 (0)	27 (2)
Tursiops sp.	1 (1)	0 (0)
D. delphis	4 (0)	3 (0)
Unidentified dolphin	27 (3) 1.59/year	30 (2) 3.75/year

Table 2

Number of Indo-Pacific bottlenose dolphins in five relative age classes before (1987–2004) and after (2005–13) the Adelaide Dolphin Sanctuary was gazetted. Estimated ages were calculated for 34 dolphins using tooth structure. Range of ages for each relative age group refer to both time periods.

Relative age group	1987–2004	2005–13	Range of estimated age
Neonate	6	5	< 3 months
Calf	2	6	3 months to 1 year
Juvenile	5	8	≤ 1–15 years
Subadult	0	1	6 years
Adult	7	6	13–23 years
Total	**20**	**26**	

old or less represented the majority (n = 19/46, 41%) of dolphins collected both pre-and post-sanctuary (Table 2). Strandings for each relative age group did not differ between these time periods. In addition, of the dolphins that could be sexed, 28 were male and 19 were female, not statistically different from an equal sex ratio ($\chi^2 = 3.8$, $p > 0.05$).

Table 3 summarises the results for Indo-Pacific bottlenose dolphins during the period of study (annual means and raw numbers). There was a slight overall increase in annual counts of strandings, with the highest number occurring in 2013 (Fig. 2). When the means of the annual counts for 1987–2004 (1.11) and 2005–2013 (3.00) were compared, the result was statistically significant (W = 40.5, $p < 0.05$). However, because 2013 was exceptional due to an UME and 4 of the 8 deaths recorded that year were attributed to disease the test was performed a second time, excluding that year. The revised annual mean for 2005–2012 (2.25) was not significantly different from that pre-sanctuary (W = 40.5, $p > 0.05$).

The mean annual number of strandings assigned to anthropogenic factors for Indo-Pacific bottlenose dolphins during 1987–2013 was 0.31. When pre- and post-sanctuary data were compared, there was a significant difference in the proportion of anthropogenic and non-anthropogenic strandings ($\chi^2 = 5.028$, $p < 0.05$). The number of anthropogenic cases decreased (n = 6 pre-sanctuary – annual mean = 0.33, n = 2 post-sanctuary – annual mean = 0.22) while non-anthropogenic cases increased (n = 9 pre-sanctuary, n = 20 post-sanctuary). No Probable Entanglements were recorded during the study period. Prior to 2005, the category Intentional Killing comprised two dolphins shot with shotguns, both in 1998, and there was one reported entanglement in a fishing line in 1987. There were no reported cases of Intentional Killing or Known Entanglement in the period 2005–2013.

The mean annual number of Other Unintentional cases was slightly higher post-sanctuary (0.17 vs 0.22 but with very small sample sizes (Table 3). During the whole study period, the majority (4/5) of Other Unintentional events were boat-related, usually evidenced by propeller wounds. The remaining event classified as Other Unintentional involved a fish hook and sinker found in a dolphin's mouth in 2000.

The mean number of Other Natural strandings increased post-sanctuary (0.22 vs 0.44) as did Live Stranding events (0.06 vs 0.11) but in all cases sample sizes are very small and do not lend themselves to statistical analysis (Table 3). One dolphin had a small number of shotgun pellets embedded in its blubber, but its death was attributed to multi-organ infection that did not appear to be directly related to the shooting. The mean number of disease-related events increased post-sanctuary (0.22 vs 1.89) dominated by the UME in 2013 (Table 3). Most (11/21) Disease events were caused by infections, of which 3 were lung infections and 4 were multi-organ infections, while other events in this category included numerous illnesses ranging from renal failure to cardiac failure.

DISCUSSION

Despite the recent rise in popularity of cetacean-based marine protected areas (Hoyt, 2005), there has been limited

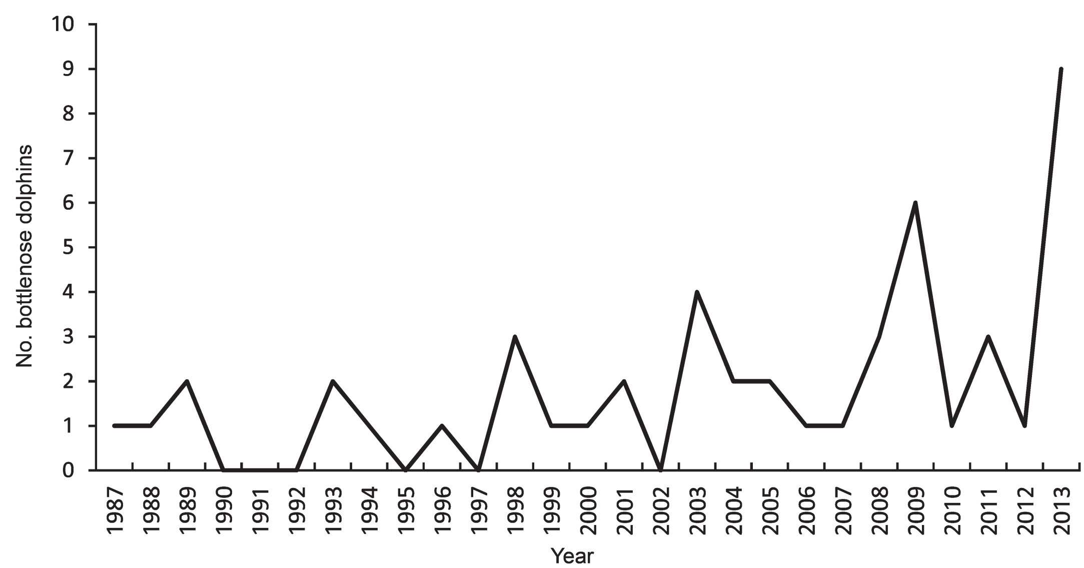

Fig. 2. Number of Indo-Pacific bottlenose dolphin strandings each year in the Adelaide Dolphin Sanctuary, South Australia.

Table 3

Number of Indo-Pacific bottlenose dolphins related to circumstance of death in the Adelaide Dolphin Sanctuary, South Australia before (*n* = 20) and after (*n* = 27) gazetting.

Circumstance of death	1987–2004	2005–13
Unknown	5	5
Anthropogenic		
Intentional killing	2	0
Entanglement	1	0
Other unintentional	3	2
Non-anthropogenic		
Disease	4	17
Other natural	4	2
Live stranding	1	1

research evaluating their effect (Hooker and Gerber, 2004; Cheney *et al*., 2014). It is argued that cetaceans can benefit from protected areas (Hooker and Gerber, 2004; Bearzi, 2012), but studies have reported conflicting results (Gormley *et al*., 2012; Cheney *et al*., 2014). It is essential that an appropriate level of monitoring is in place to allow robust evaluation as to whether mitigation measures are working and to inform changes required if they are found not to be working.

Increased public awareness, and therefore reporting effort, is another possible bias and this is important to consider when using opportunistically collected data (Segawa and Kemper, 2015).

This initial study of ADS strandings is a first step in this process. Some time-related factors also influence the ability to use the present dataset to examine changes. For example, the post-2005 dataset was skewed by 2013, when an UME occurred (Kemper *et al.,* 2016). In addition, an increase in bottlenose dolphin abundance within the sanctuary area around 2004 has been reported (Bossley *et al*., 2017) that affects statistics related to the proportion of animals in a population that may be affected by anthropogenic factors. There is also the possibility that increased effort may affect trend investigations using strandings data.

In summary, it can be noted that in terms of the present dataset, no significant changes were found in most parameters examined before and after creation of the sanctuary. However, it is recognised that the sample sizes are small, the time period is relatively short and there are issues related to effort (and numbers of animals present) that render our dataset at present not adequate to detect what may be small changes. Notwithstanding this, the reduction in strandings associated with anthropogenic factors provides preliminary evidence that the ADS may be having some positive effect.

Actual and potential threats within the ADS

Notwithstanding sample size issues, the data presented here provide information on some of the types of threats that need to be considered within the ADS, including:

(1) deliberate harm;

(2) injuries/death arising from depredation;

(3) entanglement in lines;

(4) vessel collisions; and

(5) factors that may make animals more susceptible to disease, such as contaminants.

It is encouraging that no Intentional Killings have been recorded since they were initially reported in 1998. In 2000, a multi-disciplinary team was established to investigate mortalities and promote the need for public vigilance regarding intentional harm to dolphins. This may have acted as a deterrent, though some dolphins have been shot north of the ADS. The motivation for killing dolphins is not known but studies from elsewhere have shown that fishers may react aggressively to actual or perceived depredation including frightening fish away from lines and nets (Notarbartolo di Sciara and Bearzi, 2002; Lauriano *et al.*, 2004; Loch *et al.*, 2009).

Recreational line fishing is a popular activity in the ADS (DEWNR, 2008). Elsewhere it has been identified as a major concern for inshore dolphins (Wells *et al.*, 1998; Powell and Wells, 2011). In the present study, one dolphin died with a fish hook and sinker in its mouth and this could have been a result of depredation of fish from recreational fishing activities. Studies have shown that this type of foraging activity can spread through a population rapidly (Donoghue *et al.*, 2002; Cunningham-Smith *et al.*, 2006). Although this event occurred in 2000 and similar mortality events have not been recorded since, dolphins in the ADS may still be partaking in this behaviour. Depredation, begging and provisioning behaviours tend to increase when prey are depleted (Wells, unpublished data in Powell and Wells, 2011). Studies of stomach contents have found atypical prey items (i.e. chicken bones) in some dolphins from the ADS and surrounding waters, possibly due to anthropogenic influences (Gibbs, pers. comm.) and there are unpublished cases of illegal provisioning.

With respect to entanglement deaths, only one dolphin (out of the 47 investigated) was identified as being killed from entanglement throughout the 27-year period. This is in contrast to the results from state-wide studies that identified entanglements as a leading cause of death in South Australian cetaceans (Kemper *et al.*, 2005; Segawa and Kemper, 2015). However, many non-fatal entanglements in fishing lines and other gear have been recorded in the sanctuary (Bossley, pers. comm.) and the dolphins either shed the gear or were assisted by authorities in doing so. Entanglements that result in dolphin mortality are more likely due to nets (Kemper *et al.,* 2005), which are legal in the northern part of the ADS, however the reported entanglement in this study involved fishing line.

Deaths associated with vessel collisions are more prevalent than entanglements in our dataset both before and after 2005. In fact it is the highest cause of anthropogenic deaths in our dataset although absolute numbers are low. In addition, non-fatal vessel injuries have been recorded in studies elsewhere (Wells *et al*., 2008; Bechdel *et al*., 2009). Four of the five cases categorised as Other Unintentional involved severe propeller injuries. Dolphins in the sanctuary are susceptible to vessel collisions because there is much boating and shipping activity (DEWNR, 2007).

Dolphin deaths associated with disease showed a substantial increase (mean annual values of 0.22 vs 1.89) after 2004 (Table 3). However, this was probably due at least in part to (a) improved diagnosis when a veterinary pathologist joined the team; and (b) the 2013 UME referred to above. In South Australia as a whole, disease comprised a large proportion of known circumstance of death for stranded cetaceans (Kemper *et al.*, 2005), and in New Zealand the low proportion of disease-related events was attributed to inadequate pathological testing (Stockin *et al.*, 2009). Many of the ADS dolphins had infectious diseases, including chronic and acute, and multi-organ infections. Some of the cases involved lung infections, which is common for cetaceans (Jepson *et al.*, 2000; Kemper *et al.*, 2005). Reduced resistance to disease can be associated with human-related factors such as pollution.

Mitigation measures

Legislation protecting dolphins in the ADS is the same as throughout South Australia. The National Parks and Wildlife Act (Protected Animals – Marine Mammals Regulations 2010) outlines safe distances from dolphins when swimming or operating a vessel and declares that provisioning is illegal. Furthermore, the Adelaide Dolphin Sanctuary Act (2005) amended the National Parks and Wildlife Act (1972) to increase the fine for intentionally harming a marine mammal from $10,000 to $100,000 or two years' imprisonment. Commercial fishing is permitted in some parts of the sanctuary and recreational fishing is managed through the Fisheries Management Act (2007). Strict enforcement of the law is the most likely reason for the decrease in anthropogenically-related strandings in the sanctuary.

This is facilitated by ADS staff and volunteers undertaking daily boat and land compliance patrols throughout the sanctuary to ensure that regulations are being followed and to inform sanctuary-users of proper protocol in the presence of dolphins (DEWNR, 2008; Gibbs, pers. comm.). This presence helps to deter would-be violators as well as educate people in correct behaviour. Staff and volunteers also remove debris from the water to reduce possible entanglements or ingestion of foreign objects by dolphins (DEWNR, 2008). There is an intense programme of education and outreach that raises awareness of the dolphins and the need for their protection (DEWNR, 2008; Gibbs, pers. comm.).

Continued monitoring of dolphin mortalities in the ADS is essential for sanctuary management. In addition, studies documenting the types and patterns of non-fatal entanglements are needed. Quantifying and mapping human use of the sanctuary, especially boating, and recreational and commercial fishing, may help to link activities to dolphin mortalities.

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