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IMPACTS OF PLASTIC DEBRIS ON AUSTRALIAN MARINE WILDLIFE

FINAL REPORT

C&R Consulting
for
The Department of the Environment, Water, Heritage and the Arts

Date: 19th June 2009

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Front Cover Photo: Marine Turtles entangled in derelict fishing net. Torres Strait Regional Authority. Supplied by Mark Read, GBRMPA

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SUMMARY OF RELEVANT INFORMATION

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1. EXECUTIVE SUMMARY

Plastic debris is a pervasive problem throughout the world's oceans, and various governments worldwide have officially recognised the importance of managing this issue. In response, efforts to define, monitor and reduce the problem of plastic debris in the sea are increasing, especially as it poses significant risks to protected species.

This study is a first attempt at compiling available data on interactions between plastic debris and marine wildlife in Australian waters. The geographic extent of the study included all Australian waters, including offshore and sub-Antarctic islands and Australian Antarctic Territories. The types of impacts from plastic debris include primarily entanglement and ingestions. This report provides an indication of the frequency, geographic extent, general magnitude and other details of these interactions and presents a summary of the impacts of plastic debris (including lost or discarded fishing equipment) on Australian marine wildlife. The earliest available record of these impacts was from 1974, and the most recent records were from June of 2008.

This study was prepared with information obtained from available publications, raw data and database extracts, media reports and anecdotal evidence wherever available. However, there is a paucity of information in Australia and an absence of any national, standardised database, data recording or reporting system that allows a comprehensive assessment of the interactions between plastic debris and marine wildlife. As a consequence, the magnitude of impacts of plastic debris on marine wildlife is difficult to determine.

Available information indicates that at least 77 species of marine wildlife found in Australian waters have been impacted by entanglement in, or ingestion of, plastic debris during the last three and a half decades (1974-2008). The affected species include six species of marine turtles, 12 species of cetaceans, at least 34 species of seabirds, dugongs, six species of pinnipeds, at least 10 species of sharks and rays, and at least eight other species groups. Most records of impacts of plastic debris on wildlife relate to entanglement, rather than ingestion. However, the rate of ingestion of plastic debris by marine wildlife is difficult to assess as not all dead animals are necropsied or ingested plastic debris may not be recorded where it is not considered as the primary cause of death. Species dominating existing entanglement and ingestion records are turtles and humpback whales. Australian pelicans and a number of cormorant species are also frequently reported.

The distribution of records of wildlife impacted by plastic debris in Australian waters reflects survey efforts. For example, some of the highest numbers of records come from coastal areas of north eastern Arnhem Land and south eastern Queensland where long-term surveys and regular beach clean-up activities are in place. Cetacean records are the most uniformly distributed, while records of pinnipeds and dugongs reflect the distribution of these species and occur primarily along southern Australia, and eastern Queensland, respectively. Seabird records tend to be concentrated around large urban centres, especially where zoos or wildlife rescue organisations receive dead and injured birds and maintain records, and on offshore islands where plastic ingestion by particular seabird species has been studied. Geographic areas where there are few, if any, records of wildlife impacted by plastic debris include the north western coastline of Western Australia, the Great Australian Bight, eastern Cape York, and offshore waters. Many animals that feed in offshore waters may return to coastal waters, where they are subsequently recorded. The absence of records for these areas is more likely to reflect an absence of regular observations and monitoring, not an absence of interactions occurring there.

Derelict fishing nets dominate the types of plastic debris observed entangling wildlife. A variety of plastic items are recorded as impacting marine species through ingestion. The most common items in the ingestion records are synthetic fishing line and hooks (especially in seabirds). The patterns of reports of entanglement in and ingestion of plastic debris by wildlife in Australian waters are likely to be influenced by factors such as the size and distribution of populations, foraging areas, migration patterns, diets, proximity of species to urban centres, changes in fisheries equipment and practices, weather patterns, and ocean currents, as well as the frequency of monitoring and/or observation of wildlife. While this study focuses on apparent trends in available data, it is beyond the scope of this project to draw conclusions about the causes of or influences on these trends by any of the factors outlined above.

To improve information on the impacts of plastic debris on marine wildlife, a national database needs to be established and a nationally consistent, systematic approach to monitoring and the recording of information needs to be implemented. Key future research priorities include:

- Determining the necessary statistical analyses required to develop a more accurate estimate of the magnitude of the impact of plastic debris on marine wildlife.
- Facilitating the collection of more necropsy data specifically aimed at detecting ingested plastic debris. Devise species-specific methods aimed to increase the probability of detecting ingested plastic (e.g. Francis 2007).
- Developing a method to assess cryptic mortality (unrecorded or unknown deaths) caused by impacts of plastic debris.
- Analysing climatic and oceanographic information to assist in detecting seasonal patterns in the impacts of plastic debris on marine wildlife.
- Devising a monitoring program, for feeding information into the national database from geographic locations currently devoid of data. Recommendations are given for the implementation of such a monitoring program.

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2. INTRODUCTION

This study focuses on the interactions between plastic debris and marine wildlife, but does not consider invertebrates, issues such as the spreading of wildlife through 'rafting' on plastic debris (Barnes and Fraser 2003) or the smothering effects of plastic debris on benthic wildlife (Katsanevakis et al. 2007). This study represents a first attempt to determine what data are available on interactions between plastic debris and marine wildlife in Australian waters, and to provide an indication of the frequency, geographic extent, general magnitude and other details of the available records of these interactions.

The objectives of this study are to identify:

- Known interactions between marine wildlife and plastic debris (including numbers of animals, geographic location, temporal extent of records, types of plastic debris and time of interaction);
- Gaps in knowledge of interactions between marine wildlife and plastic debris; and
- Future research priorities to progress understanding and management of the impact of plastic debris on marine wildlife.

Plastic debris is recognised as a pervasive problem throughout the world's oceans. It is estimated that seven billion tonnes of plastic litter enter the ocean every year (Faris and Hart 1995). Plastic litter is often reported to make up the highest proportion of this litter, and this is of particular concern due to its durability and its potential to injure or kill marine wildlife (Andrady 2000). The disposal of plastic litter into the ocean is prohibited under Annex V of MARPOL[1], and includes 'ropes, nets, bags (and) other items'. However, plastic debris has many sources, and its origins are both land-based (e.g. sewers, littering, landfill) and marine (e.g. commercial and recreational fishing, merchant and military vessels, offshore exploration) (Commonwealth of Australia 2008a). For the purposes of this study, plastic debris refers to all types of litter made up primarily of plastic components, including lost, discarded and abandoned (derelict) fishing gear.

Various governments worldwide recognise the importance of defining, monitoring and combating the problem of plastic debris in the ocean (Commonwealth of Australia 2008a). For example, in 2003, the Australian Government listed the 'injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris' as a Key Threatening Process under the *Environmental Protection and Biodiversity Conservation Act 1999* (*EPBC Act*), and is developing a 'Threat Abatement Plan for the impacts of Marine Debris on Vertebrate Marine Life' (Commonwealth of Australia 2008b).

More than 260 marine species have been recorded to have been impacted by plastic worldwide (Greenpeace 2006). The impacts of plastic debris have been described (reviewed by Derraik 2002), but are only just beginning to be quantified. For example, a recent desktop review of the Wider Caribbean Region summarised the results of studies on the effects of plastic debris on Caribbean wildlife (Ivar do Sul and Costa 2007).

Entanglement in plastic debris can cause drowning, suffocation, strangulation, starvation and injuries (reviewed in Commonwealth of Australia 2008a). Animals can get caught in derelict fishing gear and other types of plastic, such as packing tape and six-pack rings, either while feeding on prey nearby or adhering to the plastic itself, through curiosity (e.g.

[1] MARPOL is the *International Convention for the Prevention of Pollution from Ships 1973*; Annex V of this Convention provides for the 'Prevention of pollution by garbage from ships'. Under Annex V of the Convention, garbage includes all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of the vessel and liable to be disposed of continuously or periodically. Annex V prohibits of the disposal of plastics anywhere into the sea, and severely restricts discharges of other garbage from ships into coastal waters and "Special Areas".

pinnipeds[2]), or by other means (Page et al. 2004, Sheavly 2005). If the animals are not drowned or strangled immediately, they can be killed slowly though starvation or the restriction of breathing passages or blood vessels (Derraik 2002). They can also suffer sub-lethal effects such as injuries, increased drag while foraging, or reduced feeding and assimilation efficiency (Greenpeace 2006). Derelict fishing nets – sometimes called ghost nets – have some of the most obvious impacts on wildlife and can cause significant damage as they continue to fish passively while being carried by ocean currents (Carpentaria Ghost Nets Programme 2008).

Plastic can also be ingested by marine wildlife, blocking or perforating the digestive tract and killing or harming animals either directly or indirectly. In marine turtles, food can accumulate around an ingested foreign object, and subsequently rot. This process produces gas, which causes the turtle to float, potentially leading to death by starvation or from other causes, such as boat strike (UQ News Online 2008). Hard pieces of plastic and discarded fishing hooks can cause internal injuries, especially when regurgitated by seabirds as they feed their chicks (Commonwealth of Australia 2008a). Plastic bags are especially effective at clogging the digestive tract, causing starvation. It has been estimated that 50 to 80% of any sea turtle population has ingested at least some plastic (Greenpeace 2006). It must be noted that even biodegradable plastics take time to break down, and during the breakdown period can still pose a threat to marine wildlife (Francis 2007).

Some plastic debris, such as the plastic resin pellets used as the industrial raw material for the plastics industry, are causing increasing concern as they accumulate in the marine environment (Thompson et al. 2004). These pellets, easily mistaken for food and ingested by seabirds and other marine organisms, can serve as a source of toxic chemicals such as polychlorinated biphenyls (PCBs), phthalates, endocrine-active substances and chemicals similar to Dichlorodiphenyltrichloroethane or DDT (Bjorndal et al. 1994, Mato et al. 2001, Rios et al. 2007). These chemicals can also accumulate in marine sediments and are ingested by small detritivores - deposit- and filter-feeding organisms such as worms and crustaceans (Thompson et al. 2004). The chemicals then become increasingly concentrated as they are passed up the food chain (Greenpeace 2006). Studies on the chemicals present in resin pellets warn that the physiological effects of these substances, active at even very low levels, can include diabetes, cancers, reduced immunity and infertility when ingested (Ananthaswamy 2001, Mato et al. 2001).

With increasing awareness of the issues associated with marine debris, greater efforts have been made to document, collect and review data on marine debris in Australia's marine environment (see reviews in Wace 2000, Commonwealth of Australia 2008a). Initial attempts to quantify and describe marine debris around Australia were made by the Australia and New Zealand Environment and Conservation Council (ANZECC) Working Party on Marine Debris in 1996 (ANZECC 1996), but few studies since have attempted to review the issue on a national scale. While there are a large number of individual programs and activities around Australia that are now involved in studying and preventing the impacts of marine debris, there are still large gaps in data, particularly for offshore areas.

[2] Pinnipeds is a collective term referring to seals and sea lions.

3. METHODS

3.1 APPROACH

The information used to compile this study includes:

- Peer-reviewed publications
- Reports in the 'grey' literature
- Marine wildlife stranding and mortality reports
- Marine wildlife stranding and mortality databases and database extracts
- Records of injured, sick or dead marine animals kept in zoos, aquaria and wildlife parks
- Records of injured, sick or dead marine animals from wildlife rescue centres and organisations
- Records of necropsies conducted on marine animals

Data were compiled into a spreadsheet to enable the grouping of species, injury and mortality rates, locations, timeframes and types of plastic debris. These data were carefully checked to ensure, as far as possible, that incidents were not duplicated.

Much of the data relating to seabird interactions with plastic debris includes entanglement in, or ingestion of, fishing lines and hooks. It is usually not possible to determine whether this fishing gear was in the control of fishers (ie. 'active') at the time of interactions with the seabird or whether it had been lost or abandoned (ie. 'derelict'). The problem with separating interactions from active and passive fishing gear is relevant to all wildlife groups, but in seabirds the percentage of interactions with active fishing gear has been estimated to be over 90% by seabird rescue groups (Machado 2007). Additionally, ingestions of active fishing hooks are generally more obvious than plastic debris which may remain in the stomach unnoticed until the bird's death. Therefore records of interactions between seabirds and fishing gear of unknown (active or derelict) status are separated from interactions between seabirds and derelict fishing gear (unless otherwise specified) to avoid bias (overinflation) in overall analyses. The potential bias associated with active versus derelict fishing gear needs to be considered for species groups other than seabirds but the paucity of information available on the proportions of active (versus derelict gear) causing harm to other species groups prevents any analysis in this regard. It was also usually not possible to determine to what extent the plastic debris found with or inside a dead animal contributed to its death.

The geographic distribution of available data was mapped for each species and/or species group by locating the place where animals were initially found (where available), and then summarising records for each species in each area into a 1° grid. Where the exact location that an animal was found is unknown, the place where the animal was taken for rehabilitation was included in the grid. When there was no information about the location where the animal was found or taken for rehabilitation, or when only the state/Northern Territory in which the animal was found was recorded, the record was omitted altogether from the map.

3.2 INFORMATION SOURCES

There is currently no consistent national approach to collecting information about interactions between plastic debris and marine wildlife in Australia. A number of government and non-government organisations collect data on marine wildlife interactions with plastic debris, either as part of marine debris surveys or other research activities, or through their role in the rescue and rehabilitation of affected animals (Commonwealth of Australia 2008a). Data are currently held by at least 38 organisations or individuals throughout Australia. There are also frequent reports of wildlife impacted by debris in the media and in newsletters, but these reports are not always included in larger databases (Table 1). Existing data are very different in terms of the detail in which observations of entanglements and ingestions of marine debris are recorded. There are also differences in the geographic coverage of surveys, consistency of data gathering and recording and effort involved in collecting the data. While every effort has been made to obtain and review all existing data for the purposes of this study, there are a number of databases and information sources that were not available (Table 1), and some that may yet be identified.

Table 1. Known sources of data on wildlife impacted by plastic debris in the Australian marine environment.

Note:

- **Bold** entries indicate primary data provided for and used in this study; *italics* entries indicate data/information summaries used in this study; regular font entries indicate groups contacted to contribute to this study but that did not provide data.
- Number (%) of records relates to the number (%) of individual animals and percentage of overall records that have been recorded by the organisation.
- The number (%) of records column does not include records of interactions between seabirds and fishing gear of unknown (active or derelict) status.
- Peer-reviewed publications in this table are those that yielded numbers that could be used for some of the analyses in this study. Other cited publications yielded useful information, but not records that could be summarised.
- Table 2 contains information on individual species presented in each source; species are grouped here for ease of presentation.
- Information on geographic coverage, method and frequency of record collection varies widely and was not available for each source. The timeframe indicates the time period over which records available for this study were collected.

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
NSW	**Taronga Zoo database and Australian Registry of Wildlife Health / Pathology**	**All marine wildlife**	**Sydney region, locations not specified**	**Public reports, sporadic**	**Jan 1999 - Apr 2008**	**24(1)**
	Australian Seabird Rescue (Francis 2007, K. Southwell pers. com.)	**Turtles**	**Northern NSW, ~160km of coastline, Tweed River to Clarence River**	**Public reports on strandings, sporadic**	**Aug 2001 - Jun 2008**	**100(4.2)**
	Hutton 2004	**Flesh-footed shearwaters**	**Ned's Beach, Lord Howe Island**	**One-off survey**	**May 2002**	**18(0.7)**
	Australian Seabird Rescue	Seabirds	Northern NSW coast	Information not supplied	Information not supplied	
	The Organisation for the Rescue and Research of Cetaceans (ORRCA)	Cetaceans	NSW	Information not supplied	Information not supplied	
	Southern Oceans Seabird Study	Seabirds	Information not supplied	Information not supplied	Information not supplied	

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
	Association Inc (SOSSA)					
	NSW Department of Environment and Climate Change (database under development)	All marine wildlife	NSW	Information not supplied	Information not supplied	
NT	**Carpentaria Ghost Nets Programme**	**All marine wildlife**	**Gulf of Carpentaria, locations not specified**	**Annual beach clean-ups**	**2005-2008**	**118(4.9)**
	Kiessling 2003	**All marine wildlife**	**Arnhem Land, offshore NT, Qld coast**	**Review of existing information**	**Feb 1994 - Mar 2003**	**353(14.7)**
	World Wildlife Fund (WWF)	*All marine wildlife*	*NE Arnhem Land and Western Cape York, location not specified*	*Annual surveys and clean-ups*	*2004*	*1(0.04)*
	Dhimurru Aboriginal Corporation	*Primarily turtles*	*NE Arnhem Land, ~200km of coastline*	*Annual helicopter surveys, weekly during Apr-Jul period*	*May 1996 - Oct 2006*	*302(12.6)*
	Anindilyakwa Marine Debris Report 2006	*All marine wildlife*	*32 km of coastline in NE Arnhem Land and Groote Eylandt*	*Annual surveys and beach clean-ups*	*2006*	*10(0.4)*
	White 2005	*Fish*	*NE Arnhem Land and Western Cape York, location not specified*	*Annual surveys and beach clean-ups*	*2003*	*2(0.08)*
	NT Department of Natural Resources Environment, the Arts and Sport	No information supplied	No information supplied	No information supplied	No information supplied	
Qld	**Australia Zoo**	**All marine wildlife**	**South-east Queensland, ~140km of coastline, Noosa to North Stradbroke Island**	**Public reports, sporadic**	**Aug 2006 - Oct 2007**	**8(0.3)**

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
	Currumbin Wildlife Sanctuary	**All marine wildlife**	**Queensland / NSW coast, ~50km of coastline, Sanctuary Cove Qld to Chinderah NSW**	**Public reports, sporadic**	**Nov 2003 - Jul 2007**	**11(0.4)**
	Pelican and Seabird Rescue	**Primarily seabirds**	**Brisbane area, ~90km of urban coastline**	**Public reports, sporadic**	**Dec 2006 - Mar 2008**	**18(0.7)**
	Queensland Museum	**Turtles**	**Queensland coast between Bundaberg and Brisbane**	**Public reports, sporadic**	**Sep 1989 - Feb 2007**	**10(0.4)**
	H. Janetzki, Queensland Museum	**Flesh-footed shearwater**	**Fraser Island**	**Unknown**	**Feb 2001**	**1(0.01)**
	Queensland Environmental Protection Agency (EPA)	*Turtles, cetaceans, dugongs, pinnipeds*	*Whole Queensland coast, including western Cape York*	*Public reports, annual reporting on database*	*1999-2007*	*821(34.3)*
	Sea World	All marine wildlife	Gold Coast,Moreton Bay area, Northern NSW	Information not supplied	Information not supplied	
	University of Queensland	Turtles	Moreton Bay area	Information not supplied	Information not supplied	
SA	*Project Dolphin Safe / SA Seabird Rescue*	*Primarily seabirds*	*Adelaide area, location not specified*	*Public reports, sporadic*	*2005-2006*	*1(0.04)*
	Page et al. (2004)	*New Zealand fur seals and Australian sea lions*	*Seal colonies of Seal Bay and Cape Gantheaume Conservation Park, Kangaroo Island*	*Annual monitoring*	*1988-2002*	*126(5.2)*
	South Australian Museum	No information supplied	No information supplied	No information supplied	No information supplied	
	South Australian Research and	Australian fur seals and New Zealand fur seals	South Australia	Information not supplied	Information not supplied	

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
	Development Institute (SARDI)	and Australian sea lions, little penguins, crested terns shearwaters, pelicans, cormorants,				
	Adelaide Zoo	Seals, seabirds, turtles	Adelaide area	Information not supplied	Information not supplied	
	John van den Hoff, Australian Antarctic Division	**Subantarctic fur seals**	**Macquarie Island, locations not specified**	**Opportunistic**	**Winter 1990**	**2(0.08)**
	Glenn Atkinson, DPIW	**Pygmy right whale**	**Maria Island**	**Information not supplied**	**Information not supplied**	**1(0.04)**
	Evans and Hindell 2004	**Sperm whales**	**Marrawah and Strahan**	**Opportunistic, necropsies on stranded whales**	**Feb 1998**	**4(0.1)**
	Department of Tourism, Arts and the Environment (DTAE)	*Seabirds, pinnipeds*	*Macquarie Island, 'concentrated search areas' along ~14km of the western coastline*	*Annual debris removal, incidental observations of affected animals*	*Jul 2005 - Nov 2007*	*21(0.8)*
	Department of Primary Industries and Water (DPIW)	All marine wildlife	All of Tasmania, Macquarie Island	Information not supplied	Information not supplied	
Vic	**Wildlife Victoria**	**Primarily seabirds (Note: only ~10% of records entered)**	**~500km of Victorian coastline, from Warrnambool to Venus Bay**	**Public reports, sporadic**	**2000-2008**	**16(0.6)**
	Kate Charlton, Monash University	**Dolphins**	**Gippsland Lakes and Cape Conran**	**Opportunistic**	**Oct 2007 - May 2008**	**3(0.1)**
	Phillip Island Nature Parks	*Penguins and seals*	*Seal Rock, Phillip Island Nature Park*	*Regular observation, ongoing*	*2007*	*30(1.2)*
	Ian Temby, Department of Sustainability and Environment (DSE)	Seabirds	Port Phillip Bay	Opportunistic	Information not supplied	
WA	**WA Seabird Rescue**	**Seabirds**	**Joondalup and**	**Public reports,**	**Jan - Apr**	**2(0.08)**

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
			Shoalwater, Perth area	**sporadic**	**2007**	
	Pamela Smith, Perth Zoo	**Turtles**	**2 beaches, Perth area**	**Public reports, sporadic**	**Oct 2007 - May 2008**	**2(0.08)**
	Tangaroa Blue	*Manta rays*	*South-west WA and Ningaloo Reef*	*Public reports, sporadic*	*unspecified*	*1(0.04)*
	Naturebase (Department of Environment and Conservation online resource)	*Cetaceans*	*South-west WA, Cervantes to Albany (limited reports)*	*Public reports, database*	*Mar 2004 - Mar 2008*	*4(0.2)*
	Mawson and Coughran 1999	*Leopard seals, Australian fur seals*	*South-west WA, between Geraldton and Esperance*	*Routine beach surveys, frequency not specified*	*1980-1993*	*22(0.9)*
	Department of Environment and Conservation (DEC)	Primarily cetaceans	All of WA	Information not supplied	Information not supplied	
	Chelonia	Turtles, seabirds, sea snakes, sea lions	North-west WA	Information not supplied	Information not supplied	
Tasmania	**Pemberton et al. 1992**	**Australian fur seals**	**Seal colonies on Bass Strait Islands and southern Tasmania**	**Observations during two breeding seasons, additional opportunistic observations**	**1989-1991**	**75(3.1)**
Antarctica and Southern Ocean	**Slip et al. 1990**	**Seabirds**	**Macquarie Island, locations not specified**	**Summer investigation, regurgitated casts and stomach contents**	**1974, 1988-1989**	**13(0.5)**
	Woehler 1990	**Seabirds**	**Whitney Point near Casey Station, and Prydz Bay, Antarctica**	**Opportunistic observations**	**Feb 1986, Apr 1987**	**21(0.8)**
	Auman et al. 2004	**Seabirds**	**Atlas Cove, Heard Island, ~2km of coastline**	**Carcass dissection, one-off survey**	**Oct 2000 - Jan 2001**	**4(0.2)**

State	Organisation / Individual / Publication	Species	Geographic coverage	Method, frequency	Timeframe	Number (%) of records
	van Franeker and Bell 1988	*Cape petrels*	*Ardery Island, near Casey Station, Antarctica*	*Summer survey, stomach contents*	*Jan 1985 - Oct 1986*	*30(1.2)*
National	**Online news sources***	**News reports, all marine wildlife**	**All Australian waters**	**Media reports, opportunistic**	**1995 - Jun 2008**	**173(7.2)**
	Nathan Potter, Department of the Environment, Water, Heritage and the Arts	**Whales**	**All of Australia (primarily Victoria)**	**Annual reports from State agencies**	**May 2003 - Jan 2007**	**8(0.3)**
	Department of the Environment, Water, Heritage and the Arts (DEWHA) reports to the International Whaling Commission	*Cetaceans*	*All Australian waters*	*Annual reports from State agencies*	*Jan 2000 - Nov 2007*	*64(2.6)*

AAP, Australian Broadcasting Corporation, Sydney Morning Herald, The Daily Telegraph, University of Queensland Online, News.com.au, Perth Now, Adelaide Now, Sea World Newsletter, Indo-Pacific Sea Turtle Conservation Group Newsletter, Natural Resources, Environment, The Arts and Sport (NRETAS – Northern Territory) 2006 Northern Territory Marine Debris Monitoring Report, DEWHA Media Monitors

3.3 LIMITATIONS AND ASSUMPTIONS

Data for this study were collected from wide and varied sources. Given the significant discrepancies in data quality and type, it is currently impossible to apply formal statistical techniques to available records to test for significance of trends or patterns. Information presented in this study has therefore been summarised according to species, temporal dynamics, spatial patterns and plastic debris types affecting each species or species group.

Many records of interactions between marine wildlife and debris are derived from anecdotal reports and media stories where the accuracy and detail of information is limited, and marine wildlife stranding and mortality incident reporting collected principally through calls from the public over specialised hotlines, and wildlife rescue operations. Approximately 40 calls a month relating to marine wildlife are received through the Marine Stranding Hotline established by the Qld EPA (GBRMPA 2008). This makes a comparison of effort invested in record collection between the different information sources problematic.

It is likely that available data represent a significant under-estimate of the interactions of marine wildlife with plastic debris. This is because a large proportion of injured or dead wildlife may never be observed and/or recorded, especially wildlife that is impacted by plastics in remote and offshore areas. Even where records of wildlife are maintained, the quality and consistency of many records limits the ability to compile data in a representative and meaningful way.

In summary, the following points have limited the accuracy and comprehensiveness of analysis undertaken as part of this study:

- inconsistency, inaccuracy and absence of available data;
- inaccessibility of many existing databases;
- absence of detail in existing records. For example, many existing records list cause of wildlife stranding and/or death as 'unknown' and do not identify whether plastic in some way contributed to these impacts even when plastic has been found associated with the animal. Many records also omit any detail on geographic location or date;
- plastic ingestion is usually only possible to identify through necropsy[3]. As few necropsies are performed on stranded wildlife, many incidents of plastic ingestion are likely to go undetected. Even where a necropsy is performed on a stranded animal, plastic debris is often not recorded even where it is found present when it is not believed to be the primary cause of death;
- data associated with necropsies can skew the information associated with plastic ingestion very strongly, almost exclusively, toward dead animals; and
- many records of fishing gear being involved in the harm or death of wildlife do not specify whether the fishing gear was debris (ie. derelict) at the time of the interaction with the animal. These data were treated in the following manner:
    - Records of wildlife interactions with fishing gear where it is certain that the fishing gear was active at the time of interaction have been omitted from this study.
    - Although the potential for interaction with active fishing gear was an issue for all species groups, the likelihood that the fishing gear was active in know only for seabirds (90% or above). To avoid inflating the estimates, especially in summarising impacts on all species, records of interactions between seabirds and fishing gear of unknown (active or derelict) status are omitted from the summary analyses of all species and presented only in the seabird section.

[3] Autopsy of a dead animal

4. RESULTS

4.1 OVERVIEW: PLASTIC DEBRIS IN AUSTRALIAN WATERS

Repeated marine debris surveys have occurred (and in some cases are still occurring) on and around the Australian coastline, including in the Northern Territory (Whiting 1998, Kiessling and Hamilton 2003, White 2003, Roeger et al. 2004, 2005, NRETA 2006, Roeger et al. 2006, White 2006b), nearshore reefs in northern New South Wales (Smith et al. 2008), Kangaroo Island, South Australia (Kinloch and Brock 2007), South Australian beaches (Edyvane et al. 2004, Eglinton et al. 2005), Port Phillip Bay (KABV 2005), the south-west region of Western Australia (Taylor et al. 2007) and sub-Antarctic Macquarie Island (Australian Antarctic Division 2008). Many other irregular or one-off local surveys and 'clean up' programs have also been undertaken, particularly by schools, community groups and through initiatives such as Clean up Australia (Commonwealth of Australia 2008a).

Results from most surveys show that the quantity and composition of marine debris on Australian beaches varies according to the proximity to large urban centres (Commonwealth of Australia 2008a), the gear and practices of nearby recreational and commercial fisheries (e.g. Page et al. 2004), and the seasonal or long-term flow of wind-driven surface currents in the ocean (Greenpeace 2006). Apart from beaches close to large population centres, areas of relatively high records of plastic debris accumulation are remote areas of northwestern Cape York, Groote Eylandt, northeast Arnhem Land, the far north Great Barrier Reef, parts of South Australia including Anxious Bay, parts of Western Australia, southwest Tasmania, remote Coral Sea and Great Barrier Reef islands and cays, and Australia's sub-Antarctic Islands (Cary et al. 1987, Slip and Burton 1989, Slater 1991, Haynes 1997, Kiessling and Hamilton 2003, Raphael et al. 2003, Edyvane et al. 2004, White 2006a, Gemmell and Addison 2007, Commonwealth of Australia 2008a, DTAE Tasmania 2008). In many cases, these are locations where marine debris studies have been undertaken, rather than areas of particularly high debris accumulation. In the Northern Territory, seasonal increases in plastic debris accumulation are reported, probably driven by changes in wind strength and direction (Griffin 2008). Derelict fishing nets (especially from foreign fisheries) tend to accumulate on the Tasmanian, sub-Antarctic and northern coasts (Jones 1995). Some studies have shown temporal changes in accumulation rates, composition and source of plastic debris on an annual and longer-term scale (Edyvane et al., 2004; Page et al., 2004).

It is possible to use stranding databases (such as the Qld EPA database) to calculate the risk and probability of entanglement and ingestion for some species (e.g. Chaloupka et al. 2008), but given the limited availability of primary datasets for this study it was not possible to attempt this type of analysis. Given the absence of available data, difficulties in accessing available data, and limitations of available information, it is not possible to accurately quantify the impacts of plastic debris on wildlife (individual animals or populations) in Australian waters. Instead this study has focused on compiling and summarising available data and information to provide an indication of the frequency, geographic extent, and estimated magnitude of impacts of plastic debris on wildlife in Australian waters.

4.2 SPECIES AFFECTED IN AUSTRALIA

At least 77 species of marine fauna have been recorded as being impacted by plastic debris in Australian waters over the last three decades (Table 2). The highest concentration of recorded incidents involving plastic debris and marine wildlife has been reported from northeast Arnhem Land, southeast Queensland, northern New South Wales (NSW), the Sydney region, northern Bass Strait and Macquarie Island in the Southern

Ocean (Figure 1). This pattern may reflect several factors: the frequency of surveys conducted by certain groups such as the Dhimurru Aboriginal Corporation (Northern Territory) and the Qld EPA (e.g. Greenland et al. 2005) amongst others, the geographic distribution of affected species, high levels of human use and concentrations of debris near urban centres, location of wildlife rescue centres and lack of monitoring and resourcing of surveys and wildlife rescue work in remote areas.

Records of impacts on marine wildlife at remote island locations differ. For example, there are no known surveys specifically targeting plastic debris on Lord Howe Island, which is considered to be somewhat protected by its remoteness, lack of nearby fisheries, and distance from the primary whale migration routes (Ian Kerr, Manager, Lord Howe Island Marine Park, pers. comm.). Seabirds found on Lord Howe Island with ingested plastic fragments indicates that despite the relatively unaffected nature of the island, seabirds that forage offshore may ingest plastic debris at sea (Hutton 2004). Macquarie and Heard Islands in the Southern Ocean have been the site of targeted marine debris surveys that have also reported impacts on marine wildlife (DTAE Tasmania 2008). The largest geographic gaps in recorded entanglements and ingestions occur in the north western region of Western Australia, the Great Australian Bight coastline, the western coast of Tasmania and much of Cape York Peninsula.

Table 2. Summary of species impacted by plastic debris in Australian waters.

Note:

- This table includes seabirds that have ingested, or been entangled in fishing gear, such as hooks or lines, of unknown (active or derelict) status.
- This table includes only references to sources from which information and data were available. Other information available from each source is presented in Table 1.

Species	Common Name	Entanglement	Ingestion	Record sources (numbers refer to records numbers listed in Table 1)
Turtles				
Chelonia mydas	Green turtle	✓	✓	Taronga Zoo, Francis 2007, Carpentaria Ghost Nets Programme, Dhimurru Aboriginal Corporation, Australia Zoo, Pelican and Seabird Rescue, Queensland Museum, Queensland EPA, ABC News Online, IPSTCG Newsletter, Media Monitors, UQ Online news, Sea World Newsletter, P. Smith, Perth Zoo, Kiessling 2003
Eretmochelys imbricata	Hawksbill turtle	✓	✓	Taronga Zoo, Francis 2007, Carpentaria Ghost Nets Programme, Dhimurru Aboriginal Corporation, Anindilyakwa Marine Debris Report 2006, Australia Zoo, Queensland Museum, Queensland EPA, NRETAS Newsletter, Kiessling 2003
Natator depressus	Flatback turtle	✓		Francis 2007, Carpentaria Ghost Nets Programme, Dhimurru Aboriginal Corporation, Queensland Museum, Queensland EPA, Kiessling 2003
Dermochelys coriacea	Leatherback turtle	✓	✓	Queensland EPA, ABC Online News, Media Monitors, Kiessling 2003
Caretta caretta	Loggerhead turtle	✓	✓	Francis 2007, Queensland Museum, Queensland EPA, Kiessling 2003
Lepidochelys coriacea	Olive Ridley turtle	✓	✓	Francis 2007, Carpentaria Ghost Nets Programme, Dhimurru Aboriginal Corporation, Queensland EPA, Media Monitors, Kiessling 2003
Cetaceans				
Megaptera novaeangliae	Humpback whale	✓		Australia Zoo, Queensland EPA, Naturebase, Media Monitors, ABC Online News, Perth Now, Adelaide Now, N. Potter, DEWHA, International Whaling Commission (IWC) Reports
Balaenoptera brydei	Bryde's whale		✓	ABC Online News, International Whaling Commission (IWC) Reports
Sousa chinensis	Indo-Pacific humpbacked dolphin	✓		Queensland EPA, Kiessling 2003

Species	Common Name	Entanglement	Ingestion	Record sources **(numbers refer to records numbers listed in Table 1)**
Balaenoptera acutorostrata	Minke whale	✓		Queensland EPA, ABC Online News, International Whaling Commission (IWC) Reports
Eubalaena australis	Southern right whale	✓		Media Monitors, AAP General News, ABC Online News, N. Potter ,DEWHA, International Whaling Commission (IWC) Reports
Caperea marginata	Pygmy right whale	✓		N. Potter, DEWHA, G. Atkinson, DPIW Tasmania
Orcaella heinsohni	Australian snubfin dolphin	✓		Queensland EPA
Globicephala sp.	Pilot whale	✓		Naturebase
Delphinus delphis	Common dolphin	✓		Queensland EPA, Wildlife Victoria, International Whaling Commission (IWC) Reports
Tursiops aduncus	Indo-Pacific bottlenose dolphin	✓		Queensland EPA
Tursiops truncatus	Bottlenose dolphin	✓	✓	K. Charlton, Monash University, International Whaling Commission (IWC) Reports
Ziphiidae	Beaked whale	✓		Media Monitors
Dugong				
Dugong dugon	Dugong	✓	✓	Carpentaria Ghost Nets Programme, Queensland EPA, Media Monitors, ABC Online News, Kiessling 2003
Pinnipeds				
Mirounga leonina	Elephant seal	✓		DTAE Reports
Hydrurga leptonyx	Leopard seal	✓		Mawson and Coughran 1999
Arctocephalus tropicalis	Subantarctic fur seal	✓		DTAE Reports, J. van den Hoff, AAD, Warwick and Coughran 1999
Arctocephalus forsteri	New Zealand fur seal	✓	✓	DTAE Reports, Page et al 2004
Arctocephalus pusillus doriferus	Australian fur seal	✓	✓	Taronga Zoo, Wildlife Victoria, Phillip Island Nature Parks, Media Monitors, Mawson and Coughran 1999, Pemberton et al 1992
Neophoca cinerea	Australian sea lion	✓		Page et al 2004
Seabirds				
Pelecanus conspicillatus	Australian pelican	✓		Currumbin Wildlife Sanctuary, Pelican and Seabird Rescue, WA Seabird Rescue, Media Monitors
Catharacta skua	Subantarctic skua		✓	DTAE Reports, Woehler 1990, Slip et al 1990, Auman et al 2004

Species	Common Name	Entanglement	Ingestion	Record sources **(numbers refer to records numbers listed in Table 1)**
Eudyptula minor	Little (fairy) penguin	✓	✓	Taronga Zoo, Media Monitors
Pygoscelis adeliae	Adelie penguin	✓		Woehler 1990
Pygoscelis papua	Gentoo penguin		✓	DTAE Reports
	Unidentified penguin	✓		DTAE Reports
Macronectes halli	Northern giant-petrel	✓		DTAE Reports
Macronectes giganteus	Southern giant-petrel		✓	Taronga Zoo, Slip et al 1990
Phalacrocorax carbo	Great cormorant		✓	Taronga Zoo
Phalacrocorax melanoleucus	Little pied cormorant	✓	✓	Taronga Zoo
Phalacrocorax varius	Pied cormorant	✓	✓	Currumbin Wildlife Sanctuary
Phalacrocorax sulcirostris	Little black cormorant	✓	✓	Currumbin Wildlife Sanctuary, Pelican and Seabird Rescue
Egretta novaehollandiae	White-faced heron		✓	Taronga Zoo
Larus novaehollandiae	Silver gull	✓	✓	Currumbin Wildlife Sanctuary
Larus dominicanus	Kelp gull	✓		Media Monitors, Slip et al 1990
Puffinus carneipes	Flesh-footed shearwater		✓	Queensland Museum, Hutton 2004
Puffinus tenuirostris	Short tailed shearwater (muttonbird)	✓		Currumbin Wildlife Sanctuary
Morus serrator	Australasian gannet	✓	✓	Taronga Zoo, Australia Zoo, Currumbin Wildlife Sanctuary
Tachybaptus novaehollandiae	Australasian grebe	✓		Taronga Zoo
Ardea alba	Great egret	✓		Pelican and Seabird Rescue
Onychoprion fuscatus	Sooty tern	✓	✓	Currumbin Wildlife Sanctuary
Sterna albifrons	Little tern	✓	✓	Currumbin Wildlife Sanctuary
Sterna bergii	Crested tern	✓		Currumbin Wildlife Sanctuary
Sterna caspia	Caspian tern	✓		Australia Zoo
Diomedea exulans	Wandering albatross		✓	Slip et al 1990
Thalassarche melanophrys	Black browed albatross	✓		Taronga Zoo

Species	Common Name	Entanglement	Ingestion	Record sources (numbers refer to records numbers listed in Table 1)
Thalassarche steadi	White-capped albatross	✓		Taronga Zoo
Halobaena caerulea	Blue petrel		✓	DTAE Reports
Daption capense	Cape petrel		✓	van Franeker and Bell 1988
Larus pacificus	Pacific gull	✓		SA Seabird Rescue
Haliastur indus	Brahminy kite	✓		Currumbin Wildlife Sanctuary
Pandion haliaetus	Osprey	✓	✓	Currumbin Wildlife Sanctuary
Ephippiorhynchus asiaticus	Black-necked stork	✓		Pelican and Seabird Rescue
Anas superciliosa	Pacific black duck	✓		Pelican and Seabird Rescue
Sharks and rays				
Carcharhinus melanopterus	Black-tip reef shark	✓		Kiessling 2003
Carcharhinus amblyrhynchos	Grey reef shark	✓		Kiessling 2003
	Unidentified shark	✓		Carpentaria Ghost Nets Programme, Kiessling 2003
Stegostoma fasciatum	Leopard shark		✓	Taronga Zoo
Sphyrna sp.	Hammerhead shark	✓		Carpentaria Ghost Nets Programme
Carcharias taurus	Grey nurse shark (east coast)		✓	Taronga Zoo
Orectolobus sp.	Wobbegong shark		✓	Taronga Zoo
Pristidae	Sawfish	✓		Kiessling 2003
Dasyatis fluviorum	Estuary stingray	✓		Australia Zoo
Dasyatidae	Stingray	✓		Wildlife Victoria
Manta birostris	Manta ray	✓		Tangaroa Blue
Other species				
	Unidentified fish	✓		Carpentaria Ghost Nets Programme, Anindilyakwa Marine Debris Report 2006, Kiessling 2003
Balistidae	Triggerfish	✓		White 2005
Arius sp.	Catfish	✓		White 2005

Species	Common Name	Entanglement	Ingestion	Record sources (numbers refer to records numbers listed in Table 1)
Lates calcarifer	Barramundi	✓		Kiessling 2003
Scylla serrata	Mud crabs	✓		Carpentaria Ghost Nets Programme
	Unidentified crabs	✓		Carpentaria Ghost Nets Programme, Anindilyakwa Marine Debris Report 2006
Crocodylus porosus	Estuarine crocodile	✓		Anindilyakwa Marine Debris Report 2006
Disteria major	Olive headed sea snake	✓		Australia Zoo
Hydrophiidae	Sea snake	✓		Carpentaria Ghost Nets Programme, Kiessling 2003

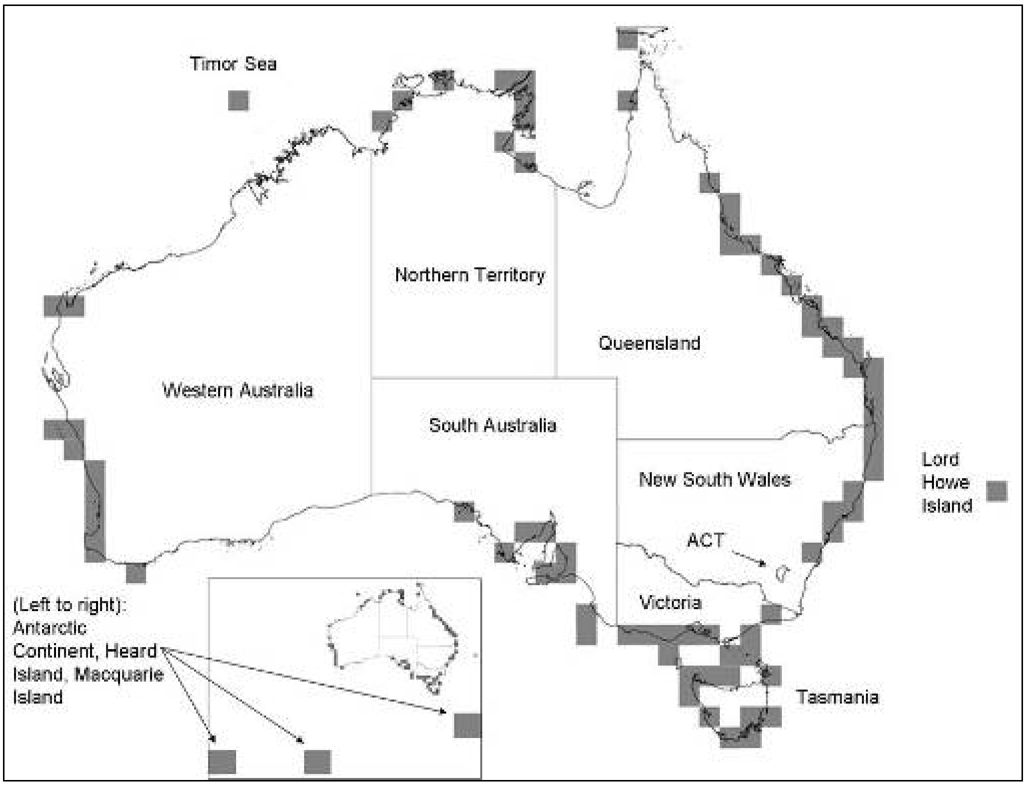

Figure 1. Distribution of known records (between 1974 and 2008) of interactions between plastic debris and marine wildlife in Australian waters.

Note: The large numbers of records of seabirds impacted by fishing gear of unknown status (active or derelict) are not included in this map (see Section 3.6), to avoid skewing the distribution in geographic areas around wildlife rescue centres.

4.3 TYPES OF PLASTIC DEBRIS AFFECTING AUSTRALIAN MARINE WILDLIFE

Many types of plastic debris have been recorded in incidents with marine wildlife in Australian waters. Most records involve derelict fishing nets, with the number of records for this type of plastic debris almost an order of magnitude greater than the second most common type, crab pot gear (involving either the pots, ropes, floats or a combination thereof - Table 3). Details about the types of derelict fishing nets impacting wildlife is recorded by groups such as the Dhimurru Aboriginal Corporation and the Carpentaria Ghost Nets Programme, with surveys showing that most derelict nets found in northern Australian waters are from foreign (notably Asian) fisheries (Kiessling and Hamilton 2003). Of these, large mesh drift, gill and trawl nets are having some of the greatest impacts on wildlife, especially turtles (Leitch 2001, Roeger et al. 2006).

Many available records do not specify the type of plastic debris impacting (through entanglement or ingestion) on wildlife. This is especially the case for records relating to ingestion, with the highest number of items being reported as ‘plastic’, ‘plastic fragments’, ‘plastic items’, ‘foreign material’, etc. One type of debris that tends to be recorded specifically are latex balloons, which have been found in the stomachs of several turtles and seabirds (Lindsay Smith, SOSSA, pers. comm.; Nick Kirby, Melbourne Aquarium, pers. comm.).

The lack of detail with which plastic types are generally recorded makes it difficult to determine which types of plastic are of most concern. Derelict fishing nets are subject to a small number of targeted surveys and recording and identification techniques in the Northern Territory (White et al. 2004), which may partially account for their numeric dominance in the entanglement records. Packing straps used to secure bait boxes in the fishing industry have played a large role in pinniped entanglements in Australia's southern waters in the past, as have fragments of derelict nets. Different types of plastic bags feature in both entanglements and ingestions, but are frequently not differentiated in the records. Ropes (with or without floats), fishing line and fishing hooks also tend not to be described in detail.

Table 3. Summary of known plastic types impacting marine wildlife through entanglement and ingestion in Australian waters. The status of all fishing gear is given as either derelict or unknown^.

Plastic Type	Entanglement (number of animals)	Ingestion (number of animals)	Sources
Fishing net (derelict)	1021		Taronga Zoo, Carpentaria Ghost Nets Programme, Dhimurru Aboriginal Corporation, Anindilyakwa Marine Debris Report 2006, Pelican and Seabird Rescue, Queensland Museum, Queensland EPA, DTAE Reports, Phillip Island Nature Parks, Online news sources, Pemberton et al. 1992, Page et al. 2004, Warwick and Coughran 1999, Woehler 1990, J. v. d. Hoff, (AAD)
Fishing net (active/derelict status unknown)	152		
Unidentified plastic type*	161	114	Taronga Zoo, Francis 2007, Currumbin Wildlife Sanctuary, Queensland Museum, Queensland EPA, DTAE Reports, Wildlife Victoria, Phillip Island Nature Parks, Online news sources, 34 H. Janetzki (Qld Museum), P. Smith (Perth Zoo), Auman et al. 2004, Evans and Hindell 2004, Pemberton et al. 1992, Slip et al. 1990, van Franeker and Bell 1988
Crab and lobster pot gear[#] (derelict)	7		Francis 2007, Pelican and Seabird Rescue, Queensland Museum, Queensland EPA, Naturebase, Online news sources, Warwick and Coughran 1999, N. Potter (DEWHA), Page et al. 2004
Crab and lobster pot gear (active/derelict status unknown)	152	1	
Rope and floats	84	1	Queensland Museum, Queensland EPA, DTAE Reports, Phillip Island Nature Parks, Naturebase, Online news sources, Pemberton et al. 1992, Page et al. 2004, N. Potter (DEWHA)
Packing straps or tape	60		DTAE Reports, Phillip Island Nature Parks, Pemberton et al. 1992, Page et al. 2004, Warwick and Coughran 1999
Fishing hook and line (derelict)	7	41	Taronga Zoo, Francis 2007, Pelican and Seabird Rescue, Currumbin Wildlife Sanctuary, Queensland Museum,

Plastic Type	Entanglement (number of animals)	Ingestion (number of animals)	Sources
Fishing hook and line (active/derelict status unknown)	25	8	Queensland EPA, DTAE Reports, Phillip Island Nature Parks, K. Charlton (Monash) , Page et al. 2004
Unspecified fishing gear (derelict)	1		Australia Zoo, Queensland EPA, SA Seabird Rescue, Online news sources, Warwick and Coughran 1999, Woehler 1990
Unspecified fishing gear (active/derelict status unknown)	13	2	
Plastic bag	10	17	Taronga Zoo, Francis 2007, Pelican and Seabird Rescue, Queensland Museum, Queensland EPA, WA Seabird Rescue, Tangaroa Blue, Online news sources, K. Southwell (ASR), P. Smith (Perth Zoo), Page et al. 2004
Unspecified rubber items	2	1	Phillip Island Nature Parks
Chips packet	1		Pelican and Seabird Rescue
Gift wrapping	1		Pelican and Seabird Rescue
Six-pack ring	1		Online news sources
Flexible plastic rings		1	Slip et al. 1990
Cigarette butts		1	Taronga Zoo
Rubber rings or band	3	1	Taronga Zoo, Pelican and Seabird Rescue, Page et al. 2004
Tyre tube	1		Page et al. 2004
Lid of plastic drum		1	DPIW Tasmania
Cellophane and clingwrap		4	Francis 2007, Queensland EPA
Polystyrene spheres		7	Slip et al. 1990
Latex balloons and string	1	12	Taronga Zoo, Francis 2007, Queensland EPA, Page et al. 2004

^ Interactions with fishing gear identified as 'active' are not included in this study, as they pertain to the issue of fisheries bycatch, not marine debris

* Items described in available records as 'plastic items', 'plastic fragments', 'plastic debris', 'foreign material', etc.

Crab and lobster pots, while usually not made of plastic, have plastics associated with them (synthetic ropes and floats), and can be classified as 'derelict fishing gear' when discarded or abandoned.

4.4 MARINE TURTLES

4.4.1 AFFECTED MARINE TURTLE SPECIES

Figure 2. Green turtle drowned in fish trap. Photo courtesy of Mark Read, GBRMPA.

Available records indicate that at least 1,122 marine turtles have been impacted by plastic debris either through entanglement or ingestion since 1989 (e.g. Figure 2). Of these animals, 88.7% (996) were entangled and 11.2% (126) had ingested plastic debris (Figure 3). While the incidence of ingestion is relatively low, it is likely to be a significant underestimate of the true numbers of marine turtles ingesting plastic debris as very few animals were assessed through necropsy. An additional 447 turtles were injured or killed by unknown causes, where it was not possible to ascertain whether impacts were attributable to plastic debris or not.

The fate of turtles impacted by plastic debris is often unknown; the fate of 40% (402) of animals impacted through entanglement was not noted in the available records (Figure 3a). Impacts associated with ingestion of plastic debris are usually only detected during necropsies of dead turtles (99 individuals), skewing the ingestion data toward dead individuals. It is unknown whether the ingestion of plastic caused the deaths of these individuals. The fate of some turtles (16) that ingested plastic was unknown. Ingested plastic was detected in the faeces of a small number (11) of live turtles during rehabilitation (Figure 3b).

Many records of turtles entangled in plastic debris do not note the species of turtle impacted or the fate of the turtle once found. Of the turtle species identified, green (214), hawksbill (187) and olive ridley turtles (127) are most frequently represented in the available entanglement records. More individuals died through entanglement than were released alive for all species except flatback turtles, where the proportions of live and dead turtles were almost equal, and olive ridleys, where the numbers released alive outweighed those that died. Dead green turtles dominated the ingestion records (68 individuals, Figure 4b). Very few records of both entanglement and ingestion exist for leatherback and loggerhead turtles. The fate of turtles after release from entanglement and/or rehabilitation is generally unknown. With currently available data, it is not possible to draw conclusions about the survival rates of turtles following rescue from entanglement or ingestion.

In addition to the figures above, 79 turtle strandings were recorded by the Dhimurru Aboriginal Corporation in northeastern Arnhem Land in 2005 (Roeger et al. 2005), and an unspecified number of hawksbill and unidentified turtles were reported through WWF surveys (White 2005), but the presentation of results did not allow inclusion into the dataset for this study. Of the 79 strandings reported by Roeger et al. (2005), 44% (35) were released alive.

In Queensland, an average of 7.2% (527) of all turtle strandings recorded each year between 1999 and 2002 were reportedly caused by interactions with plastic debris (Greenland et al. 2004). However, this is a proportion of all recorded stranded turtles; it must be noted that 65.9% of all turtle strandings recorded during those years were ascribed to 'unknown reasons'. The annual average proportion of recorded strandings attributed to plastic debris from records where reasons were known was approximately 20%.

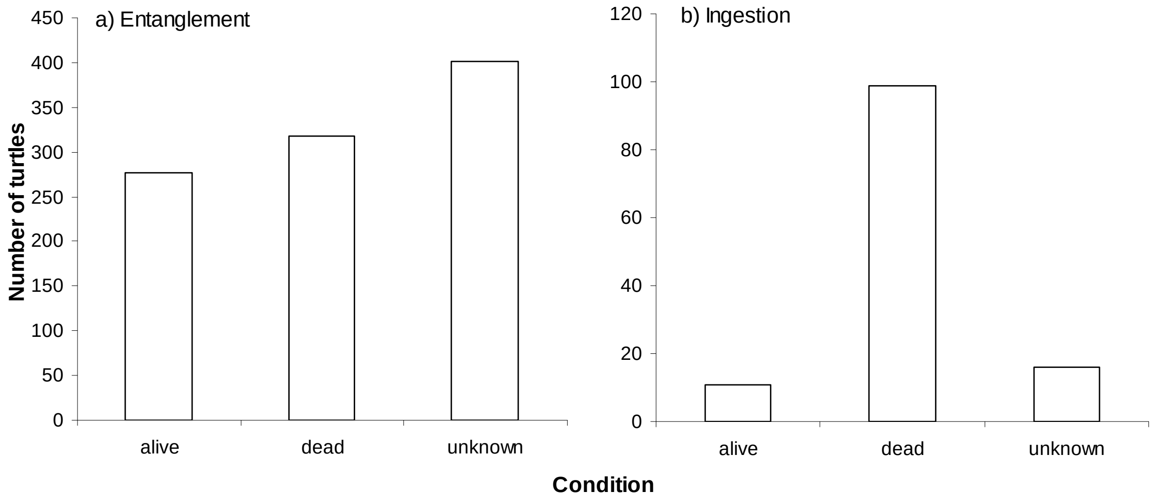

Figure 3. Known records of turtles impacted by entanglement in and ingestion of plastic debris since 1989 in Australian waters (Sources: see Table 2: Marine Turtles). Note the difference in the y-axes.

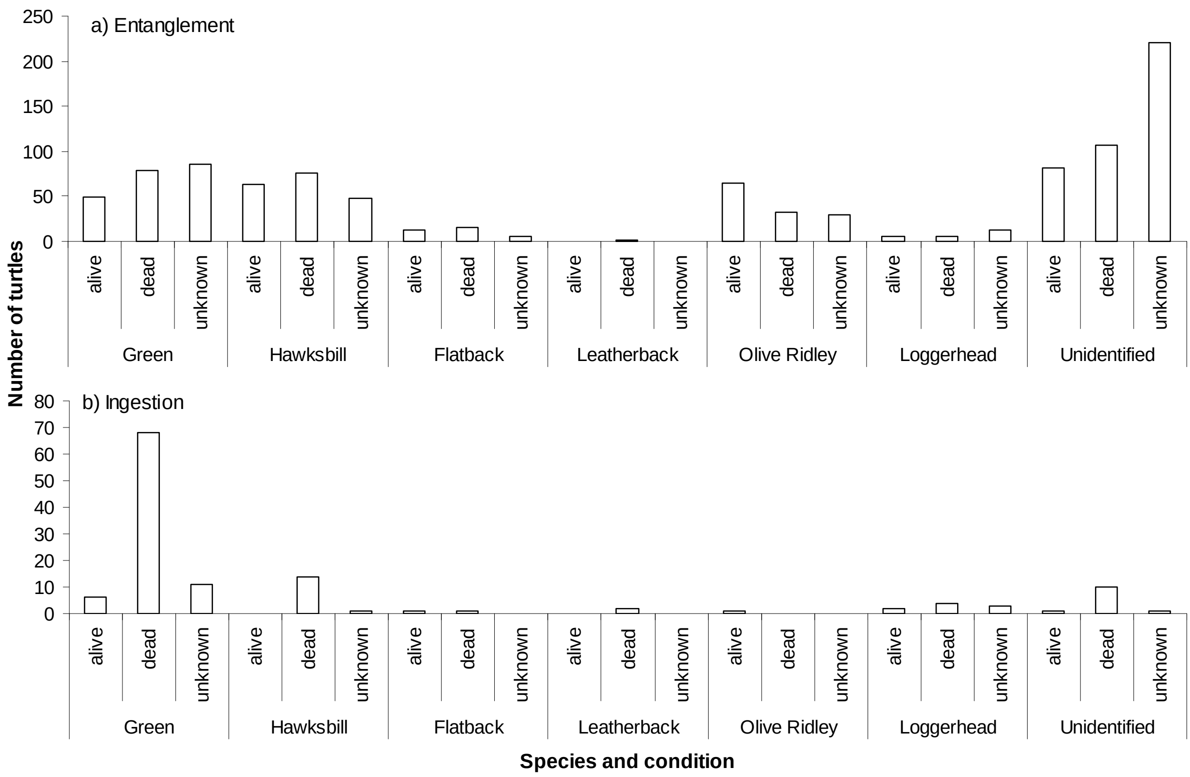

Figure 4. Records of turtle species impacted by entanglement in and ingestion of plastic debris since 1989 in Australian waters (Sources: see Table 2: Marine Turtles)

4.4.2 DYNAMICS AND DISTRIBUTION OF AFFECTED MARINE TURTLES

Of the total number of records of impacted turtles, less than 40% of records (436) may be analysed in relation to the month in which the animal was impacted, because most records only note the year or period of years which they were collected. Available data suggest that there is an increase in records of interactions between marine turtles and plastic debris during the middle of the year, especially around May. August and November show the fewest numbers of records and most months show records of between 15 and 40 interactions (Figure 5).

Evidence indicates that the number of turtles found stranded along the northern Australian coastline, which make up almost one third of these data, is correlated with seasonal wind and tide patterns, and that there is a strong seasonality of stranding patterns (Griffin 2008): during the dry season debris tends to accumulate with prevailing south-easterly winds along south-east facing coastlines, and during the wet season debris tends to accumulate with prevailing north-westerly winds along north-west facing coastlines.

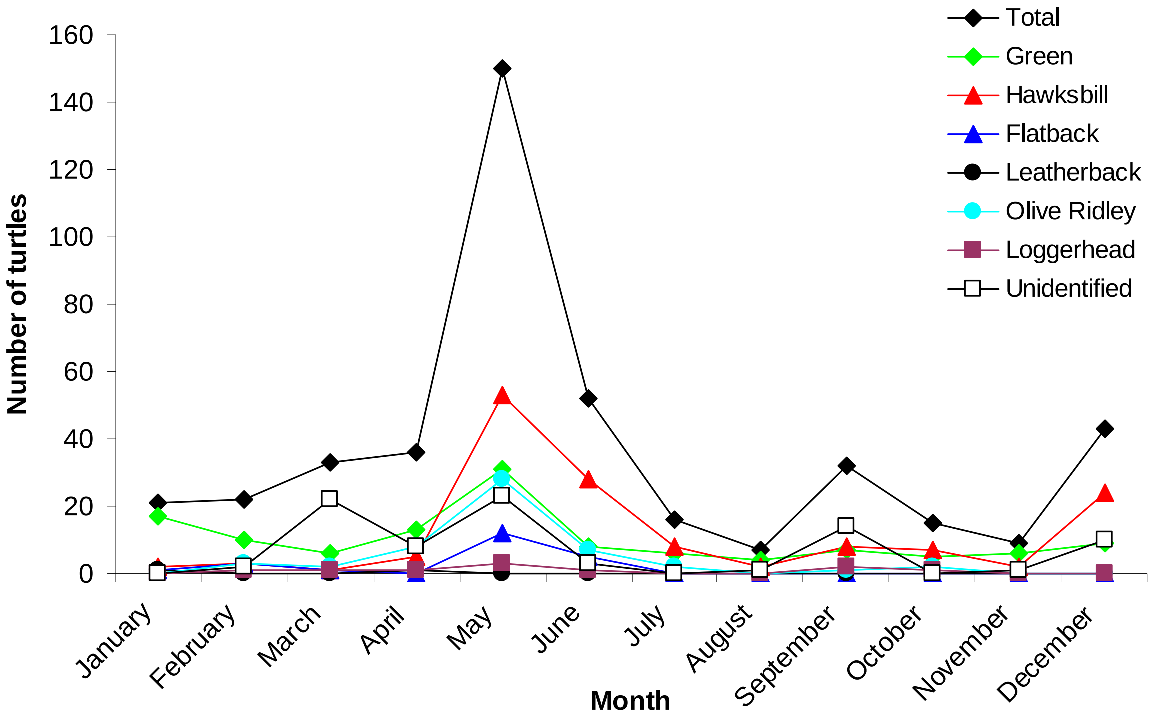

Figure 5. Monthly variation in available records of marine turtle strandings in Australian waters. This figure does not include records summarised over a period of months or years (Sources: see Table 2: Marine Turtles)

Records of marine turtle interactions with plastic debris were most common in the years between 2000 and 2005 (Figure 6). The earliest records were collected in 1989, and reporting appears to have remained sporadic until approximately 1996. Records declined to between 10 and 39 per year after 2005. Years of high incident records range from 2000, when 91 turtles were recorded, to 2005 when 99 turtles were recorded. Several studies, which could not be represented in this figure, report entanglements and ingestions for a range of years. In total, there are 291 such records, 200 of which were collected from eastern Cape York between 1999 and 2003 (Kiessling 2003).

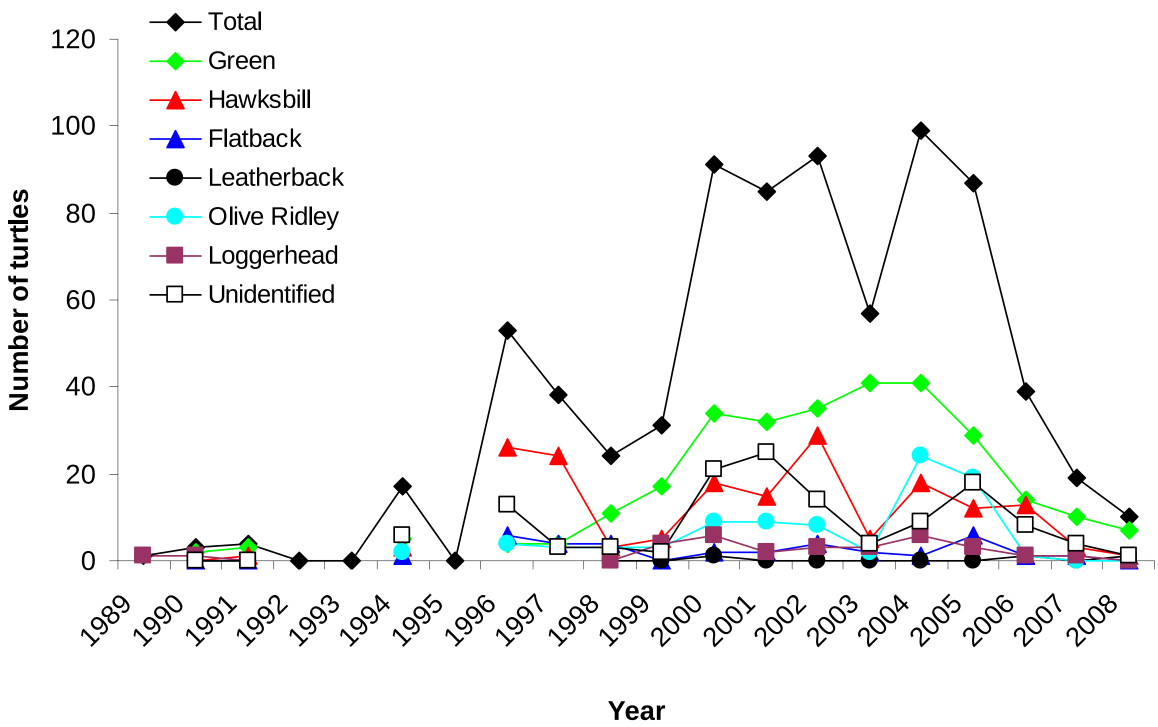

Figure 6. Annual trends in available records of marine turtle entanglements in and ingestion of plastic debris in Australian waters between 1989 and 2008. This figure does not include records summarised over a period of more than one year (Sources: see Table 2: Marine Turtles)

Approximately 28% of available data are the results of surveys by the Dhimurru Aboriginal Corporation in northeast Arnhem Land (Roeger et al. 2004) and an additional 31% are from the Qld EPA strandings database. The proportion of the sampling effort captured by these two groups is reflected in the concentration of records in northeast Arnhem Land and the Queensland coast (Figure 7). Individual records come from as far south as Venus Bay in Victoria and Coorong in South Australia, and there are seven records from the Timor Sea (including Ashmore Reef and the MOU Box[4]). Additional information suggests that turtles are found to be impacted in some areas where there are derelict nets, but not in others. No regular surveys are conducted on Christmas Island, but it is reported that each year, four or five turtles and a number of frigatebirds (species were not recorded) are found entangled in ropes, nets or fishing line, primarily on the eastern (exposed) side of the island (Max Orchard, Christmas Island National Park, pers. comm.). Anecdotal evidence from Pulu Keeling indicates that derelict fishing nets are often found washed up on the shore, but no impacted turtles were recorded (Chris Boland, Pulu Keeling National Park, pers. comm.). No turtle or derelict net records appear to be available along most of western half of the Australian coast between Darwin and Adelaide.

[4] The MOU Box covers an area in the Timor Sea where Indonesian fishing activities in Australian waters are regulated by a Memorandum of Understanding between the Australian and Indonesian governments.

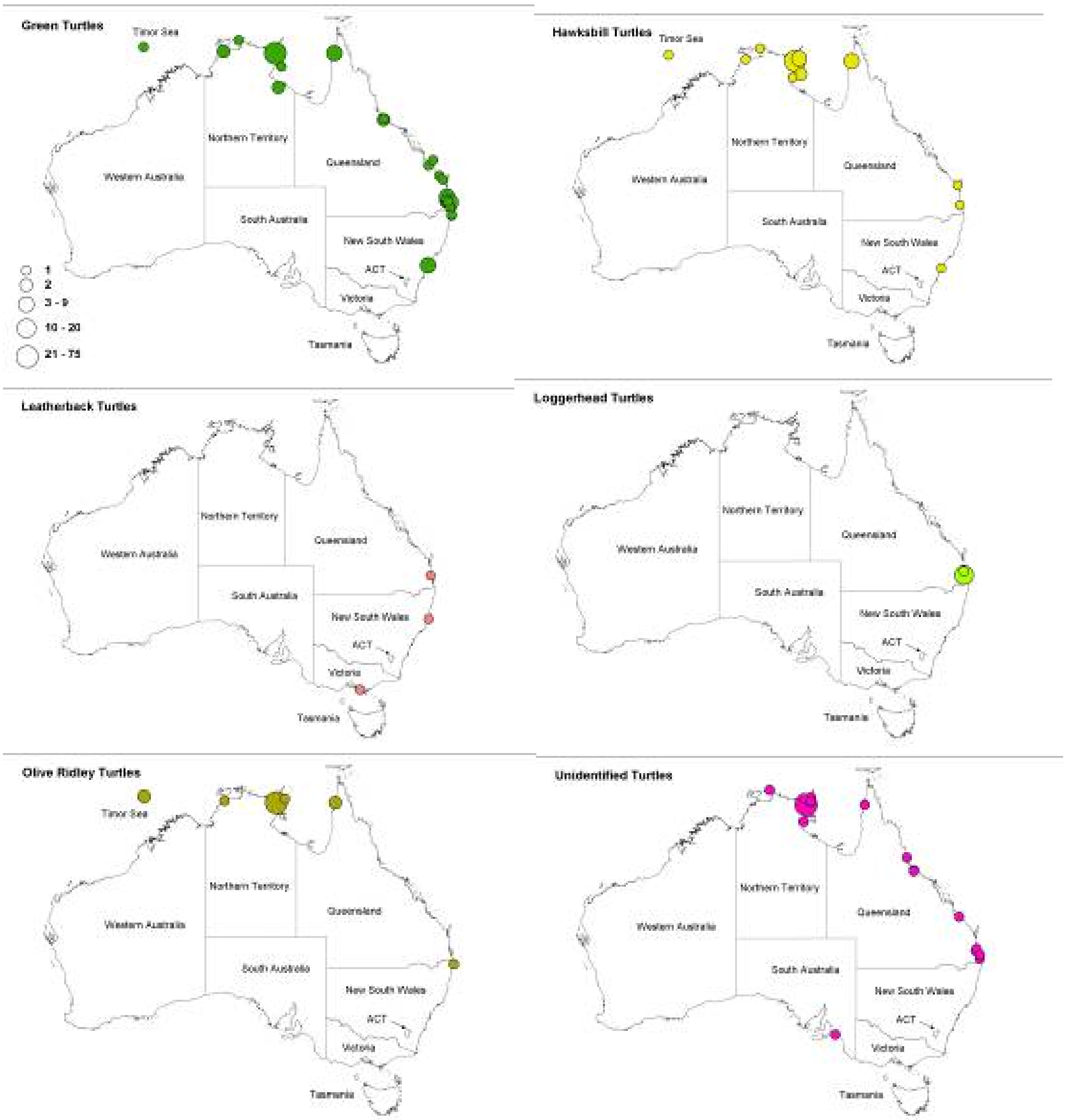

Figure 7. Distribution of known records of marine turtle entanglement in and ingestion of plastic debris since 1989 in Australian waters, separated by species (Sources: see Table 2: Marine Turtles)

In the Gold Coast region, abandoned, or derelict, crab pots may play a bigger role in killing and injuring turtles than other types of derelict fishing gear, with one report stating that at least one such death occurs daily (Dillaway 2007). Plastic debris other than derelict fishing gear may also play a greater role in the observed entanglements and ingestions in areas of higher human use, such as southeast Queensland. Staff at the University of Queensland's Moreton Bay Research Station attended to 30 marine turtle strandings in 2007, 23% of which were reportedly caused by the ingestion of 'marine rubbish', doubling the estimate from 2006, where 12% of strandings were attributed to 'marine rubbish' (UQ News Online 2008).

Weather patterns and wind direction are very important in determining the numbers of turtles washing on land where they are most often recorded. Monthly and more long-term temporal stranding patterns can be strongly influenced by climatic events such as storms, when large numbers of derelict fishing nets with entangled turtles can wash ashore (Anon 2006, 2008, Reghenzani 2008).

Records show that turtle species most affected by plastic debris include: loggerhead turtles from the eastern Australian population; green turtles from the southern Great Barrier Reef population; hawksbill turtles from the northeastern (Queensland) Australian population; leatherback turtles; olive ridley turtles from the Northern Territory; and flatback turtles from Arnhem Land (Commonwealth of Australia 2003). The current extent of the problem for Western Australian turtle populations remains unknown.

4.4.3 Types of Plastic Debris Impacting Marine Turtles

Available data suggest that entanglement in derelict fishing nets is the predominant type of interaction with plastic debris impacting marine turtles in Australian waters. This probably reflects the high proportion of data from the Northern Territory, where derelict nets wash ashore and are documented in high numbers. The Carpentaria Ghost Nets Programme, in particular, has analysed the derelict net types found during their surveys. They suggest that, according to a guide on derelict nets in Australian waters (White et al. 2004), almost all net types recorded as impacting on marine turtles in northern Australian waters are foreign nets, largely of Asian origin. In particular, a type of drift net originating from fisheries operating in Indonesian waters is causing impacts to marine turtles in the greatest numbers (Riki Gunn, Carpentaria Ghost Nets Programme, pers. comm.).

Available records show a large number (343) of 'unidentified turtle / unknown net' combinations in relation to types of debris entangling marine turtles, amounting to 34% of entanglement records. Entanglements in crab pots and associated ropes and floats are recorded most frequently for green turtles, followed by loggerhead and unidentified turtle species. Very few marine turtle entanglements arising from fishing line, plastic bags or rope have been recorded. 'Other' types of debris recorded as impacting marine turtles includes 'unknown' types, 'various plastic types', and a bag of woven plastic strips (Figure 8a).

Green turtles dominate records of identified types of ingested plastics, most of which were combinations of fishing hooks and lines of unknown (active or derelict) status (Figure 8b). Plastic bags were also abundant in available green turtle ingestion records, although none of the available records specify the type of plastic bag ingested (e.g. supermarket bag, garbage bag, etc.). Green turtles also had the widest variety of recorded plastic types in their stomachs, including latex balloons and various types of plastic wrappers. Latex balloons were also found in the stomachs of hawksbill and flatback turtles. One loggerhead turtle was found to have ingested 'crab pot gear'. 'Other' items include records of 'soft plastic', 'hard plastic' and 'plastic items'.

With many records, it was impossible to determine whether the incident involved entanglement or ingestion, or the type of plastic involved in the incident. Green and loggerhead turtles appear most frequently in these records, with over 250 green turtles and more than 80 loggerhead turtles undergoing some form of detrimental interaction with unidentified plastic debris (Figure 8c). Some of these records indicate that the turtle was floating at the time of observation, suggesting that digestive problems, such as compacted faeces obstructing the intestines and releasing excess gas, were responsible for the distress or death of these individuals. In most cases it was not possible to determine whether plastic debris was contributing to the compaction of the faeces, but at least one rescue worker cautions that if faeces or the digestive tract are not examined carefully, significant amounts of plastic could be missed (Francis 2007).

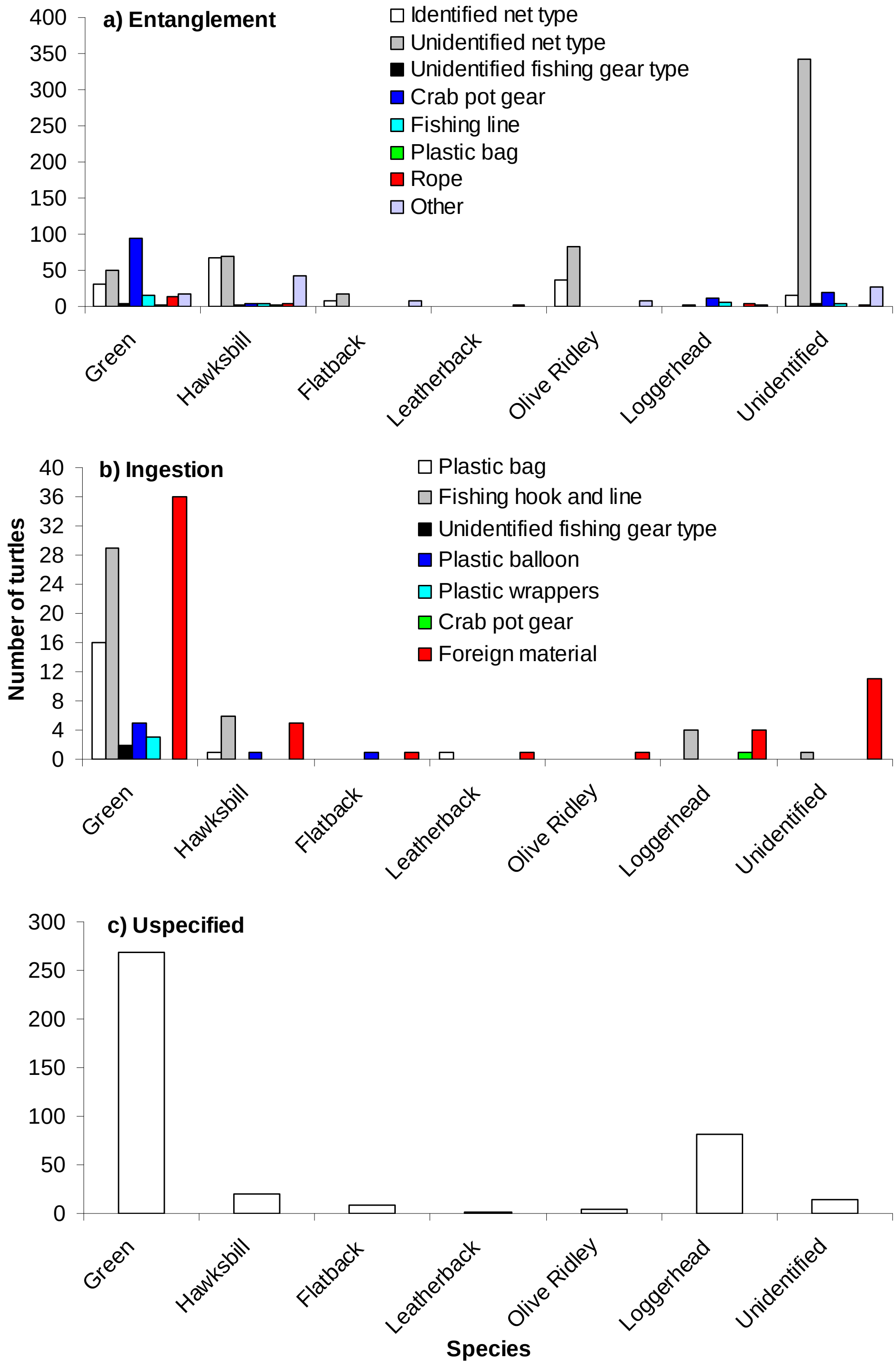

Figure 8. **Known records of marine turtle a) entanglement, b) ingestion, and c) unspecified interactions (either entanglement or ingestion) by type of plastic debris in Australian waters. Note that in all records where it is unclear whether the type of interaction was entanglement or ingestion (c), the type of debris was also not specified (Sources: see Table 2: Marine Turtles)**

4.5 CETACEANS

4.5.1 AFFECTED CETACEAN SPECIES

Whales and dolphins are prone to entanglement, especially in derelict fishing gear, however very little information is available about plastic ingestions in cetaceans (e.g. Figure 9).

Figure 9. Unidentified dolphin entangled in fishing line. Photo courtesy of Dolphin Discovery Centre, Bunbury.

A total of 104 records of cetaceans impacted by plastic debris through entanglement or ingestion are available since 1998. Of these, the vast majority (92.2%) of or records relate to entanglements. An additional 110 cetaceans were killed by unknown causes, where it was not possible to ascertain whether the deaths were human-related or not. Approximately 61% of entangled cetaceans reported during this period were freed, released or successfully rehabilitated (Figure 10a). However, the final fate of released or rehabilitated cetaceans remains largely unknown or unreported.

Necropsy results showing ingested plastic exist for just nine individuals for the period that records are available (1998-2008) (Figure 10b). This does not necessarily reflect the rarity of plastic ingestions, but the fact that necropsy results may not report on ingested plastic if this was not considered the primary cause of death. It may also reflect the decreasing frequency with which necropsies have been carried out over recent years. For example, an average of 47.4% (+/- 2.9 S.E.) of stranded cetaceans were necropsied each year in Queensland between 1999 and 2003, but in 2004 and 2005 necropsies were carried out on 9.2% and 9.8% of stranded cetaceans respectively.

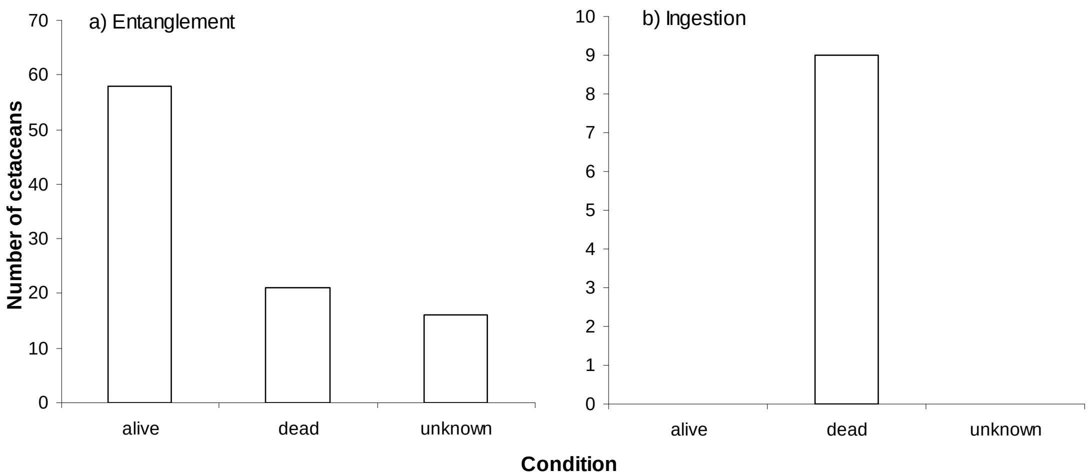

Figure 10. Available records of cetaceans impacted by entanglement in and ingestion of plastic debris since 1998 in Australian waters (Sources: see Table 2: Cetaceans)

Worldwide, over 26 species of odontocetes (toothed whales and dolphins) have been reported to ingest plastic debris (Baird and Hooker 2000). In Australia, deaths and injuries of 14 species of cetaceans could be attributed directly to interactions with plastic debris between 1998 and 2008. A further 11 species were found dead for unknown reasons. Humpback whales dominated the available records, probably due to their relatively large population and their tendency to undertake annual migrations close to the east and west coasts of Australia (Figure 11a). Other identified species affected by entanglement were southern right whales, common dolphins, Indo-Pacific humpbacked and bottlenose dolphins, Australian snubfin dolphins, and a rare beaked whale (family Ziiphidae, species not given).

The most notable record of plastic ingestion in a cetacean was in a Bryde's whale, found in Cairns in August 2000 with a stomach full of plastic litter, photographs of which were used for educational purposes (Haines and Limpus 2000b). Three bottlenose dolphins were recorded in Victoria with fishing hooks in their digestive tract (K. Charlton, Monash University) and dietary studies on sperm whales found plastic fragments in the stomachs of four individuals (Evans and Hindell 2004) (Figure 11b). The four sperm whales, recorded in Tasmania, were part of a study investigating the stomach contents of two groups of sperm whales that had stranded *en masse* in Strahan and Marrawah, northwestern Tasmania. Overall, these four whales represent 11.1% of all animals necropsied during this study. However, it was stated that complete stomach contents were only examined for 47% of the stranded animals (Evans and Hindell 2004). A necropsy of a pygmy southern right whale found on Maria Island (Tasmania) revealed that the animal had ingested a chainsaw file cover and a cap from a 20-litre drum (Glenn Atkinson, DPIW Tasmania, pers. comm.).

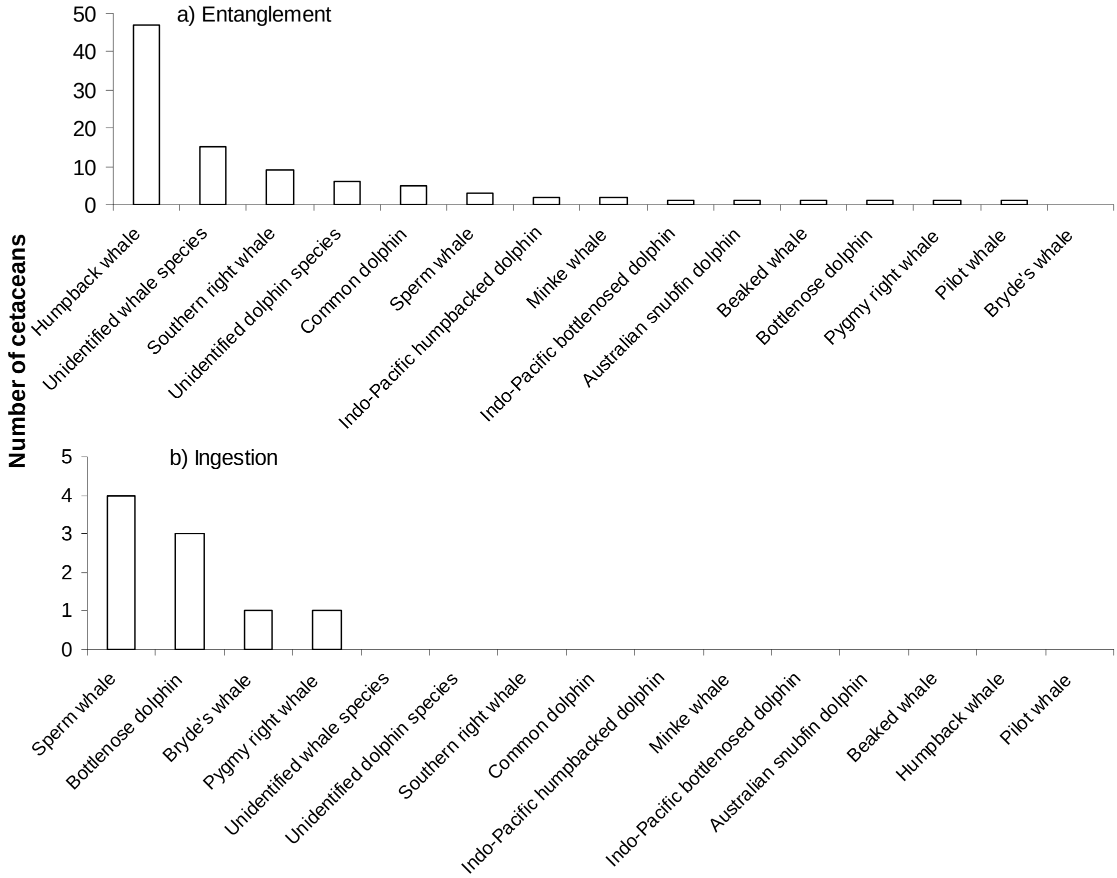

Figure 11. Available records of cetacean species impacted by a) entanglement in or b) ingestion of plastic debris in Australian waters since 1998 (Sources: see Table 2: Cetaceans)

4.5.2 TEMPORAL PATTERNS AND DISTRIBUTION OF AFFECTED CETACEANS

Available records suggest that most cetaceans being impacted by plastic debris are found during the second half of a calendar year, especially between June and September (Figure 12). Between 50 and 60% of interactions between plastic debris and cetaceans recorded between June and August involve humpback whales. It is likely that there is a seasonal peak in interactions between humpback whales and plastic debris during their annual migration north and south along Australia's eastern and western coastlines, which occur during the Austral winter (between May and October) (Bannister et al. 1996); indicating that this apparent monthly variation is directly related to seasonal humpback whale presence. Southern right whales are also considered at high risk of entanglement due to their tendency to aggregate inshore during travel and calving (Jones 1995, Allen and Bejder 2003), but records available for this study were too few to discern seasonal patterns for any species.

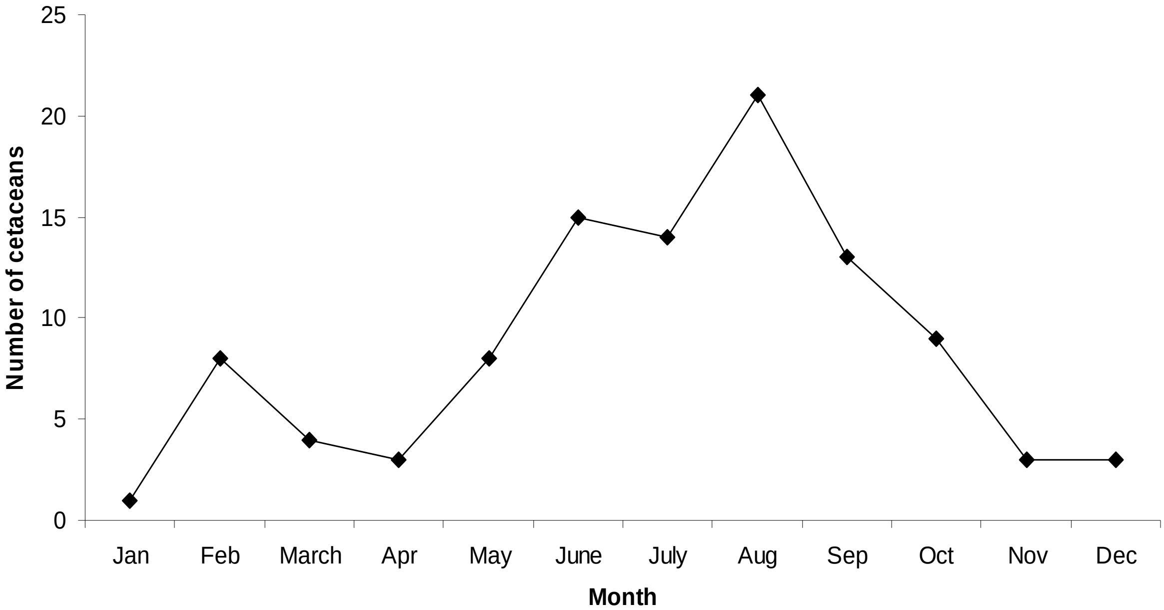

Figure 12. Monthly variation in available records of cetaceans impacted by plastic debris (entanglement and ingestion) since 1998 in Australian waters (Source: see Table 2: Cetaceans).

Note: This figure does not include records summarised over a period of months or years

Available records suggest that there have been two peaks in numbers of cetaceans impacted by plastic debris over the last decade; a smaller peak in 2000 and a maximum yearly total of 29 incidents reported in 2006 (Figure 13). These peaks may correspond to peaks in data collection and reporting efforts by the Australian Government Department of the Environment, Water, Heritage and the Arts and the Qld EPA, which have contributed approximately 34% and 40% of available cetacean data respectively.

A lack of consistency in reporting makes it impossible to estimate an annual average entanglement or ingestion rate on a national scale, although such estimates have been made for specific parts of the Australian coastline. For example, Project Dolphin Safe attends to between one and four dolphin entanglements per year in the Adelaide region (Aaron Machado, SA Seabird Rescue, pers. comm.), and another study suggests that dolphin entanglements in the Spencer Gulf (SA) have increased dramatically since 2001 (Gedamke 2007). It is not possible to ascertain the status of any fishing gear (active or derelict) causing these entanglements.

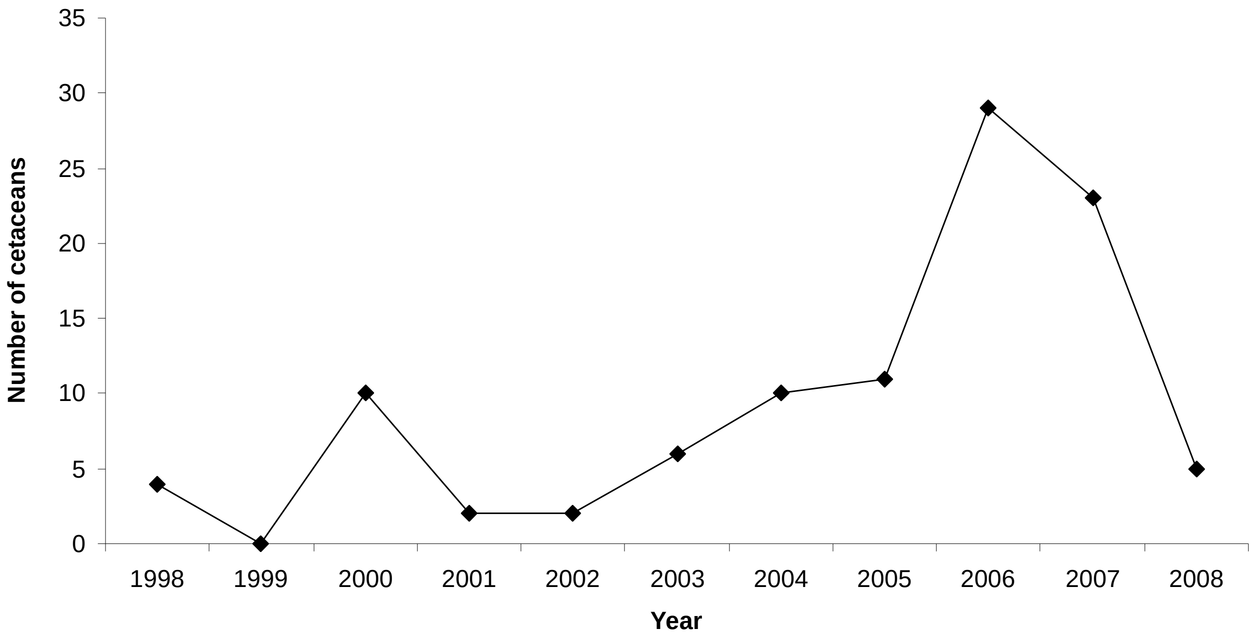

Figure 13. Annual trends in available records of cetaceans impacted by plastic debris (entanglement and ingestion) in Australian waters (Source: see Table 2: Cetaceans).

Note: This figure does not include records summarised over a period of more than one year

The highest density of reports comes from areas where human population centres coincide with habitats and migration routes of the most common cetacean species, most notably around the New South Wales-Queensland border (Figure 14). Areas devoid of records were the Cape York coastline, the Gulf of Carpentaria, the northern Western Australian coast and the Great Australian Bight. It is important to note that the geographic range of species, including the seasonal presence of some migratory species in Australian waters, is likely to have a strong influence on data availability.

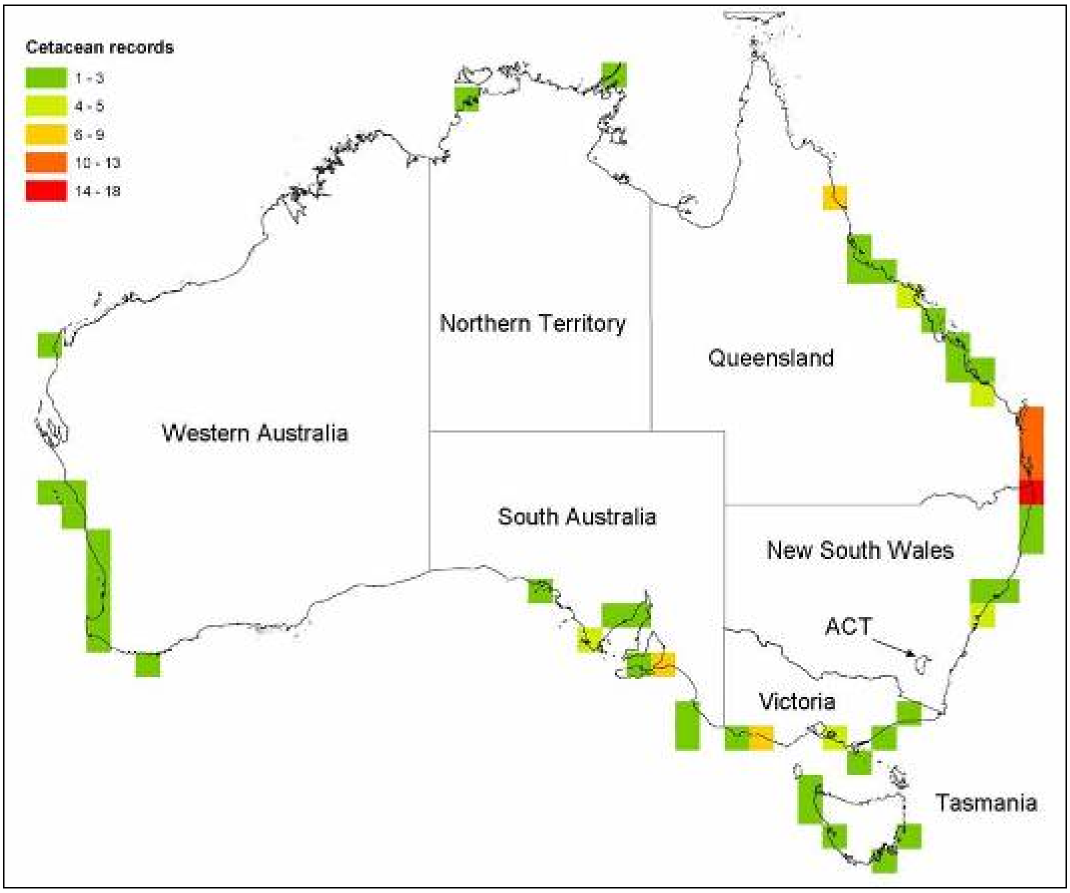

Figure 14. Distribution of known records of cetaceans impacted by plastic debris (entanglement and ingestion) in Australian waters since 1998 (Source: see Table 2: Cetaceans)

4.5.3 TYPES OF PLASTIC DEBRIS AFFECTING CETACEANS

Most entanglements of cetaceans between 1998 and 2008 were caused by unidentified fishing nets of unknown (active or derelict) status. Unlike the turtle records, none of the cetacean records included identification or descriptions of the nets, except to label them as 'fishing nets'. Likewise, closer descriptions were not available for cases where cetaceans were entangled in rope, with or without floats or buoys attached, except for the fact that the rope was synthetic. Crab and lobster pots and associated ropes and floats (collectively labelled 'crab/lobster pot gear') also caused a number of entanglements, but it is not possible to determine whether the crab or lobster pot gear was active at the time of entanglement. Abandonment of crab pots is reported as being an issue along the Gold Coast (Dillaway 2007), suggesting that entanglement in derelict pots is possible. Five cetaceans were reportedly entangled in fishing line, six were recorded as entangled in plastic debris of unknown type, and four were affected by unidentified fishing gear (Figure 15).

The plastic items ingested by cetaceans (not included in Figure 15) were not described in any detail; the Bryde's whale stomach yielded primarily plastic bags of unspecified origin, common dolphins in Victoria had ingested fishing hooks and sperm whales in Tasmania were found with 'plastic debris' – including the 'top section of a plastic container' (Evans and Hindell 2004) – in their stomachs. A necropsy of a pygmy southern right whale found on Maria Island (Tasmania) revealed that the animal had ingested a chainsaw file cover and a cap from a 20-litre drum (Glenn Atkinson, DPIW Tasmania, pers. comm.).

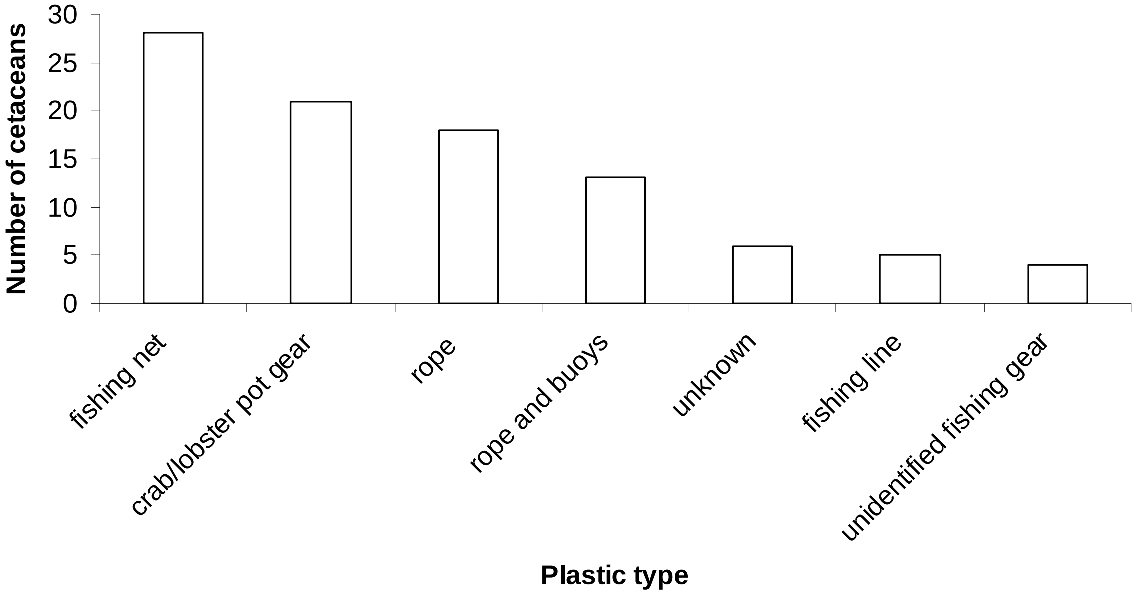

Figure 15. Known types of plastic debris impacting cetaceans through entanglement since 2000 in Australian waters. The available records do not specify whether the fishing gear was active or derelict at the time of interaction (Source: see Table 2: Cetaceans)

4.6 SEABIRDS

Seabird rescue organisations report that active recreational fishing gear appears to pose a much greater threat to seabirds around the Australian mainland coast than derelict fishing gear or other types of plastic debris. However, there is only one instance where the proportions of impacts from active or derelict gear were estimated: approximately 94% (120) of seabirds attended to by South Australian Seabird Rescue in the 2005-2006 period had been entangled in active recreational gear, including fishing hooks, lines and nets (Machado 2007). The nature of all other existing records makes it difficult to tease apart injuries or deaths caused by active and derelict fishing gear. For instance, Pelican and Seabird Rescue in Brisbane recorded 15 cases of entanglement and ingestion in seabirds between January and the beginning of June 2008, but it was impossible to tell whether any of the birds had been affected by active or derelict fishing gear. Records of interactions with both commercial and recreational fishing gear (hooks and lines), unless specifically identified in the records as derelict fishing gear, are therefore considered separately in this section.

Figure 16. Hoary-headed grebe entangled in mesh netting. Photo courtesy of Mandy Hall, Hobson's Bay Wildlife Shelter.

4.6.1 AFFECTED SEABIRD SPECIES

For the purposes of this study, available seabird records have been separated into two categories: interactions with plastic debris (including fishing gear clearly identified as derelict), and interactions with fishing gear of unknown (active or derelict) status (e.g. Figure 16). Many seabird rescue organisations state that most seabirds are affected by active fishing equipment (e.g. Linda Emery, WA Seabird Rescue, pers. comm.; Aaron Machado, SA Seabird Rescue, pers. comm.; Kathrina Southwell, Australian Seabird Rescue, pers. comm.).

This study found 205 known interactions between seabirds and plastic debris since 1974, involving 29 species (Figure 17, Table 4). Of the seabirds impacted, just over 17% were freed and released alive, while around 70% perished. The latter were either found dead or died in the care of rescuers. The fate of live and rehabilitated seabirds after release is largely unknown. While most animals must be necropsied in order to find out whether plastic has been ingested, many seabirds regurgitate food in order to feed their chicks, and regurgitation can be induced to test for plastic ingestion in live birds (Copello and Quintana 2003). However, this method was not encountered often in the literature, and plastic ingestion was therefore predominantly recorded in dead birds (Figure 17b). Only a small number of records of interactions between seabirds and plastic debris do not specify the nature of the interaction (Figure 17c).

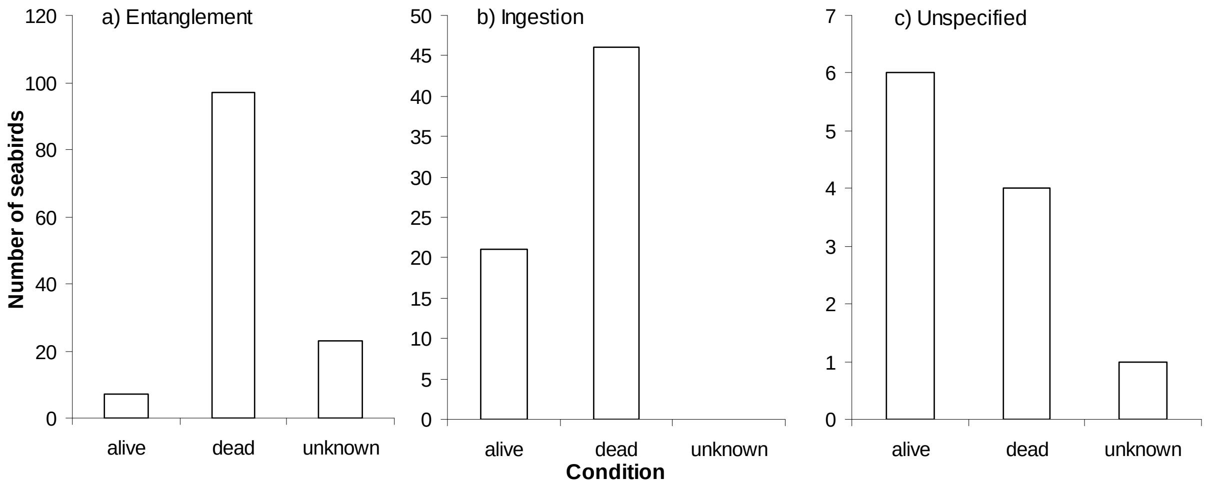

Figure 17. Available records of seabirds affected by entanglement in ingestion of, and unspecified interactions with plastic debris (including derelict fishing gear) since 1974 in Australian waters (Source: see Table 2: Seabirds)

Seabird rescue organisations state that more than 50% of birds attended to have been affected by entanglement in or ingestion of fishing lines and hooks of unknown (active or derelict) status (Figure 18). This study found 293 records of interactions between seabirds and fishing gear of unknown status from 1987 to 2008. Of the affected seabirds, comprising 43 species (Table 4), 58.3% survived the interaction, while 27.3% were either dead at the time of recording, or are known to have died of their injuries from plastic debris subsequently.

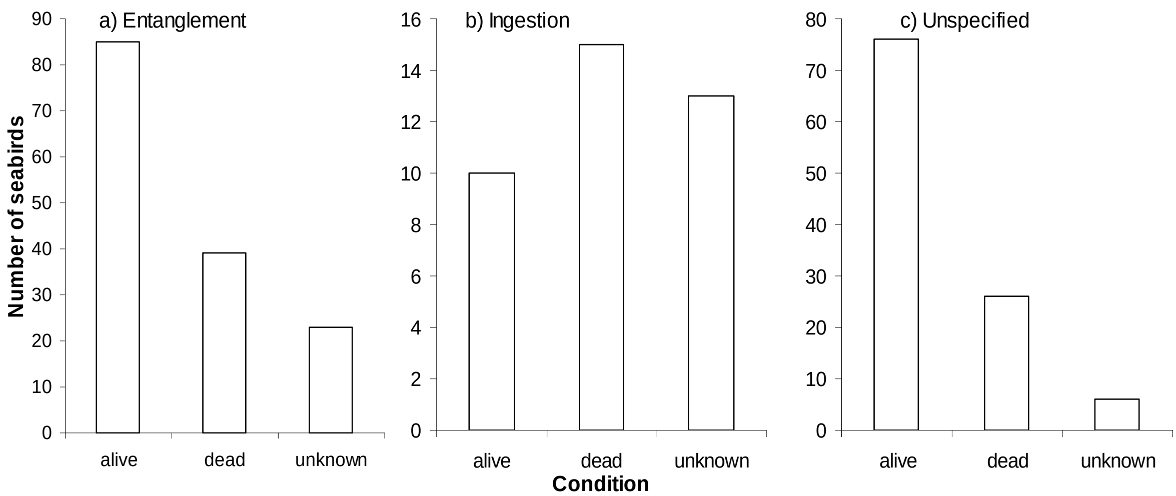

Figure 18 Available records of seabirds affected by entanglement in ingestion of, and unspecified interactions with fishing gear of unknown (active or derelict) status since 1987 in Australian waters (Source: see Table 2: Seabirds)

The highest numbers of records of entangled seabirds are from incidents involving mass entanglements involving large numbers of individual birds in a single event (Table 4). Data from mass entanglements tend to skew records to show high numbers of animals being impacted at one time or geographic location without necessarily reflecting seasonal or other factors that may influence stranding incidents. Mass entanglements are nevertheless presented here as the number of individual birds affected, as this represents the actual impact of entanglement on seabird populations. The Australian pelican is the species that is most often recorded as entangled in fishing line or caught on fish hooks (Machado 2007).

Table 4. Known species of seabirds affected by plastic debris and fishing gear of unknown (active or derelict) status in Australian waters since 1974 (Source: see Table 2: Seabirds)

Species	Common Name	Entanglement (number of individual animals)		Ingestion (number of individual animals)	
		Debris	Fishing	Debris	Fishing
Anas superciliosa	Pacific black duck	1	3		
Catharacta skua	Subantarctic skua		1	10	
Halobaena caerulea	Blue petrel			8	
Daption capense	Cape petrel			10	
Macronectes halli	Northern giant-petrel		1		
Macronectes giganteus	Southern giant-petrel			5	2
Pelecanus conspicillatus	Australian pelican	5	75	1	11
Phalacrocorax atriceps purpurascens	Macquarie Island cormorant			5	
Phalacrocorax carbo	Great cormorant				1
Phalacrocorax melanoleucus	Little pied cormorant		1	1	
Phalacrocorax sulcirostris	Little black cormorant		2		1
Phalacrocorax varius	Pied cormorant		5		6
Puffinus carneipes	Flesh-footed shearwater			19	1
Eudyptula minor	Little (fairy) penguin	23	3		1
Pygoscelis adeliae	Adelie penguin	20			
Pygoscelis papua	Gentoo penguin			1	
	Unidentified penguin	1			
Egretta novaehollandiae	White-faced heron		1	1	
Ardea alba	Great egret		3		
Larus dominicanus	Kelp gull	1		3	
Larus novaehollandiae	Silver gull		11		7
Larus pacificus	Pacific gull	1			
Haliastur indus	Brahminy kite		1		
Pandion haliaetus	Osprey		1		
Puffinus tenuirostris	Mutton bird	70			

Species	Common Name	Entanglement (number of individual animals)		Ingestion (number of individual animals)	
Morus serrator	Australasian gannet		9		2
Tachybaptus novaehollandiae	Australasian grebe		1		
Sterna bergii	Crested tern		13		2
Sterna caspia	Caspian tern		1		
	Unidentified tern				1
Diomedea exulans	Wandering albatross			1	
Thalassarche melanophrys	Black-browed albatross		1		
Thalassarche steadi	White-capped albatross		1		
	Unidentified albatross		1		
Ephippiorhynchus asiaticus	Black-necked stork	1			
Pachyptila desolata	Antarctic prion			2	
	Unidentified darter	2	2		
	Unidentified seagull	1	5		2
	Unidentified cormorant	1	4		1
	Unidentified seabird		1		

4.6.2 TEMPORAL PATTERN AND DISTRIBUTION OF AFFECTED SEABIRD SPECIES

Peaks in the records of seabird interactions with plastic debris occurred in January and May. However, these peaks were largely affected by single entanglement events in which a large number of individual birds were affected. For example, one record alone notes that 70 mutton birds died from entanglement in a derelict net near Tasmania (ABC News 2006) (Figure 19a). These isolated events were recorded here as numbers of individuals affected, rather than as numbers of events, to reflect the impact of such an event of seabird populations. Records of interactions between seabirds and fishing gear of unknown status are generally evenly distributed throughout the year, varying between 15 and 40 records each month (Figure 19b), with peaks around May, August and October.

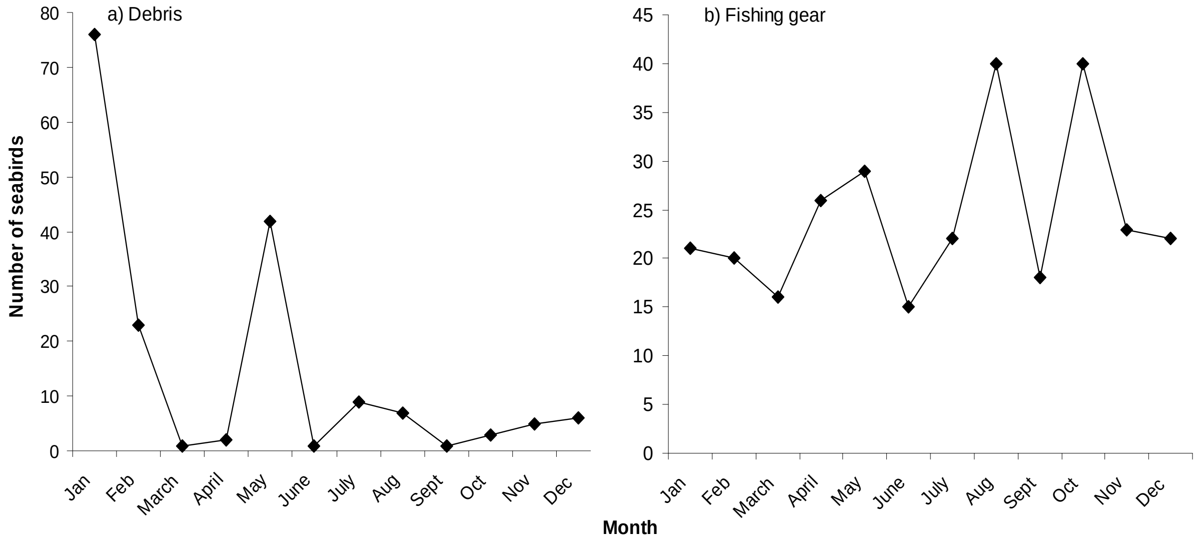

Figure 19. Monthly variation in available records of seabirds impacted by a) plastic debris (including derelict fishing gear) and b) fishing gear of unknown (active or derelict) status since 1974 in Australian waters. This figure does not include records summarised over a period of months or years (Source: see Table 2: Seabirds)

Long-term trends of interactions between seabirds and plastic debris are also strongly skewed by isolated incidents of mass strandings of seabirds in derelict nets (Figure 20a). Such events are recorded in 1986, 2002 and 2006. Records of interactions between seabirds and fishing gear of unknown status undergo a dramatic increase in the years since 2004 (Figure 20b). Despite the fact that records are still incomplete for 2008, the numbers of interaction recorded so far (ending with two records for the month of June) exceed the total number recorded in 2005.

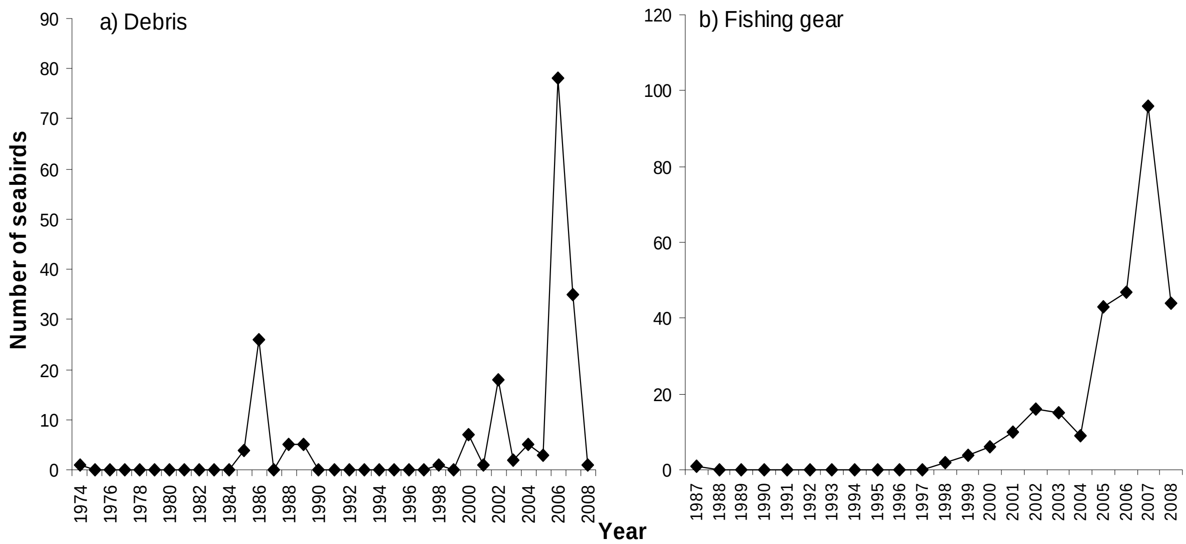

Figure 20. Annual trends in available records of seabirds impacted by a) plastic debris (including derelict fishing gear) and b) fishing gear of unknown (active or derelict) status in Australian waters. This figure does not include records summarised over a period of more than one year (Source: see Table 2: Seabirds)

Available records of seabird entanglements in and ingestion of plastic debris are generally restricted to southern Australia, Lord Howe Island, sub-Antarctic islands (Macquarie and Heard) and the Antarctic continent (Figure 21). Southern Queensland also yielded relatively high numbers of records. This pattern is likely to correlate more with the geographic location of specific studies and the location of wildlife rescue organisations that maintain records than with the distribution of actual impacts.

The largest number of available records for seabird entanglements or ingestions through fishing gear of unknown (active or derelict) status comes from organisations dedicated to the rescue of seabirds and other wildlife (Figure 22). The bulk of these data were provided by Taronga Zoo, Australia Zoo, Currumbin Wildlife Sanctuary, and Pelican and Seabird Rescue. These organisations primarily receive injured and distressed wildlife from nearby coastal locations, which means that records tend to be concentrated around the Sydney region and the southern Queensland coastline. Australian Seabird Rescue (based in Ballina), South Australian Seabird Rescue (Adelaide), Western Australian Seabird Rescue (Perth) and Chelonia (Broome) are other organisations that provided information (e.g. Machado 2007) for use in this study but no primary data. It is estimated that in the Adelaide region alone, over 450 seabirds were impacted by interactions with (mostly active, recreational) fishing gear between late 2003 and late 2006 (Machado 2007).

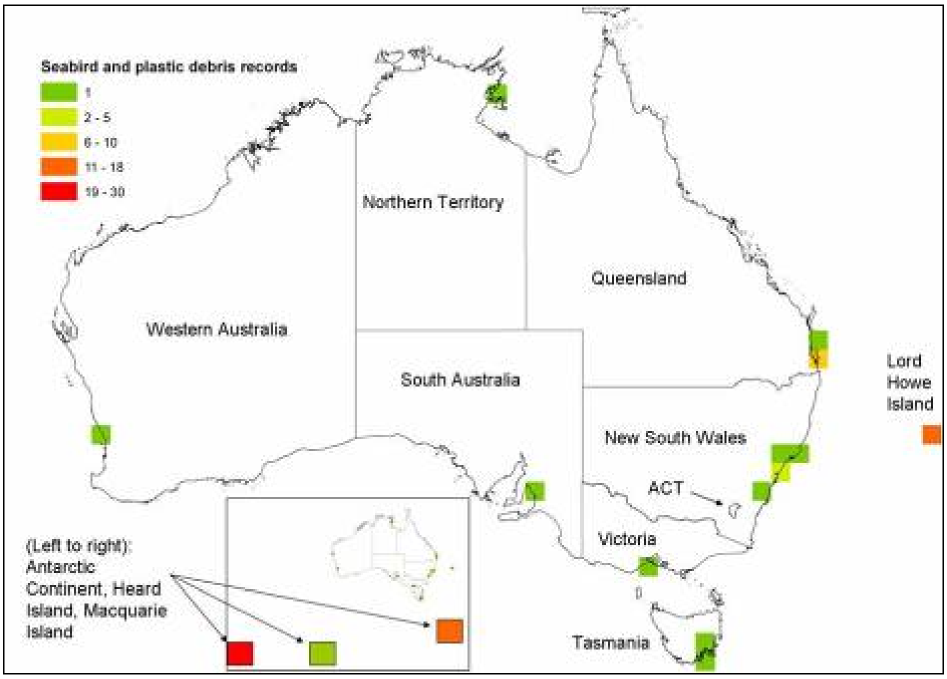

Figure 21. Available records of seabirds impacted by entanglement in and ingestion of plastic debris and fishing gear recorded as 'derelict' since 1974 (Source: see Table 2: Seabirds)

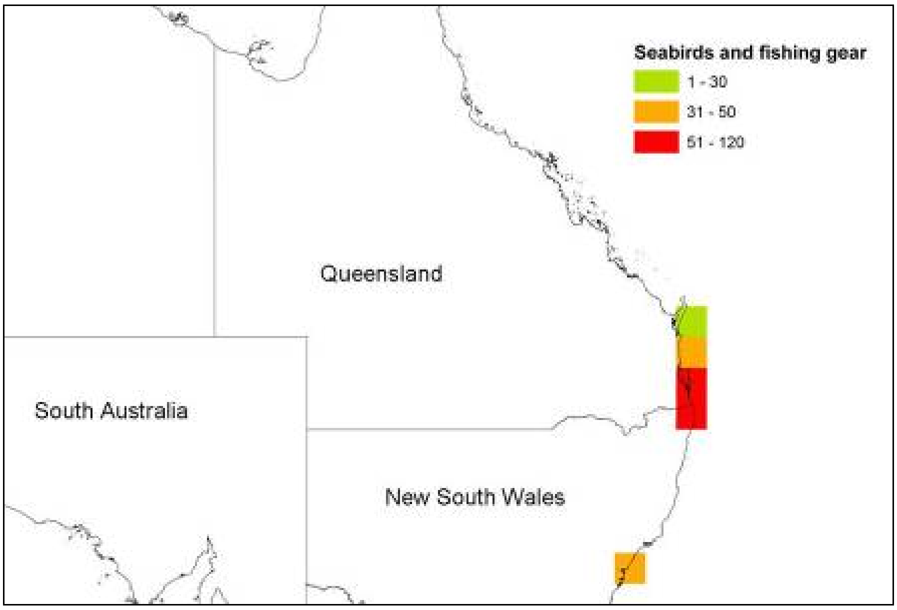

Figure 22. Known records of seabirds impacted by fishing lines and hooks of unknown (active or derelict) status since 1998 and 2008; the timeframe reflects the years for which records were available (Source: see Table 2: Seabirds)

4.6.3 TYPES OF PLASTIC DEBRIS AFFECTING SEABIRDS

A number of different plastic types are recorded as impacting seabirds, with derelict fishing nets dominating entanglement records (Figure 23a). Only one record clearly attributes entanglement of a seabird to a derelict fishing line. Seabirds have also been recorded entangled in plastic bags of unspecified type, rubber rings and bands of unspecified origin, black mesh netting, an onion bag, a chips packet, crab pot ropes (of unknown status) and gift wrapping. Smaller plastic items tend to be found wrapped around seabirds' bills or legs.

Ingestion of plastic fragments by seabirds has been examined primarily on sub-Antarctic islands, in Bass Strait (e.g. Hedd and Gales 2001) and on Lord Howe Island (Hutton 2004). The majority of records from sub-Antarctic islands and Lord Howe island note that ingested items are 'plastic items' or plastic fragments but provide little other detail (Figure 23b). This is primarily because it is difficult to determine the origins of plastic in seabirds' stomachs, as they are usually modified and/or decayed before being ingested (van Franeker and Bell 1988). Latex balloons and polystyrene spheres have also been found in seabird stomachs (Taronga Zoo, Slip et al. 1990).

A number of available records provide no detail on whether the interaction between seabirds and plastic debris involved entanglement or ingestion (Figure 23c), or the type of plastic debris involved.

When recording interactions between seabirds and fishing gear of unknown (active or derelict) status, seabird rescue organisations primarily report entanglements and ingestions caused by fishing hooks, fishing lines or both. Many records from these groups simply list impacts as being caused by as 'fishing tackle'. Interactions with fishing hooks tend to be recorded as an 'entanglement' when they are found externally on a seabird's body (Figure 24a). Fishing hooks are the items most often appearing in ingestion records (Figure 24b), and are also listed most often when the type of interaction is not specified (Figure 24c). However, seabird rescue personnel suggest that most fish hook injuries are likely to be internal and are therefore causing damage through ingestion (Natasha Graham, Currumbin Wildlife Sanctuary, pers. comm.).

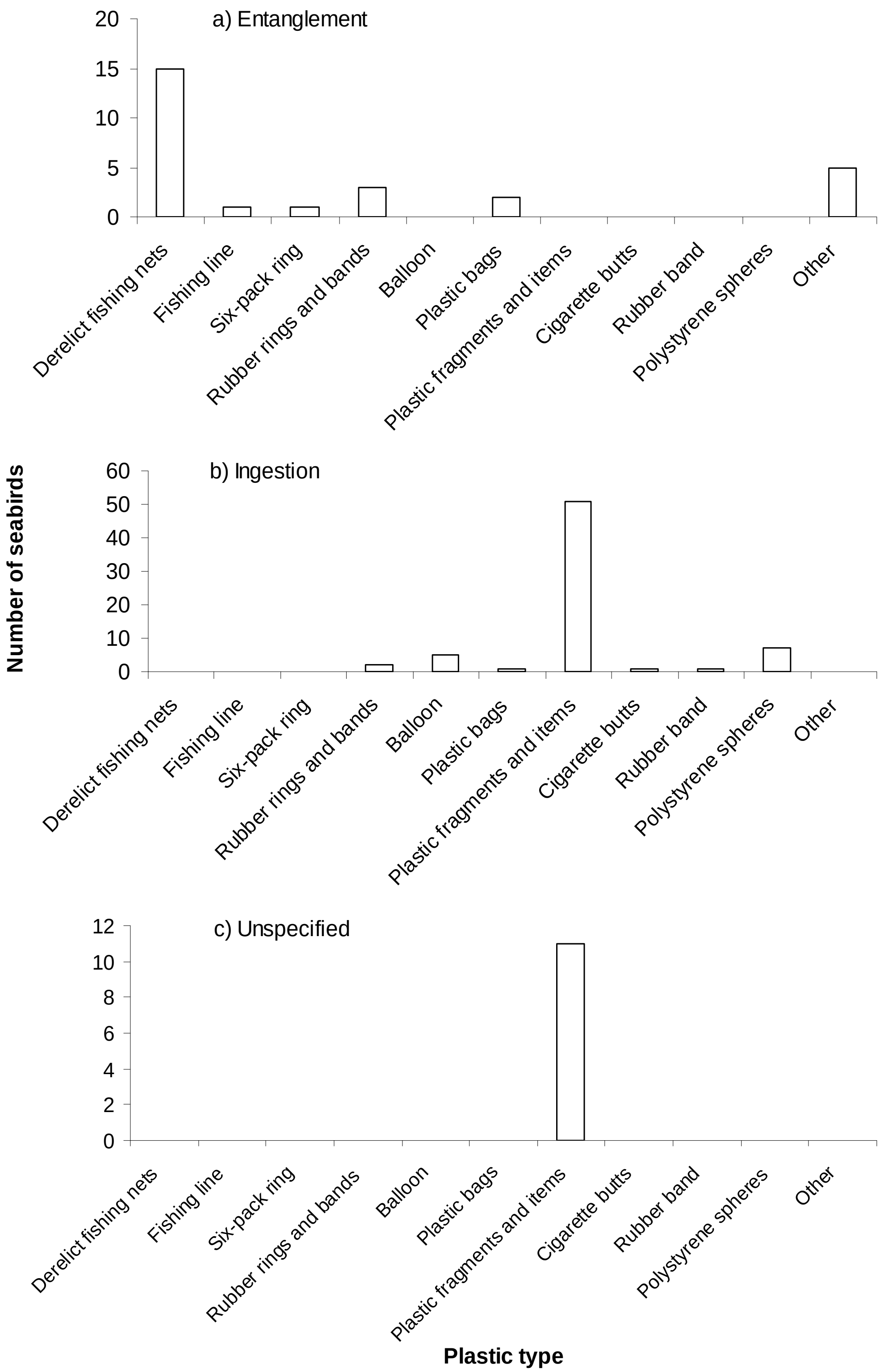

Figure 23. Known plastic debris types (including derelict fishing gear) impacting seabirds through entanglement, ingestion and unspecified causes since 1974 in Australian waters (Source: see Table 2: Seabirds)

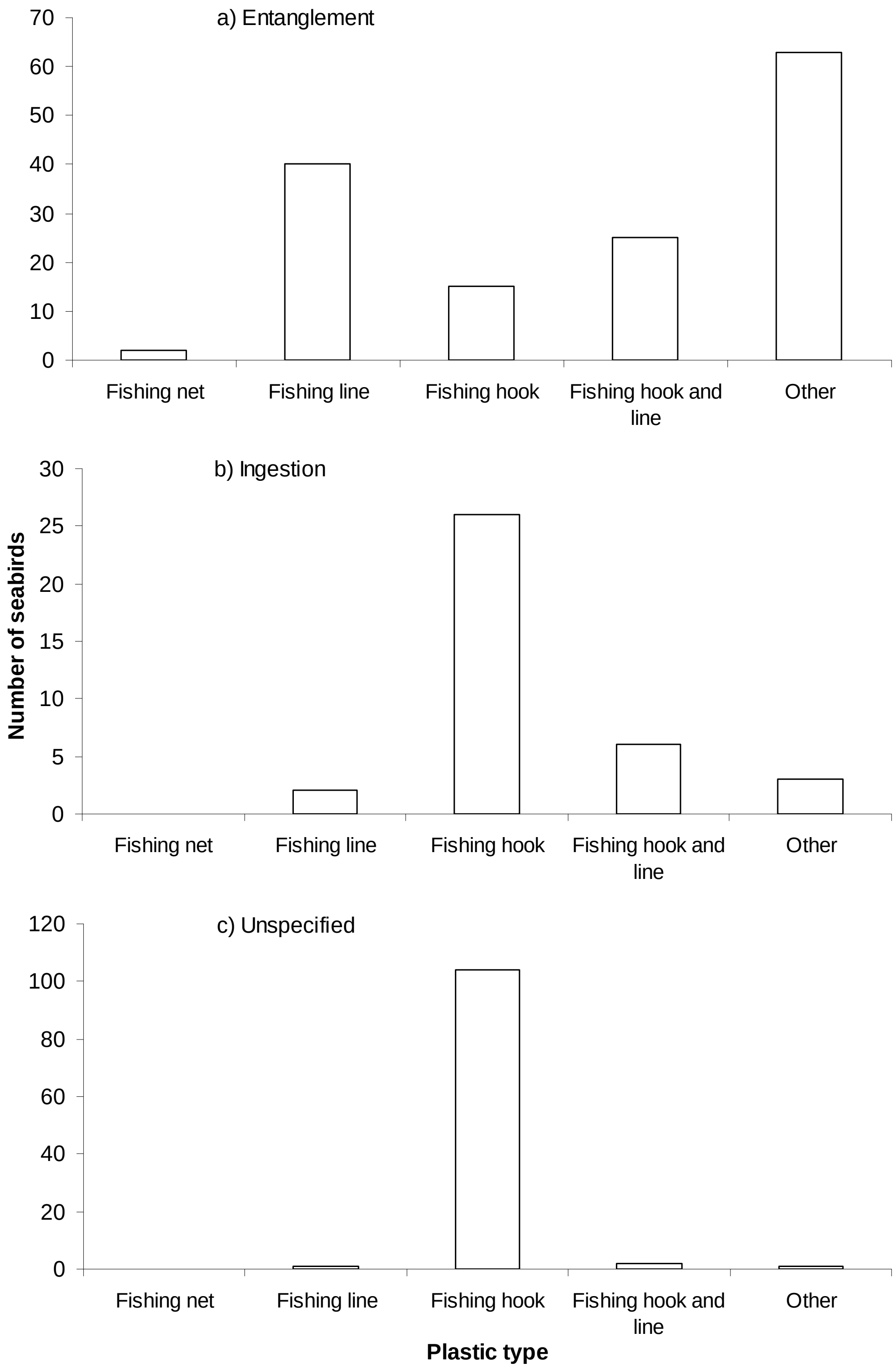

Figure 24. Known fishing gear types (where active or derelict status is unknown) impacting seabirds through entanglement, ingestion and unspecified causes since 1989 in Australian waters (Source: see Table 2: Seabirds)

4.7 DUGONGS

Incidents involving entanglement in or ingestion of plastic debris were recorded for a total of 56 dugongs between 1996 and 2007. Of these, only one dugong was recorded as having been freed and released alive, while 14 died and the fate of 41 individuals was not reported (Figure 25a). The majority (96.4%) of dugongs were entangled, and only two necropsies recorded ingestion of fishing line (Figure 25b). Almost all dugong records come from the reports of the Qld EPA database, and it is unclear from these reports how many dugongs were necropsied each year. It is therefore not possible to estimate the proportion of necropsied dugongs with plastic in their digestive tracts.

Figure 25. Records of dugongs impacted by entanglement in and ingestion of plastic debris in Australian waters between 1996 and 2007 (Source: see Table 2 – Dugongs)

4.7.1 TEMPORAL DYNAMICS AND DISTRIBUTION OF AFFECTED DUGONGS

Data available for this study were not sufficient to determine national patterns in temporal dynamics of dugong interactions with plastic debris, although available records suggest that interactions between dugongs and plastic debris are recorded throughout most of the year (Figure 26). Gaps in data also preclude the examination of trends over time (Figure 27). The highest number of known plastic-related incidents for dugongs in any one year was recorded in 1999, but a record exists of approximately 30 dugongs entangled in nets found in Numbulwar, Northern Territory, between 1996 and 1998 (Table 6 in Kiessling 2003).

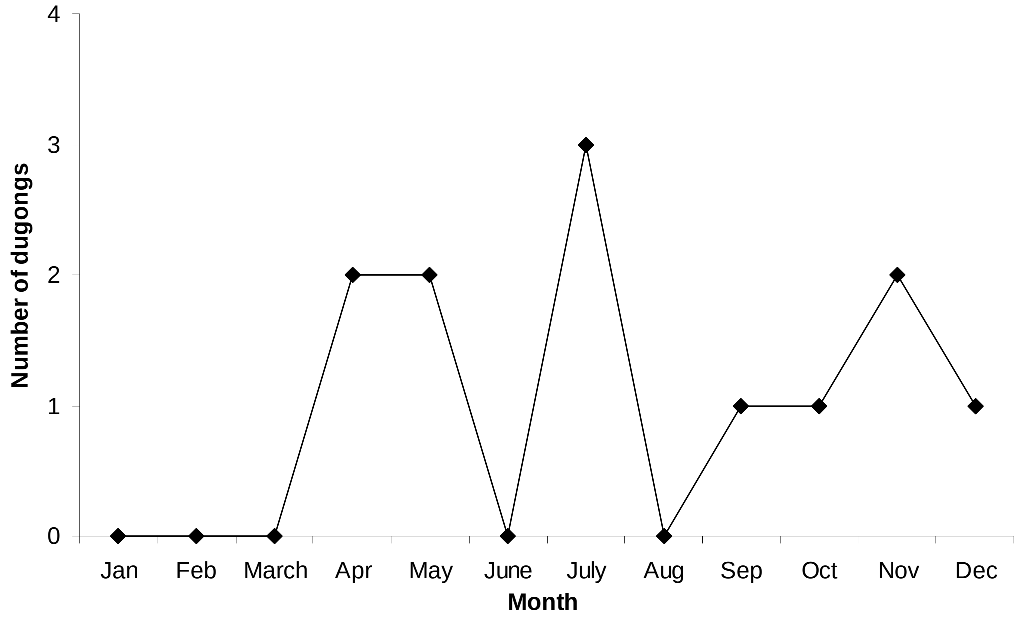

Figure 26. Monthly variation in available records of dugongs impacted by plastic debris between 1999 and 2008 in Australian waters. This figure does not include records summarised over a number of months or years (Source: see Table 2 – Dugongs)

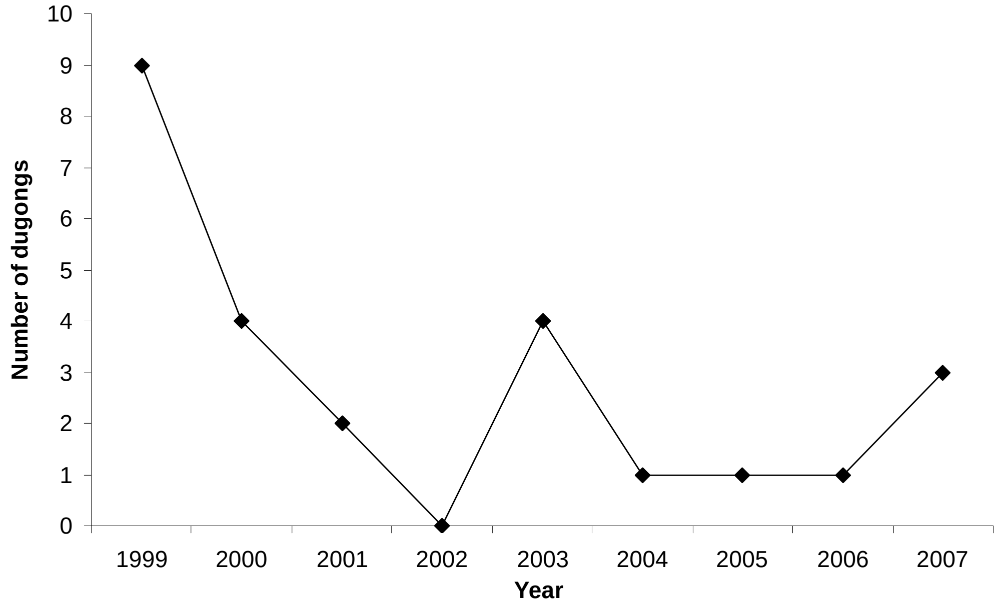

Figure 27. Annual trends in available records of dugongs impacted by plastic debris in Australian waters. Records summarised over multiple years are not included in this figure (Source: see Table 2 – Dugongs)

Records of dugongs are mainly restricted to the east coast of Queensland, with two records from the Northern Territory and one from the Queensland / New South Wales border (Figure 28). At each location, only one or two observations were recorded. Interactions between dugongs and plastic debris occur relatively evenly along most of the Queensland coastline.

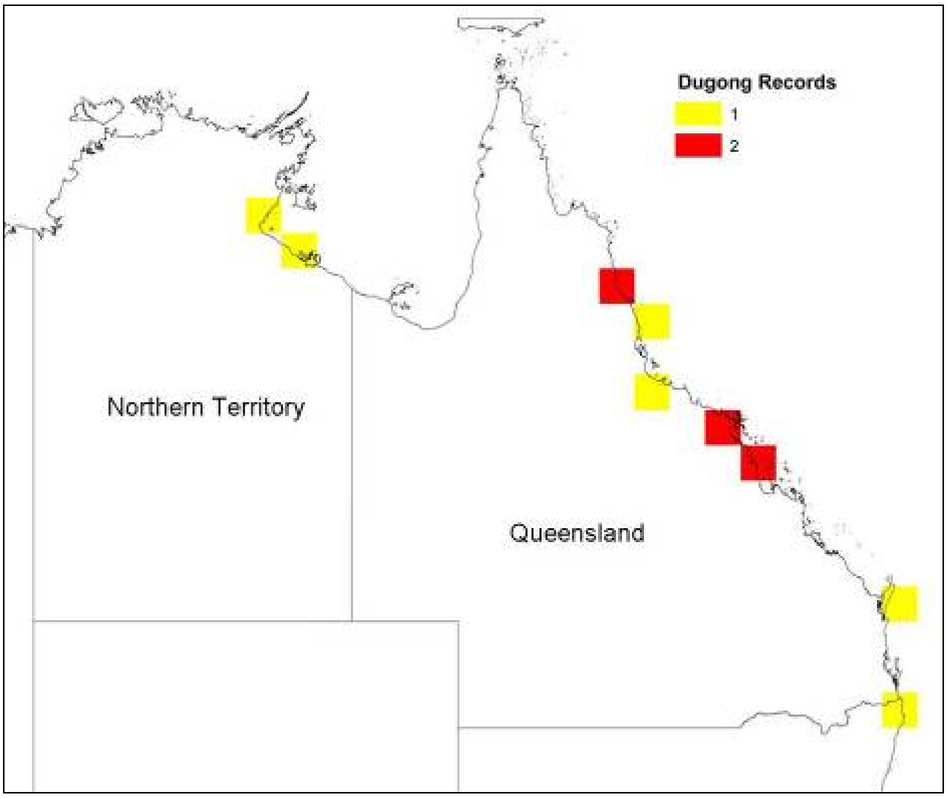

Figure 28. Known records of dugongs impacted by entanglement in or ingestion of plastic debris since 1996 (Source: see Table 2 – Dugongs)

4.7.2 TYPES OF PLASTIC DEBRIS AFFECTING DUGONGS

Reports of plastic entanglements and ingestions for dugongs suggest that they are most often entangled in nets or net fragments (Figure 29). The nets recorded in dugong entanglements include mostly unidentified net types and one gillnet, where it was not specified whether the net was active or derelict at the time of entanglement. It is unknown whether the other fishing gear (ropes, lines, hooks and pots) was active or derelict at the time of interaction.

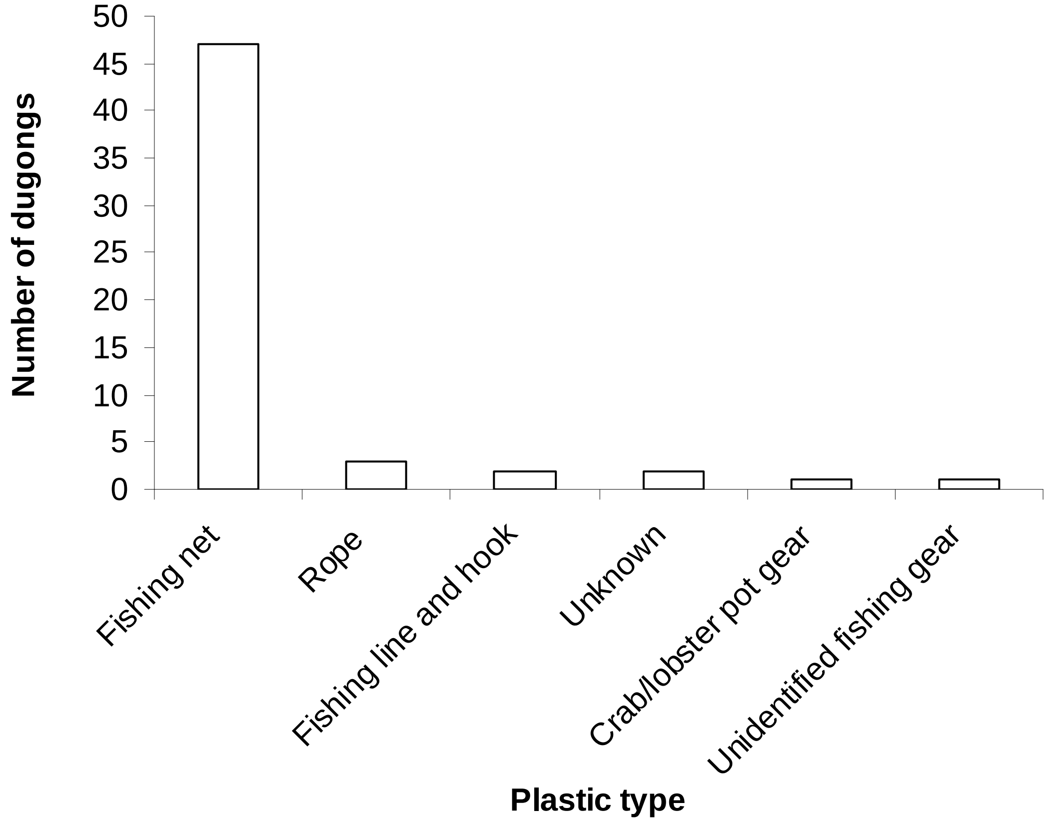

Figure 29. Plastic impacting dugongs since 1996 in Australian waters (Source: see Table 2 – Dugongs)

4.8 PINNIPEDS

Figure 30. Australian fur seal with rope neck collar. Photo courtesy of DPIW Tasmania

4.8.1 AFFECTED PINNIPED SPECIES

In Australia, available studies recording incidents of entangled pinnipeds range between the years of 1980 and 2007, and report a total of 275 entanglements (Figure 31). Of these individuals, 85 survived, 19 died as a result of, or despite the removal of, the entangling material, and the fate of 42 was recorded as ‘unknown’. It must be noted that the pinniped numbers reported here include the results of studies conducted specifically on seal entanglements (Pemberton et al. 1992, Page et al. 2004, Phillip Island Nature Parks 2007). Reports from the Phillip Island Nature Parks report an average long-term rate of seal entanglement of 3.3 per day, with 27 entangled seals encountered at Seal Rocks over 12 days of the 2006 – 2007 reporting period (Phillip Island Nature Parks 2007). Records of ingestion of plastic debris by pinnipeds are rare and involve only two individuals that ingested fishing hooks and lines (sources: Taronga Zoo Pathology Database, DTAE Tasmania 2006). Whether the fishing gear was active or derelict at the time of ingestion is unknown.

Five of the eight pinniped species that live and / or breed in Australian waters were affected by some form of interaction with plastic debris. Most entanglement records are of Australian fur seals (Pemberton et al. 1992), followed by New Zealand fur seals (Page et al. 2004) and Australian sea lions (Page et al. 2004), and sub-Antarctic fur seals (Warwick and Coughran 1999, DTAE Tasmania, AAD) and unidentified seal species (Wildlife Victoria). A study of Antarctic and sub-Antarctic fur seal scats on Macquarie Island found that between 85% and 100% of examined fur seal scats contained pieces of plastic, which were most probably ingested first by fish that formed a large part of the seals’ diets (Eriksson and Burton 2003).

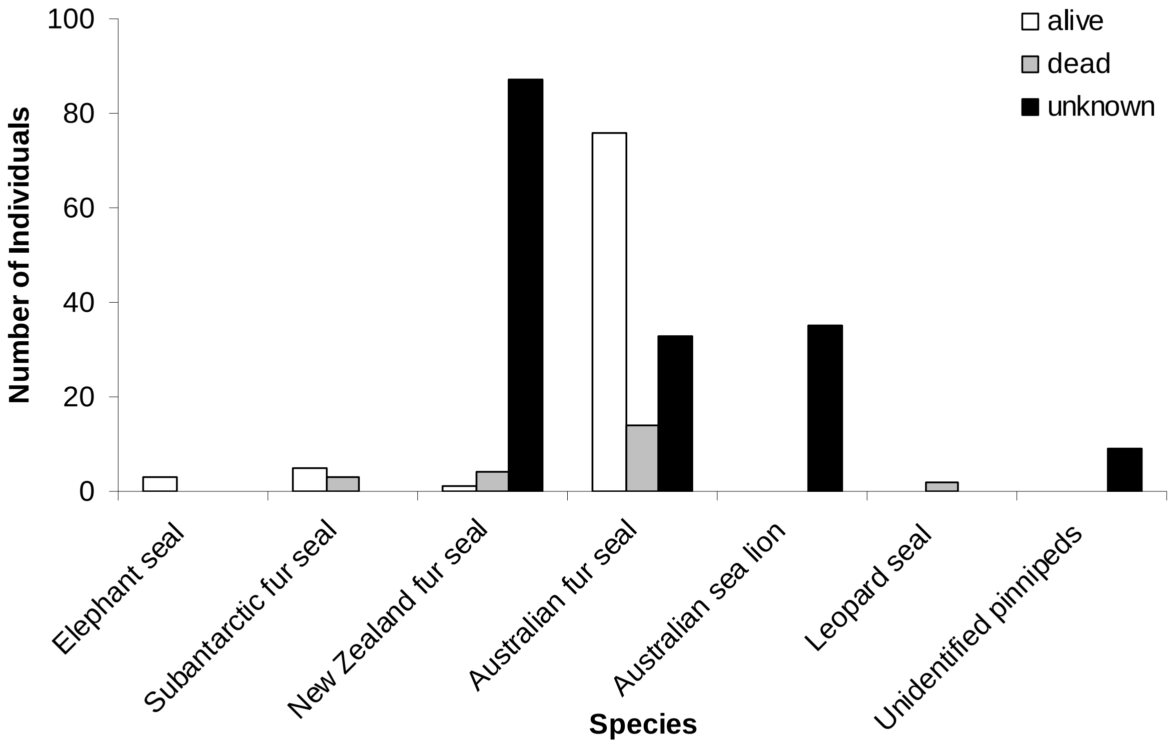

Figure 31. Known records of pinnipeds impacted by entanglement in plastic debris in Australian waters since 1980 (Source: see Table 2 – Pinnipeds)

A comprehensive study conducted on Kangaroo Island to quantify the extent of entanglement of Australian sea lions and New Zealand fur seals estimated that 1,478 seals die annually from entanglement in Australia (Page et al. 2004). This project found no decline in entanglement rates at the time of publication, despite the onset of attempts by government and the fishing industry to reduce the plastic debris problem, and suggests that most of the material causing the entanglements comes not from land, but from nearby fishing activities (Page et al. 2004).

4.8.2 Temporal Dynamics and Distribution of Affected Pinnipeds

Data available for this study were not sufficient to determine national patterns in temporal dynamics of pinniped interactions with plastic debris. Most records of pinniped interactions with plastic debris were reported on an annual basis and could not be categorised by month to examine seasonality. Those data that allow the plotting of monthly records suggest that more pinnipeds are recorded in the early and middle parts of the year (Figure 32). However, no clear conclusions about seasonality can be drawn from these data until they are analysed.

This is also the case when examining longer-term dynamics; there are significant gaps in the records and inconsistencies in the data (Figure 33). High numbers of incidents involving pinnipeds were recorded during the years when specific studies were conducted on rates of pinniped entanglements in Tasmania and Bass Strait (1989-1990, Pemberton et al. 1992), and on Kangaroo Island (1988-2002, Page et al. 2004). The two peaks in interaction rates closely reflect patterns found in these longer-term studies.

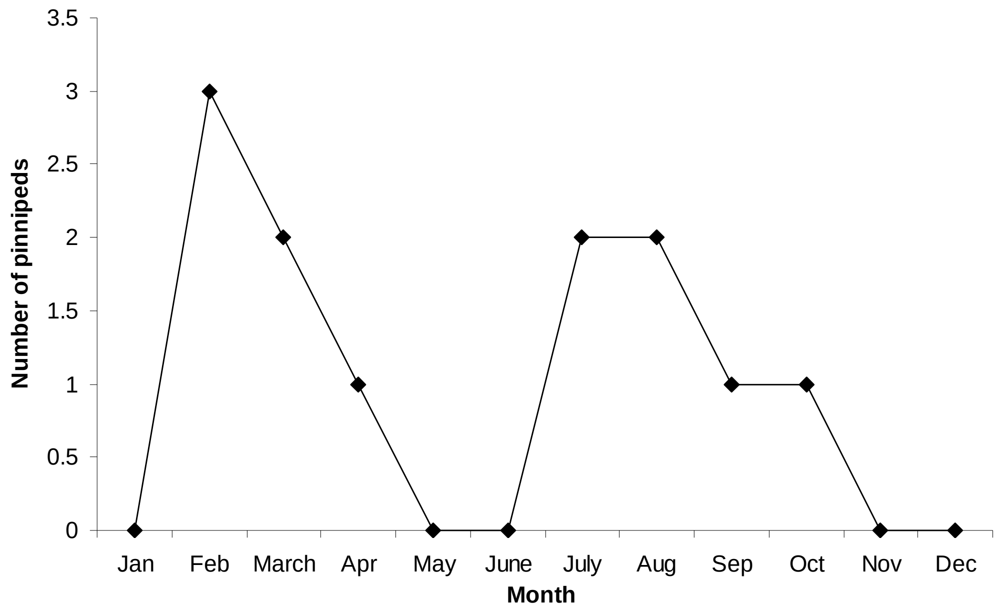

Figure 32. Monthly variation in available records of pinnipeds impacted by plastic debris between 1992 and 2008 in Australian waters. This figure does not include records summarised over a number of months or years (Source: see Table 2 – Pinnipeds)

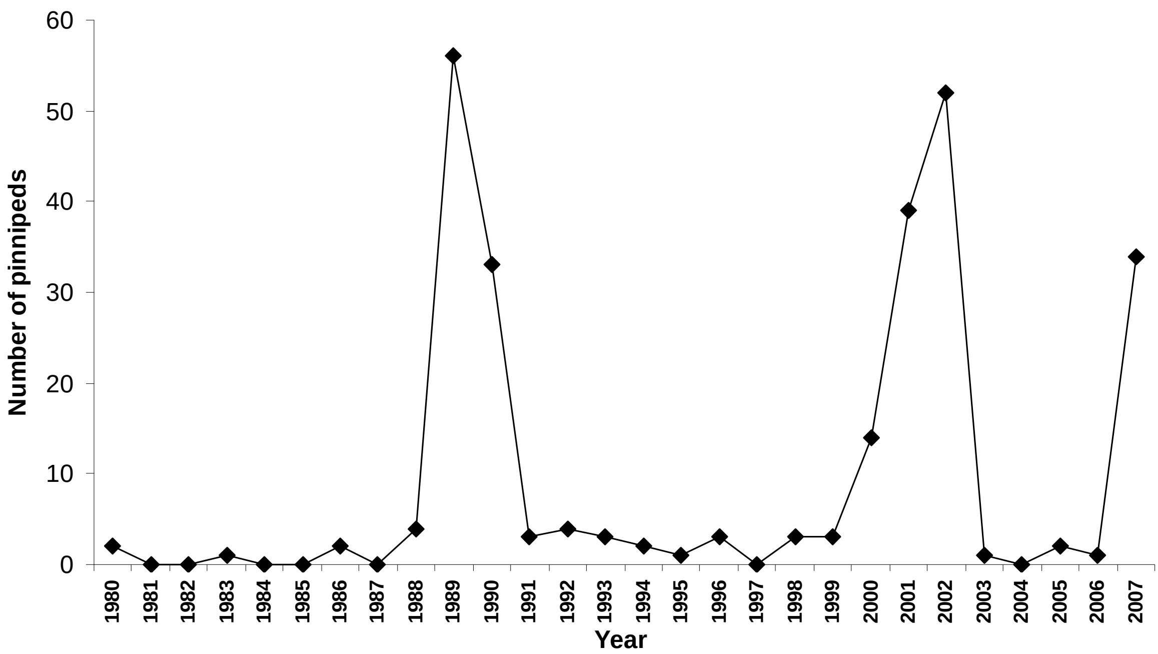

Figure 33. Annual trends in available records of interactions between pinnipeds and plastic debris in Australian waters. This figure does not include records summarised over a number of years (Source: see Table 2 – Pinnipeds)

The distribution of pinniped records is strongly affected by the distribution of pinniped species in Australia, the location of major study sites and the presence of rescue organisations (Figure 34). These places include Kangaroo Island, Macquarie Island, Tasmania and Bass Strait, Victoria and the NSW coast. The northern-most records come from the coast of the NSW – Queensland border.

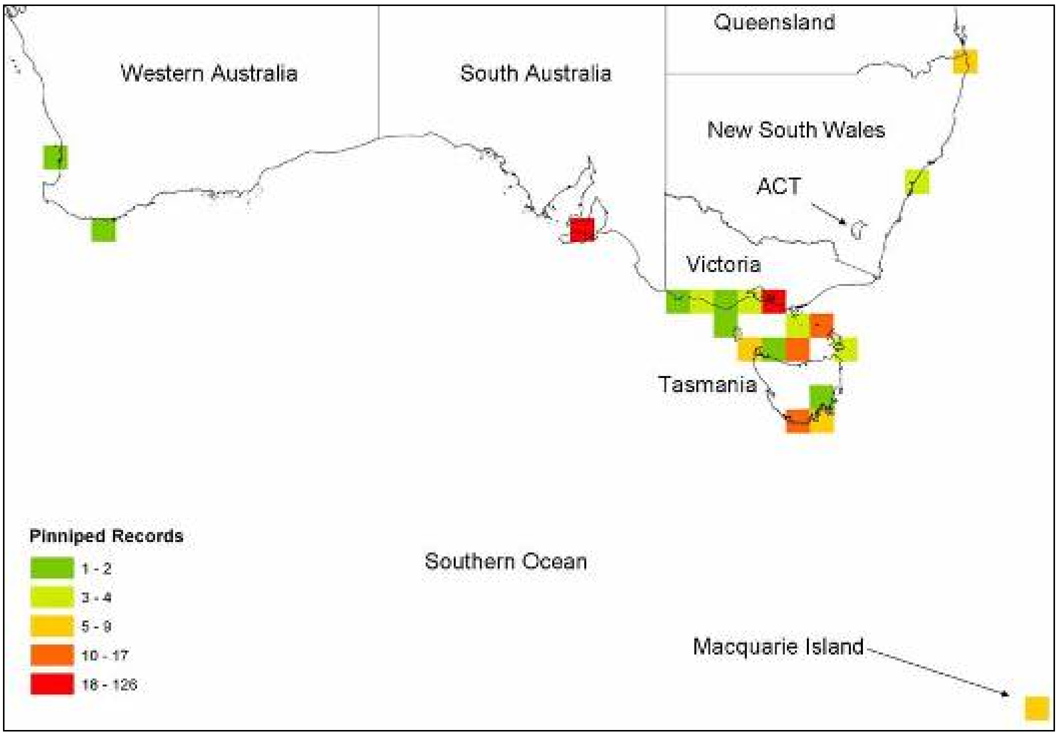

Figure 34. Distribution of known records of pinnipeds impacted by entanglement in or ingestion of plastic debris since 1980 (Source: see Table 2 – Pinnipeds)

4.8.3 TYPES OF PLASTIC DEBRIS AFFECTING PINNIPEDS

Reports of plastic entanglements and ingestions for pinnipeds suggest that they are most often entangled in nets or net fragments (Figure 35). Of the 105 pinnipeds entangled in nets, around 55% (58) were entangled in trawl nets, and a further 33% (35) were entangled in monofilament netting. The nets were generally classed as 'debris', suggesting that they were derelict at the time of entanglement (Page et al. 2004). Pinnipeds appear likely to be affected by a number of plastic debris types, because fragments of material become caught around individuals' necks (Pemberton et al. 1992). These are most often made of net, rope, rubber and bait straps, also recorded as plastic banding tape or strapping tape (Pemberton et al. 1992). Small numbers of pinnipeds are also recorded in incidents with fishing lines or hooks and crab or lobster pot gear (e.g. Taronga Pathology Database, Page et al. 2004, Warwick and Coughran 1999).

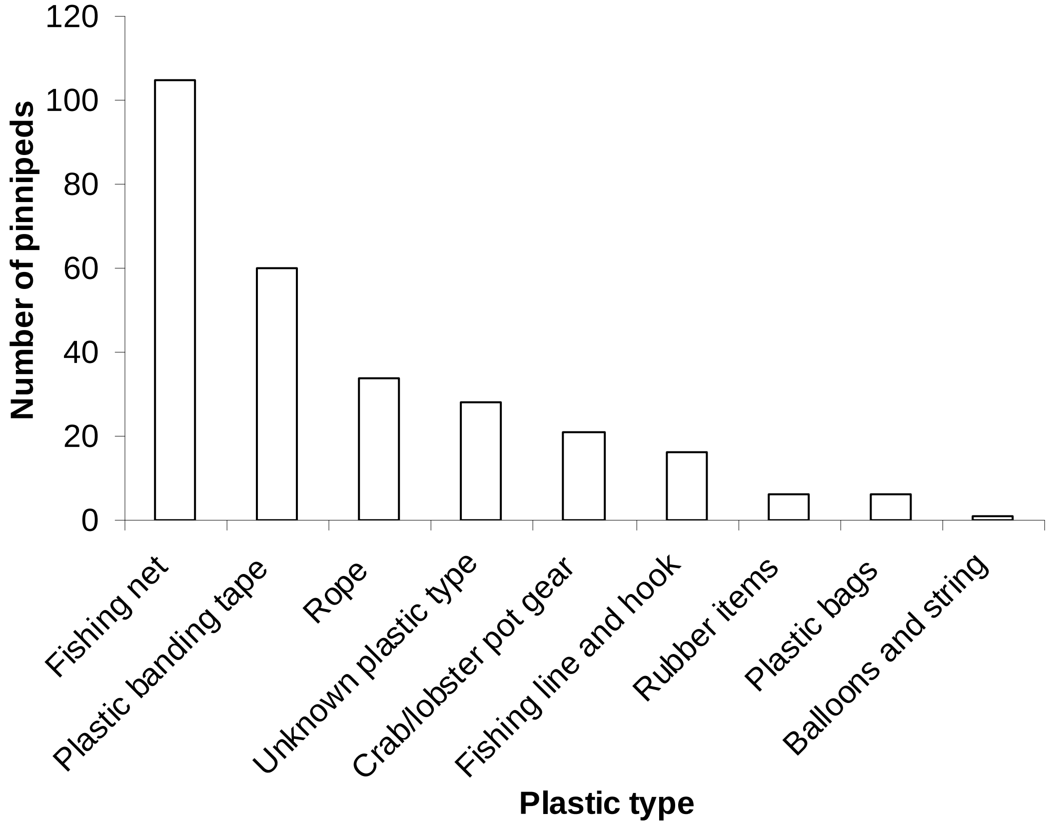

Figure 35. Known types of plastic impacting pinnipeds since 1980 in Australian waters. (Source: see Table 2 – Pinnipeds)

4.9 OTHER SPECIES

4.9.1 OTHER SPECIES AFFECTED BY PLASTIC DEBRIS

Sharks and many species of fish may be affected by derelict fishing gear, although few records are available. Reports also exist of entangled crabs, sea snakes, estuarine crocodiles and stingrays (Table 5). Sharks entangled in fishing gear have been recorded on at least 15 occasions, and necropsies have revealed fishing gear and other plastic debris in the stomachs of dead sharks (e.g. Taronga Zoo). As with seabirds, it is difficult to determine whether shark injuries caused by fishing hooks and lines are caused by derelict or active fishing gear. In the 1980s, Western Australian shark fishermen noted a large number of sharks injured and killed through entanglement in plastic straps used to close bait boxes (Simpendorfer 1997). It is estimated that approximately 6% of eastern grey nurse sharks sighted during surveys show evidence of interactions with fishing gear (Commonwealth of Australia 2001). However, other studies specifically targeting shark diets have found no plastic in the stomachs of a number of species (*Carcharhinus leucas, C. tilstoni, C. sorrah* and *C. ambionensis*) in the Northern Territory (Dr. Iain Field, Charles Darwin University, pers. comm.). Some species, such as tiger sharks and estuarine crocodiles, are reported to ingest a wide variety of discarded objects (Bateman 2008 and Charlie Manolis, Crocodylus NT, pers. comm.). Manta ray feeding activities are also thought to be disrupted by plastic debris (Heidi Taylor, Tangaroa Blue, pers. comm.).

Table 5. Known records of sharks, rays and other animals impacted by entanglement in or ingestion of plastic debris in Australian waters since 1994 (Source: see Table 2 – Sharks and Rays, and Other Species)

Group	Species	Common Name	Entanglement (number of individual animals)	Ingestion (number of individual animals)
Sharks and Rays	*Carcharhinus melanopterus*	Black-tip reef shark	7	
	Carcharhinus amblyrhynchos	Grey reef shark	1	
		Unidentified shark	Unspecified number	
	Stegostoma fasciatum	Leopard shark		1
	Sphyrna sp.	Hammerhead shark	1	
	Carcharias taurus	Grey nurse shark		1
	Carcharhinus sp.	Unidentified shark	1	
	Orectolobus spp.	Wobbegong shark		2
	Pristidae	Sawfish	2	
	Dasyatis fluviorum	Estuary stingray	1	
	Dasyatidae	Stingray	1	
	Manta birostris	Manta ray	Mouth wrapped in plastic bag while feeding	
Other		Unidentified fish	Various reports, unspecified number	
	Arius sp.	Catfish	1 report,	

		unspecified number
Lates calcarifer	Barramundi	2 reports, Unspecified number
Balistidae	Triggerfish	1 report, unspecified number
Scylla serrata	Mud crabs	2
	Coral crabs	1
	Unidentified crabs	Approx. 100
Crocodylus porosus	Estuarine crocodile	1
Disteira major	Olive headed sea snake	1
Hydrophiidae	Sea snake	2

4.9.2 DISTRIBUTION OF IMPACTED SPECIES

Most records of other species were collected from the Queensland and Northern Territory coastline, with only one record from the Sydney region and one from southwestern Western Australia (Figure 36). A further anecdotal record comes from the Ningaloo area of Western Australia (Manta ray entanglement in plastic bags while feeding, Heidi Taylor, Tangaroa Blue, pers. comm.).

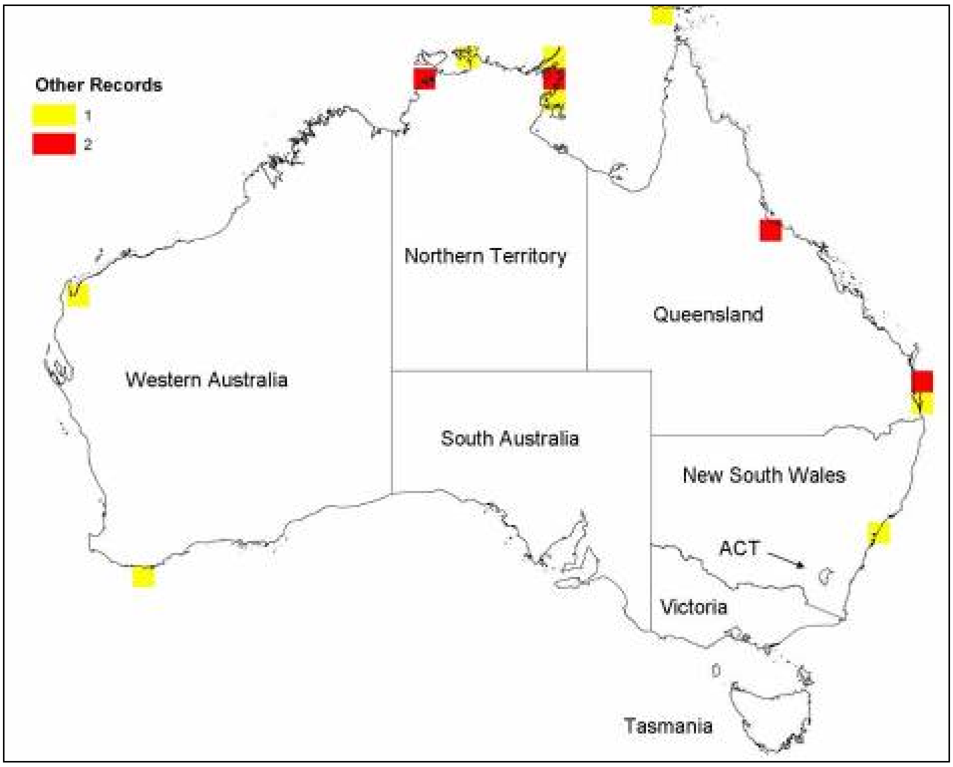

Figure 36. Known records of other species impacted by plastic debris in Australian waters since 1994 and 2008 (Source: see Table 2 – Sharks and Rays, and Other Species)

4.9.3 TYPES OF PLASTIC DEBRIS AFFECTING OTHER SPECIES

Derelict fishing nets are recorded as impacting the highest numbers of individual animals, but the net type is generally not noted in the records (Table 6). The only records of ingested plastic debris involved fishing hooks and 'unknown' plastic types, and it is not possible to ascertain whether the fishing hooks were in active use or derelict. Despite anecdotal reports of various plastic items in the stomachs of large sharks and crocodiles, no documented records were found.

Table 6. Known types of plastic debris impacting other species since 1994 in Australian waters (Source: see Table 2 – Sharks and Rays, and Other Species)

Plastic Type	Entanglement (number of individual animals)	Ingestion (number of individual animals)
Unidentified derelict fishing nets	140	
Derelict gill nets	7	
Derelict trawl nets	1	
Derelict bait nets	2	
Fishing hooks (status unknown)		3
Unknown	4	1

5. DISCUSSION

This study represents the first attempt in Australia to determine the extent and quality of information available on species impacted by plastic debris. The results show that at least 77 species of marine wildlife found in Australian waters are impacted by plastic. This figure is likely to under-represent the number of species impacted, as data are not available or difficult to access for large areas of the Australian marine environment and for many less visible species.

The frequency and geographic extent of records of impacted species reflects the frequency of surveys conducted by certain groups such as the Dhimurru Aboriginal Corporation (Northern Territory) and the Qld EPA (e.g. Greenland et al. 2005) amongst others, the geographic distribution of affected species, areas of debris accumulation/concentration, the location of wildlife rescue centres and the lack of monitoring and resourcing of surveys and wildlife rescue work in remote areas. Concentrations of records therefore occur in northeast Arnhem Land, southeast Queensland, northern NSW, the Sydney region, northern Bass Strait and Macquarie Island in the Southern Ocean. The largest geographic gaps in records occur in the north western region of Western Australia, the Great Australian Bight coastline, the western coast of Tasmania and much of Cape York Peninsula.

Many available records do not specify the type of plastic debris involved in interactions with wildlife, especially in the case of ingestions. This lack of detail makes it difficult to determine which types of plastic are of most concern for marine wildlife. Derelict fishing nets numerically dominate the entanglement records, followed by other types of derelict fishing gear such as crab and lobster pot and associated synthetic ropes and buoys, and fishing line and hooks. Derelict nets are recorded primarily in northern Australian waters (Commonwealth of Australia 2008a). These nets can remain in the ocean for a long time and can continue to fish indiscriminately ("ghost fishing"), causing substantial damage (Laist 1987). The impact of derelict nets through ghost fishing varies with net type: gill nets (Ayaz et al. 2006) and demersal[5] trawl nets (Jones 1995) are reported to cause the most damage. The rate at which animals are caught in derelict nets may change with time as the nets degrade, lose or gain buoyancy, become more visible with increasing fouling, and wash ashore, etc. (Tschernij and Larsson 2003, Ayaz et al. 2006, Brown and Macfayden 2007).

The economic impact of derelict nets is usually calculated either as the percentage of the catch that has commercial value in the region, or as a percentage of the commercial catch of the individual species caught. It has been estimated that in some cases, over 90% of species caught in derelict fishing gear are of commercial value (Al-Masroori et al. 2004). The catch of derelict fishing gear has ranged from 1.46% of the commercial monkfish catch in northern Spain (Sancho et al. 2003) and 4-5% of the commercial catch in the Baltic Sea (Tschernij and Larsson 2003), to 20-30% of the Greenland halibut catch in Norway (Humborstad et al. 2003). Derelict crab pots can also continue to catch prey; reports include 7% of dungeness crab commercial catch rates through lost crab pots in British Columbia (Breen 1987), and 20% in the Gulf of Oman (Al-Masroori et al. 2004). Some studies use experimental 'derelict' nets to estimate the catch rate for different species (Natural Resources Consultants Inc. 2008). There is yet to be a comprehensive estimate of the number of derelict nets and pots in Australian waters, or of the economic and environmental damage they may be causing.

This review assessed records of impacts to marine turtles, cetaceans, seabirds, dugongs, pinnipeds and other species and species groups, such as fish and sharks. The frequency, geographic extent, temporal dynamics of records were particular to each group, reflecting the species' ranges, abundance and seasonal movements. Moreover, the records tend to

[5] Close to the sea floor

be concentrated in areas and times of specific surveys, studies or monitoring and rescue efforts.

5.1 MARINE TURTLES

Many records of turtles entangled in plastic debris do not note the species of turtle impacted or the fate of the turtle once found. Of the turtle species identified, green (214), hawksbill (187) and olive ridley turtles (127) are most frequently represented in available records of interactions between plastic debris and marine wildlife. The fate of turtles after release and/or rehabilitation is generally unknown, and it is not possible to draw conclusions about the survival rates of turtles following rescue from entanglement or ingestion.

A large number of factors are likely to contribute to the differences in impacts between turtle species, including population size in Australian waters, diet, behaviour and distribution relative to the distribution of plastic debris. Pelagic feeders, such as juvenile loggerhead and leatherback turtles, may ingest plastic while foraging at sea (Bjorndal et al. 1994). A number of studies conducted in Florida and the Mediterranean have found that between 32% and 79.6% of stranded juvenile turtles (including green and loggerhead turtles) had ingested plastic, and that even when the plastic debris made up a very low percentage of the gut contents, the plastic caused significant declines in food assimilation (Bjorndal et al. 1994, McCauley and Bjorndal 1999, Tomás et al. 2002). Other studies confirm that leatherback and olive ridley turtles can also ingest plastic debris (Barreiros and Barcelos 2001, Bugoni et al. 2001, Mascarenhas et al. 2004).

A number of marine turtle species, such as loggerhead and olive ridley turtles, are vulnerable to the accumulation of floating plastic along lines of converging currents (Carr 1987). Loggerhead turtles may remain in the open ocean for up to five years, during which time they and their food resources are drawn into convergences, rips and driftlines by downwelling and currents. These convergence zones form visible lines along the ocean's surface, and tend to be areas where plastic debris accumulates (Carr 1987) and marine turtles seek food.

Estimating the rates of mortality caused by plastic ingestion is difficult and usually requires conducting a necropsy on a dead turtle. A study in southern Brazil estimated that the deaths of 13.2% of the green turtles examined were caused by the ingestion of plastic debris, and that interaction with fishing equipment caused the deaths of 13.6% of loggerheads and 1.5% of green turtles (Bugoni et al. 2001). Plotkin and Amos (1990) reported ingestion of plastic by 46% of turtles stranded on Texas beaches in a period of 18 months. The susceptibility of different turtle species to both entanglement and ingestion is likely to be closely related to their diet and movement patterns, both of which can change during their lifespan (Francis 2007).

Research conducted in North Carolina suggests that the percentage of dead marine turtles that reach the shore can be calculated, and that this percentage can be as low as 7 to 13% (Epperly et al. 1996). If the 228 entangled turtles recorded between 1996 and 2004 by the Dhimurru Aboriginal Corporation (Roeger et al. 2005) represent only 13% of turtles actually entangled at sea, it could be postulated that up to 1,753 marine turtles could have died of entanglement in derelict fishing nets during this period, without ever washing ashore or being recorded in northeastern Arnhem Land alone. Calculations of this type must be carefully calibrated with knowledge of conditions and currents relevant to each region, however, and can only be used here to illustrate the problem of how the reliance on strandings can lead to the underestimation of the magnitude of the problem.

5.2 CETACEANS

Whales and dolphins are prone to interaction with derelict fishing gear, and the majority of records relate to entanglements. The high proportion (approximately 61%) of individuals that were freed in recent years suggests that when entangled cetaceans are discovered, response measures are generally proving successful. There is growing knowledge, expertise and cooperation on methods of cetacean disentanglement in Australia, primarily through workshops (Naturebase 2006, DEWHA 2009). The low frequency of recorded ingestions relates primarily to the small and declining proportion of dead cetaceans that are necropsied. Records from the QEPA show that between 1999 and 2005, necropsies on stranded animals declined from approximately 47% to 9.5% per year.

The numeric dominance of the entanglement records by humpback whales explains the peak in entanglement rates recorded during seasonal humpback whale migrations. Times of higher entanglement records also correspond to peaks in data collection and reporting efforts. The frequency of records appears to increase over time, possibly reflecting an increasing public awareness of and engagement in reporting of cetacean entanglements and strandings (Naturebase 2006).

The highest density of reports comes from areas where human population centres coincide with habitats and migration routes of the most common cetacean species, most notably around the New South Wales-Queensland border. Areas devoid of records were the Cape York coastline, the Gulf of Carpentaria, the northern Western Australian coast and the Great Australian Bight. It is important to note that the geographic range of common species is likely to have a strong influence on data availability, especially in the case of species with distinct seasonal migration patterns such as humpback whales, right whales and blue whales. However, the absence of interaction records should not be equated with the absence of interactions.

Whale and dolphin strandings, especially mass strandings that occur periodically on Australian beaches, provide an opportunity to estimate the proportion of the population affected by plastic debris ingestion, even if the presence of plastic in the stomach may not be the primary cause of death (Evans and Hindell 2004). For instance, the Tasmanian Parks and Wildlife Service stranding record between 1995 and 2003 lists 21 species of toothed whale and seven species of baleen whale, represented by 4,559 individuals (in 457 stranding events) and 102 individuals (in 96 stranding events), respectively (Parks and Wildlife Service Tasmania 2008). Only one published study exists where a mass stranding event was used as an opportunity to study the diet of sperm whales (Evans and Hindell 2004). Australian stranding hotspots include Ocean Beach at Strahan, Marion Bay and King Island in Tasmania (Parks and Wildlife Service Tasmania 2007), as well as Bunbury and Augusta in south western WA, with Tasmania recording the most cetacean strandings than any other State.

5.3 SEABIRDS

The high proportion of seabirds affected by active recreational fishing gear (94%, Machado 2007) prompted the separation of records from plastic identified as debris from records of fishing gear of unknown (active or derelict) status, to avoid inflating the records of interactions with plastic debris. While the difficulty in separating the impacts of active fishing gear from those of derelict fishing gear is an issue for all affected species, the proportion of impacts from active gear was only estimated for seabirds.

Seabirds were affected both by entanglement and ingestion, but ingestion was recorded more frequently in seabirds than in other species. While most animals must be necropsied in order to find out whether plastic has been ingested, many seabirds regurgitate food in order to feed their chicks, and regurgitation can be induced to test for plastic ingestion in live birds (Copello and Quintana 2003). However, this method was not encountered often in the Australian literature,

Seabirds are prone to ingesting plastic, particularly small plastic particles or pellets (van Franeker and Bell 1988). A wide range of lethal and sub-lethal effects of plastic ingestion have been documented for seabirds (Derraik 2002), and because parents feed chicks by regurgitating food, impacts can be greater on the young (Commonwealth of Australia 2008a). Studies of plastic ingestion by seabirds have often found that surface feeders and plankton-feeding divers are most commonly impacted (Robards et al. 1995). A study on a population of Cape petrels from Australian Antarctic waters (Ardery Island, near Casey Station) found that rates of plastic particle ingestion ranged from 20% to 56%, with a single stomach containing 11 plastic particles with a combined weight of 294mg (van Franeker and Bell 1988). Studies outside Australian waters have shown that over 92% of some seabird populations (mainly petrels and fulmars) have plastic in their stomachs (van Franeker 1985, van Franeker and Bell 1988), and that around 84% of some short-tailed shearwater populations are impacted by ingestion of plastic debris (Vlietstra and Parga 2002).

Patterns in available records of interactions between seabirds and plastic debris may be influenced by isolated incidents of mass strandings of seabirds in derelict nets. For example, one record alone notes that 70 mutton birds died from entanglement in a derelict net near Tasmania (ABC News 2006). These isolated events may be more frequent than appear in the records, as there is anecdotal evidence of large flocks of birds observed above drifting nets where they may easily become entangled (Aaron Machado, SA Seabird Rescue, pers. comm.). A study that used experimental "derelict" nets found that some species of seabirds (especially cormorants) can became entangled at a rate of approximately one animal every four days (Natural Resources Consultants Inc. 2008).

Records of interactions between seabirds and fishing gear of unknown status appear to have increased in recent years, especially since 2004. This increase may reflect the increased availability of data through the activities of wildlife rescue operations such as Currumbin Wildlife Sanctuary (first started collecting records in 2000), Australia Zoo (first started collecting records in 2005) and Pelican and Seabird Rescue (first started collecting records in 2006).

Birds that live, breed or forage close to the mainland are more likely to interact with land-generated plastic debris or recreational fishing activities (Hartwig et al. 2007). Additionally, seabirds and birds nesting on the coast can sometimes use plastic debris as nesting material, usually in proportion with its occurrence in the surrounding environment, posing an entanglement risk to the chicks in areas of high plastic debris accumulation (Hartwig et al. 2007).

Records suggest that ocean-going birds such as albatrosses, shearwaters and petrels are most often affected by vessel-sourced plastic debris and plastic fragments ingested at sea. For example, research conducted on Lord Howe Island found 14 dead flesh-footed shearwater fledglings with plastic fragments in their stomachs (Hutton 2004). A wide range of plastic items had been ingested, including mainly flat sheets from bottles and containers, but also golf tees, biro tops, bottle caps, plastic bag ties and strapping tape. Between 80 and 90% of the items were white, reflecting either the percentage of different coloured plastics used in packaging, or the birds' preferences for certain colours they may associate with food (Hutton 2004). Another study that examined the stomach contents of 540 shy albatross chicks that died on Albatross Island (Tasmania) found that 1% of the sampled individuals had plastic in their stomachs (Hedd and Gales 2001), while an earlier study concluded that the frequency of plastic ingestion for laysan albatross chicks in Hawaii was 90% (Fry et al. 1987). The current recovery plan for albatrosses and petrels acknowledges the difficulty in quantifying the frequency of plastic debris entanglement and ingestion due to the likelihood that most deaths would occur at sea without ever being recorded (DEWHA 2007).

5.4 DUGONGS

Records on interactions between dugongs and plastic debris were very limited, but there is much concern about deaths and injuries due to plastic debris in dugongs, due to their slow breeding rates. The Australian population, while the healthiest in the world (Marsh and Lawler 2000), can sustain only very limited, if any, deaths from anthropogenic causes (Marsh et al. 2002). Records in Queensland give no clear indication of the relative risk posed by plastic debris in comparison with other mortality sources (Greenland and Limpus 2005) such as drowning in mesh netting and shark nets, boat strike, habitat loss and degradation and traditional hunting (Marsh et al. 2002).

Temporal trends in interaction records were not evident, and the geographic extent of the records closely reflected the range of dugongs in northern and eastern Australian waters. The Qld EPA marine strandings database reports include records of dugong entanglements, primarily in derelict fishing gear (Limpus et al. 1999, Haines and Limpus 2000a, 2001, Limpus et al. 2002). However, the reports do not give details on the results of stomach contents analyses that may be carried out during necropsies of dead dugongs, which would provide some information on the incidence of ingestion of plastic debris. Two studies from the 1980s that examined the stomach contents of a total of 98 dugongs from northern Australia did not report any ingested plastic (Marsh et al. 1982, Marsh 1989). However, ingestion of plastic has been recorded in 14.4% of 439 strandings of the closely related Florida manatee, and at least four manatee deaths were attributed to plastic ingestion (Beck and Barros 1991), suggesting that the capacity for dugongs to ingest plastic should not be discounted.

5.5 PINNIPEDS

Pinnipeds are considered to be especially prone to plastic debris entanglement due to their feeding habits and the curious and playful nature of juveniles (Pemberton et al. 1992, Page et al. 2004). Three seal species breed in Australia (Australian sea lions, Australian fur seals and New Zealand fur seals), and all three have entanglement rates that are among the highest reported for any species of pinniped in the world (Pemberton et al. 1992, Page et al. 2004). The entanglement rate observed for Australian sea lions and New Zealand fur seals in 2002 on Kangaroo Island was 1.3% and 0.9% of the population, respectively. Pemberton et al. (1992) also recorded high entanglement rates in Bass Strait and southern Tasmanian waters, estimating that 1.9% of the Australian fur seal population was affected. In comparison, the rate of entanglement was estimated at between 0.3 and 1.4% for Antarctic fur seals at South Georgia (Southern Ocean, United Kingdom)(Arnould and Croxall 1995); 0.001% for southern elephant seals in Patagonia (Argentina) (Campagna et al. 2007); 0.024-0.059% on Bouvetøya (Southern Ocean, Norway) (Hofmeyr et al. 2006); 0.05-0.15% for pinnipeds on the Channel Islands (USA) (Stewart and Yochem 1987); 0.11-0.12% for Cape fur seals in south western Africa (Shaughnessy 1980); and at 0.4% for northern fur seals in the Bering Sea (Fowler 1987). Entanglement rates of New Zealand fur seals at Kaikoura, New Zealand (0.6-2.8%) are higher than entanglement rates of the Australian fur seal and Australian sea lion populations (Boren et al. 2006), and the highest overall entanglement rates for pinnipeds are estimated at 7.9% in Baja California (Harcourt et al. 1994). Rates of 0.4% are considered to be sufficient to affect colonies of some pinnipeds (Fowler 1987).

Five of the eight pinniped species that live and / or breed in Australian waters were affected by some form of interaction with plastic debris. Most records relate to entanglements, but a study of Antarctic and subantarctic fur seal scats on Macquarie Island found that between 85% and 100% of examined fur seal scats contained pieces of plastic (Eriksson and Burton 2003). Plastic ingestion in pinnipeds may be more common than the available records suggest, although the effects on the individuals themselves are unknown.
A comprehensive long-term study conducted on Kangaroo Island to quantify the extent of entanglement of Australian sea lions and New Zealand fur seals estimated that 1,478 seals

die annually from entanglement in Australia (Page et al. 2004). The study also found that while monofilament netting posed the biggest entanglement threat to Australian sea lions (accounting for 55% of entanglements), New Zealand fur seals were most often entangled in packing tape and trawl netting (30% and 28%, respectively). These results highlight the fact that different species, even within the same family, are vulnerable to different types of plastic debris (Page et al. 2004). Other plastic items responsible for seal entanglements were fishing lines and hooks, lobster float ropes, other ropes, plastic bags, tyre tubes, and to a lesser extent rock lobster pots, balloons and o-rings. In future studies on the impacts of plastic debris on marine wildlife, it will be important to document the type of plastic debris involved, to assist in targeting a reduction in each type of plastic debris at its source.

5.6 OTHER SPECIES

Records of species impacted by plastic debris tend to be focused on protected species or larger species of interest to the public. Smaller animals that may be affected by plastic debris, such as fish and crabs, may decompose more rapidly than larger animals, or may be consumed by larger animals so that they are less likely to be found and recorded (Natural Resources Consultants Inc. 2008).

Few records are available of sharks, fish and other marine species impacted by plastic debris. The most consistent records exist for sharks and fish, and some anecdotal evidence exists of crocodiles and plastic ingestion. Shark species that dwell, reproduce or feed preferentially in shallow coastal waters are expected to be at highest risk from interactions with plastic debris (Sazima et al. 2002, Seitz and Poulakis 2006).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Available information indicates that at least 77 species of marine wildlife found in Australian waters have been impacted by entanglement in, or ingestion of, plastic debris during the last three decades. The entanglement and ingestion records include six species of marine turtles, 12 species of cetaceans, at least 34 species of seabirds, dugongs, six species of pinnipeds, at least 10 species of sharks and rays, and at least eight other species groups. This is likely to be an underestimate of both the numbers of species and numbers of individuals impacted by plastic debris, due to the general difficulty in accessing records, the lack of necropsy data, and the number of deaths likely to occur at sea where they remain undetected.

The spatial and temporal trends in reports of entanglement in and ingestion of plastic debris by wildlife in Australian waters are likely to be influenced by factors such as the size and distribution of populations, foraging areas, migration patterns, diets, proximity of species to urban centres, changes in fisheries equipment and practices, weather patterns, and ocean currents, as well as the frequency of monitoring and/or observation of wildlife. Geographic areas where there are gaps in records include the north western coastline of Western Australia, the Great Australian Bight, eastern Cape York, and offshore waters. Understanding the distribution and frequency of specific mortality sources is crucial to developing strategies for conservation, especially for protected species (Hart et al. 2006). The large number of factors determining the magnitude of interactions between wildlife and plastic debris (e.g. population size and distributions of species, behavioural traits, distributions and conduct of nearby fisheries and sizes of nearby urban centres, ocean currents, weather patterns etc.) contribute to the difficulty in obtaining accurate estimates of trends in plastic-based mortality rates. However, the first step is to collect standardised records from replicate locations around the country.

A number of government and non-government organisations and individual researchers collect information on the impacts of plastic debris on marine wildlife around Australia. Unfortunately, as data are not collected in a standardised or consistent manner, the information cannot be adequately compared or reviewed to accurately quantify impacts across Australian waters. It must be stressed that this study is restricted to information that is publicly available and accessible within the comparatively short study timeframe. A more in-depth project is required, with collaboration from all owners of records and databases, to allow a more detailed examination of all available evidence.

The development of a national stranding, entanglement and ingestion database and a systematic approach to establishing a monitoring program is the first step towards understanding the magnitude of the impacts of plastic debris on wildlife in Australian waters. Such a database should be preceded by decisions on the type and amount of information necessary to conduct analyses that will inform management decisions. Coordinating the existing expertise on the impacts of plastic debris in Australia will ensure that these decisions can be based on sound, consistent and rigorous data.

6.2 RECOMMENDATIONS

The development of a centralised national database would permit statistical analyses to further define the magnitude of the impacts on each species, through time and space. It would also allow the development of risk assessments through the calculation of the probability of entanglement or ingestion of plastic debris for any given species in different locations and in different months of the year. Modelling could then be applied to link plastic debris accumulation ‘hotspots’ to turtle feeding grounds and rookeries (Kiessling and

Hamilton 2003), and also whale migration routes, dolphin habitats, dugong protection areas and feeding grounds, pinniped foraging habitats and seabird nesting sites. Supplementing the analysis of a centralised database with experimental work to track patterns of plastic debris movement (e.g. Wilson and Randall 2005) will provide further information to support measures to prevent and mitigate the impacts of debris on marine wildlife.

A national database would ideally be able to draw on existing recorders and expertise, and would complement those with targeted surveys that monitor locations where there are gaps in the existing coverage. Monitoring methods would vary according to the location, as much of the existing monitoring in remote locations is already driven by the accessibility of an area (Riki Gunn, Carpentaria Ghost Nets Programme, pers. comm.), but still allow comparisons with other areas. Expertise about an area could be provided by people or organisations already engaged in existing studies, including local indigenous communities.

Ideally, a number of steps would then be followed in the development of a national database.

- Make use of the existing State databases (Qld, NT, SA) to aid and inform the development of similar databases in other States (NSW, Vic, WA, Tas).
- Standardise the methods used to collect and store information, with a standardised training program for all data collectors. Ensure that plastic debris causing entanglements and ingestions are described in as much detail as possible.
- Collect State data into a central national database and allow access for those wishing to conduct relevant and related research projects.
- Determine the necessary statistical analyses required to develop a more accurate estimate of the magnitude of the impact of plastic debris on marine wildlife.
- A national workshop engaging scientists, managers and coastal communities could elicit key questions that need to be asked of the national database. This workshop may also recommend research to supplement the results likely to emerge from analyzing the database.
- Facilitate the collection of more necropsy data specifically aimed at detecting ingested plastic debris. Devise species-specific methods aimed to increase the probability of detecting ingested plastic (e.g. Francis 2007). This may include examining regurgitated food in seabirds (Copello and Quintana 2003) or scats in pinnipeds (Eriksson and Burton 2003).
- Develop a method to assess cryptic mortality (unrecorded or unknown deaths) caused by impacts of plastic debris.
- Seek involvement of fishers (commercial and recreational), fisheries authorities and marine tourism operators in collecting and sharing information about marine wildlife entanglements observed at sea. This could be aided by the distribution of a standardized recording form and clear instructions for submitting completed forms to the appropriate authorities.
- Analyse climatic and oceanographic information to assist in detecting seasonal patterns in the impacts of plastic debris on marine wildlife.
- Devise a reporting system for the national database and supporting research, to monitor trends in the magnitude of the impacts of plastic debris on marine wildlife. Reporting must take into account the limitations of survey methods and provide the framework for updating and refining methods.
- Develop a system of regular public reporting to increase the general awareness of the issue.

An ideal monitoring program, especially for feeding information into the national database from geographic locations currently devoid of data, would contain the following elements.

- The program is nation-wide and involves existing organisations where possible, while filling the geographic gaps with targeted surveys.
- Areas targeted for surveys are located through an in-depth oceanographic study which, coupled with knowledge of the distribution of target species, may highlight areas where interactions between marine wildlife and plastic debris may be most likely to occur.
- Methods for monitoring are devised to be consistent on a nation-wide scale, with the flexibility to allow for the specific requirements of different locations. The questions to be addressed through data analysis should at least partially drive the development of the methodology. Advice from experts already engaged in this work, including indigenous communities, will be very important. The methodology also sets out the frequency of monitoring at each location, and the data storage requirements.
- At each location, monitoring surveys are assisted by local wildlife rescue organisations or veterinarians, so that injured animals can be rehabilitated if possible, and dead animals can be necropsied where possible. All necropsy reports are submitted to the central database. Necropsies carried out on mass standings of cetaceans that are not linked to plastic debris are also submitted, as this can provide valuable information on the rates of ingestion in the stranded species.
- Recorded data includes at least: time, date, exact location (preferably marked with a GPS), species, condition, cause, fate (eg. whether it was euthanased, rehabilitated, etc.), person(s) / organisation(s) involved in the monitoring and necropsy / rehabilitation, exact plastic type, and any other notes of importance. The development of a template would aid the consistency of these records.

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8. PERSONAL COMMUNICATIONS

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