# Evaluating the impacts of marine debris on cetaceans

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## Abstract

Global in its distribution and pervading all levels of the water column, marine debris poses a serious threat to marine habitats and wildlife. For cetaceans, ingestion or entanglement in debris can cause chronic and acute injuries and increase chemical pollutant loads, resulting in morbidity and mortality. This literature review assesses the impacts of marine debris on cetaceans reported to date. It finds that ingestion of debris has been documented in 303 individual cetaceans and entanglement in 38 individuals, representing 46 cetacean species and 53% of all cetacean species. No population impacts of debris have been documented but given the low ability to detect impacts this should not be taken as evidence of an insignificant issue. Data indicate a 17% increase in the number of species documented with debris interactions since the last comprehensive review in 1997 and a concerning increase in the incidence of ingestion of plastic debris.

KEYWORDS: Marine debris, Cetaceans, Entanglement, Ingestion, Plastic

## 1. Introduction

The continued accumulation of debris in the marine environment constitutes a growing global concern. Plastics, which constitute between 60-80% of marine debris, may fragment but do not biodegrade and may persist in the marine environment for hundreds to thousands of years (Barnes *et al*., 2009; Derraik, 2002). A wide spectrum of marine habitats is under pressure from its affects and quantities of marine debris are increasing in even the most remote areas, far removed from source locations (Derraik, 2002; Barnes *et al*., 2009). Combined, macro and micro-debris can affect all trophic levels and there is the potential for impacts to travel through the food chain, from planktonic microorganisms through to marine megafauna (Barnes *et al*., 2009; Derraik, 2002; Gregory, 1996). Only recently recognised as a significant environmental problem, ecological, social and economic consequences have already been observed and marine debris is now considered a major threat to marine biodiversity (Stefatos et al., 1999; UNEP, 2009; Sutherland et al., 2010; Secretariat of the Convention on Biological Diversity, 2012).

Cetaceans were first recorded ingesting or becoming entangled in debris in the 1890s (Turner, 1903). Since then an increasing number of acute and chronic impacts have been documented (Laist, 1997; Katsanevakis, 2008). Entanglement in and ingestion of debris can be fatal, causing blockage of the digestive tract, starvation, drowning, suffocation or strangulation (Laist, 1997). It can also have a range of sub-lethal consequences, compromising movement, feeding capacity and digestion, causing malnutrition and disease and decreasing body condition, reproductive output, growth rates and longevity (McCauley and Bjorndal, 1999; Katsanevakis, 2008). In addition to physical trauma, ingestion of plastic debris represents an additional source of pollutants for cetaceans, facilitating the transfer of chemical additives, as well as persistent, bioaccumulative and toxic (PBTs) substances from seawater, into the food web (Engler, 2012; Fossi et al., 2012).

Whilst there is a growing awareness of the impacts of marine debris, the nature of the marine environment makes it intrinsically difficult to measure and monitor both the quantity of marine debris and its effects. An estimated 6.4 million tonnes of marine litter is dumped in oceans every year (UNEP, 2005) and in hotspots of accumulation more than 3.5 million pieces of litter occur per square kilometre (Yamashita and Tanimura, 2007). Such figures on marine debris are shocking, but we rarely see the consequences and determining the magnitude of its effects remains problematic. In cetaceans detection of debris interactions largely depends on opportunistic data collected from the small sample sizes provided by stranded animals and publishing of such reports is sporadic. With this in mind, this paper builds on previous reviews undertaken (Walker and Coe, 1990; Laist, 1997; Katsanevakis, 2008; Cornish et al., 2011; Simmonds, 2011) and collates an up to date overview of the number of cetacean species and, for the first time, an inventory of the number of cases of debris interactions documented. The goal is that this will prompt a coordinated global effort to better evaluate the conservation concerns posed by marine debris and inform the development of appropriate mitigation measures.

## 2. Materials and methods

### *2.1 Data collection*

The study consulted published literature to search for documented impacts of marine debris on cetaceans, using Laist (1997) and other reviews conducted to date (Walker and Coe, 1990; Katsanevakis, 2008; Simmonds, 2011; Cornish *et al*., 2011) as valuable resources for historical incidences dating back to 1960. In addition, data requests were posted to two academic mailing lists – 'marmam' and 'marinedebris' – and representatives from strandings networks were contacted for additional records of ingestion and entanglement. Where possible, data were collated on the number of individual animals, species, types of debris and the associated types and rates of pathology and mortality observed, although in many cases such information was not available. In total 86 references were collated from published literature or personal communications (Appendix A, Table 1). Data were provided by strandings networks in the UK, U.S.A., New Zealand, Israel, Canary Islands, Madeira, Belgium, Reunion Island, Venezuela and Brazil. Whilst every effort was made to include all available data and data sources, the information presented here cannot be considered comprehensive. Records received from strandings networks indicate that many cases never make it into the public domain. Furthermore, many strandings networks record information in a format that prohibits the required data queries.

In some cases with historic data sources, it was not possible to access the original paper. Where this was the case, we have included the relevant data published within the reviews conducted to date (e.g. Laist, 1997). However, as these previous reviews did not detail the number of individual animals per species recorded in debris interactions, the species referred to were assigned only a value of more than zero to avoid over-reporting the total number of cases. In addition, some references in these previous reviews were included on the basis that they reported a total number of entanglement cases, with the assumption that a subset of these would be due to marine debris (Laist, 1997). Most notably in Laist (1997), there is reference to Kraus (1990) and the Humpback Whale Recovery Team (1991) which detail a total of approximately 70 North Atlantic right whale (*Eubalaena glacialis*) and 600 humpback whale (*Megaptera novaeangliae*) entanglements in fishing gear, respectively. As an unknown proportion of these were derived from marine debris, we have included these references in recognition that a proportion are likely to result from derelict gear, but again have assigned them only a value of more than zero to avoid over-reporting the prevalence of debris entanglement in these species.

### *2.2 Data analysis*

Data analysis was carried out separately for ingestion and entanglement interactions. The total number of reported cases of each type of debris interaction was calculated for each taxonomic group, at the level of species, family, sub-order and order (Appendix A, Table 2). To identify the prevalence of different types of debris in cases of ingestion and entanglement, debris was assigned to discrete categories and the frequency with which they occurred was calculated. Three categories were used for ingestion and two for entanglement. For ingestion incidences, debris was categorised as follows:

- Fishing gear, including nets, lines, ropes, traps and all other types of fishing gear;
- Plastic items, including sheeting, bags, containers and other items; and
- Miscellaneous debris, including fabric, rubber, paper, cellophane, polystyrene, glass and unidentified items.

For entangling incidences, debris was categorised as follows:

- Fishing gear, including nets, lines, ropes, traps and all other types of fishing gear; and
- Miscellaneous debris including packing bands, plastic, fabric, rubber and unidentified items.

For most instances of entanglement in fishing gear, reports do not identify which were due to gear deployed at the time of entanglement (hereafter referred to as operational gear) and which were due to abandoned, lost or otherwise discarded fishing gear (hereafter referred to as derelict gear). More often than not this differentiation was not or could not be determined at the data gathering stage. Reports in which gear was identified as likely having been deployed at the time of entanglement were excluded from all analyses. Our principal analysis includes only those reports in which derelict fishing gear was identified as likely to be responsible. In a separate analysis, we included cases where the origin of gear was unknown, or likely included both operational and derelict fishing gear.

In order to determine mortality rates resulting from debris interactions each instance was classified depending on whether it was assessed that (a) debris was the likely cause of mortality (b) mortality was likely due to other factors or (c) the cause of mortality was unknown, either because the cause of mortality could not be determined or because the relevant information was not available in the published report. To examine temporal changes in the number of reported cases each reference was assigned to a decadal period. A finer-scale temporal evaluation was not possible as publications often document data which span several years or decades and do not give the specific year in which each interaction took place. Where multiple cases were reported for a period spanning two decades, they were assigned to the decade in which the majority of the date span fell. Where they spanned three or more decades they were assigned to the decade in which the mid-point of the data span fell.

## 3. Results

### *3.1. Ingestion of debris*

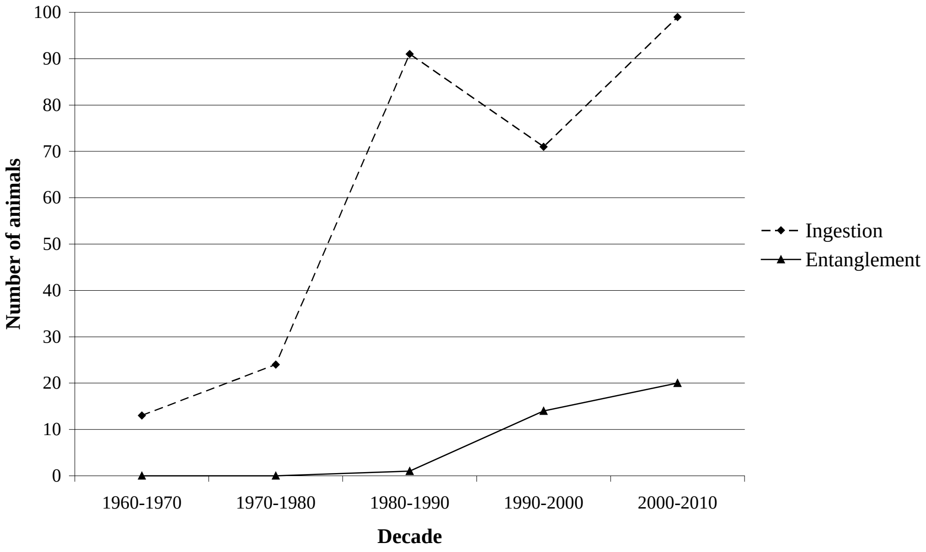
Ingestion of debris has been documented in at least 303 individuals (Appendix A: Table 1), representing 43 cetacean species –seven mysticete and 35 odontocete species (Appendix A: Table 2). This represents 50% of all cetacean species. The number of cases of debris ingestion by cetaceans recorded per decade has risen relatively steadily from the 1960s, with a slight decrease between 1990 and 2000 before peaking in the last decade (2000-2010) (Figure 1). The number of report instances of debris ingestion in the last decade is more than seven times greater than that between 1960 and 1970 (Figure 1).

Where debris types were identified, items ingested by cetaceans were most commonly plastic (54%), with fishing gear (20.7%), miscellaneous (15.2%) and unknown (10.1%) constituting the remainder. Debris items ingested ranged in size from small particles (<5mm) to large plastic sheeting or netting. Exceptional examples included 134 different net types of up to 16m$^2$ documented in a sperm whale (*Physeter macrocephalus*) (Jacobsen *et al*., 2010), and 378 items recorded in a Cuvier's beaked whale (*Ziphius cavirostris*) with a collective weight of 33kg (Poncelet *et al*., 2000).

The pathology associated with ingestion of debris was similar across species groups and ranged from no discernible pathological effects through to internal injuries and complete blockage of the digestive tract, with associated malnutrition, starvation and mortality. In addition, the presence of toxins associated with microplastic ingestion has been detected in fin whales (Fossi *et al*., 2012). In the majority of cases (58%) where ingestion of debris was detected the cause of death was unknown. However, in cases where a cause of death could be determined, debris ingestion was identified as the likely cause of 14% (21 individuals) of deaths, with 86% being attributed to another cause.

Information on the proportion of species within each family and order of cetaceans reported with debris interactions is included in Appendix A, Table 2. However, this should be interpreted with caution in relation to ascribing a particular susceptibility of certain species groups to interact with debris. Different species have widely differing geographical distributions, relative abundance and likely differential stranding tendencies that may bias detection and reporting rates. An independent comparison of debris interaction rates between species could therefore only be gained by strategic experimental sampling of different species. Thus, the incidental nature of the source data prevents any firm conclusions regarding which species or taxonomic groups are at highest risk from debris. What is clear is that ingestion of marine debris occurs in a large number of cetacean species that employ a variety of foraging strategies at different levels of the water column.

Figure 1: Number of documented debris interactions involving cetaceans from 1960-2010.



### *3.2. Entanglement in debris*

Entanglement in debris has been documented less frequently and in a smaller number of cetacean species than ingestion, with 14 species recorded as entangled in debris (Appendix A). The number of reported interactions per decade increased by a factor of 20 since the first case in the 1980s, with a total of 38 individual entanglement cases documented in this review (Figure 1 and Appendix A, Table 1). Almost all of the entanglements documented were caused by fishing gear (97%), with the exception of one case of a bottlenose dolphin (*Tursiops truncatus*) with a rubber strap of unknown origin wrapped around its head (Science Daily, 2008).

Additional records of cetacean entanglement where the origin of fishing gear was unknown or likely included both operational and derelict gear provided more than 2,000 additional cases of cetacean entanglement, including 11 additional species not identified as having been entangled in known debris. Although operational fishing gear may be responsible for a significant portion of these entanglements, it is likely that derelict gear caused a subset of them.

Pathology documented from debris entanglement ranges from immediate mortality through drowning to injury and progressive debilitation over a period of months or years (Laist, 1997). Ensnaring debris has been found to frequently cause progressive constriction and tissue damage as individuals grow, impairing movement, limiting foraging ability and often ultimately leading to starvation and a painful and prolonged death (Knowlton and Kraus, 2001). For example, in lethally-entangled North Atlantic right whales the average time to death was 5.6 months but in some individuals up to 1.5 years (Moore *et al.,* 2006; Knowlton and Kraus, 2001). The welfare implications are therefore severe, representing “one of the worst forms of human-caused mortality in any wild animal” (Cassoff *et al.,* 2011). For debris entanglement, 76% of documented cases resulted in mortality of the individual and 21% did not. In the remaining 2% of cases the outcome was unknown. This mortality rate would be higher without human intervention, which occurred in 21% of cases.

## 4. Discussion

### *4.1. Temporal trends*

The first cases of cetaceans ingesting or becoming entangled in debris were documented in the 1890s (Turner, 1903), with the first records of plastic debris ingestion occurring in the 1970s; twenty years after mass-production of synthetic materials began (Laist, 1997). Over time there has been an increase in the number of interactions reported per decade (Figure 1) and the number of cetacean species affected. An additional 20 cetacean species have been recorded ingesting debris since Laist’s review in 1997, demonstrating a 87 % increase in the number of species affected over the last 15 years. With regards to entanglement, an additional three species have been recorded entangled in debris since 1997, a 27% rise (Laist, 1997). The number of reported instances of debris ingestion, and the number of species affected, was greater than for entanglement. The data, however, should be interpreted with caution. More than 2,000 additional records of cetacean entanglement were excluded from analysis where the origin of fishing gear was unknown or likely included both operational and derelict gear.

The number of reported entanglement and ingestion events reached an unprecedented high in the last decade, at a level more than double that of 1970-1980 (Figure 1). When considered independently, the number of reported ingestion events has increased by a factor of more than seven over the last fifty years (1960-2010), entanglement rising by a factor of 20 since the 1980s, when the first case was recorded. Such trends suggest a progressive increase in the number of individuals interacting with marine debris over the last forty years; though it is possible that sampling and reporting rates may also have increased. The longevity and continued input of non-biodegradable debris into the marine environment coupled with indications that debris quantities are rising in certain regions would lead to an expected increase in encounter rates but further study is required before this trend can be confirmed (Johnson, 1994; Henderson, 2001; UNEP, 2005).

### *4.2. Types of debris*

Plastic is estimated to comprise between 60% and 80% of marine debris (Derraik 2002) and constituted 54% of the debris ingested, with derelict fishing gear also a dominant component (20.7%). In entanglement, derelict fishing gear (much of which is also composed of plastics) appears to pose the greatest risk compared to other debris types, being responsible for almost all reported cases (97%) of entanglement of cetaceans. This is presumably due to its size, structure, longevity and coincidence with key cetacean habitat and it presents a high risk of repeated ‘ghost-fishing’ where nets and lines ensnare multiple individuals. Mitigation measures for derelict fishing gear will need to be area and fishery-specific in order to address the key causes of gear loss. They could include measures to reduce dumping and loss of gear, increase recovery of lost gear and the use of technology that deters cetaceans from investigating derelict gear, such as passive acoustic beacons and acoustic reflectors (Macfayden *et al*., 2009). Avoiding the loss of gear will likely provide a more cost-effective and long-term solution than clean-up operations, but both have their role to play in restoring the marine environment. Meanwhile, reducing sources of marine debris that can be ingested by cetaceans will require measures that address both marine and land-based sources of marine debris. Global production of plastics, which constituted 64.9 % of the debris ingested, has increased from 5 million tonnes in the 1960s to 280 million tonnes (PlasticsEurope, 2011), whilst increases in recycling recovery rates lag behind, standing at only 13% of the plastic generated (Secretariat of the Convention on Biodiversity, 2012).

### *4.3. Individual and population level effects of debris interactions*

Mortality was frequently documented in cases of entanglement (74%) and to a lesser extent ingestion (14%), along with symptoms such as injuries, blockage of the digestive tract, malnutrition and disease. However in many cases the cause of death (54% of ingestion reports) or outcome of the interaction (2% of entanglements) was unknown. Stranded specimens are often in poor condition with a clear cause of death and the pathological effects of debris interactions difficult to determine (Williams *et al*., 2011). In cases of debris ingestion there are often no obvious external signs that items have been ingested and its occurrence therefore has a high potential to remain undetected, only being discovered when stranded or bycaught animals are subject to a comprehensive necropsy involving examination of stomach contents (Derraik, 2002). Detection may be particularly low in mysticete species due to lower stranding and necropsy rates (Jauniaux pers. comm.).

Whilst increased population mortality rates are the principal concern, multiple chronic fitness-reducing effects are also likely to occur a result of entanglement and ingestion, but are as yet unexplored (McCauley and Bjorndal, 1999). The reductions in foraging ability, movement and feeding capacity and the higher incidence of malnutrition and disease associated with debris interactions are likely to reduce individuals' growth rates, reproductive output and life expectancy (McCauley and Bjorndal, 1999; Katsanevakis, 2008). Given the difficulty in detecting the debris interaction itself, the likelihood of detecting such chronic symptoms is very low.

The chronic and acute impacts of entanglement and ingestion of debris undoubtedly represent a welfare concern at the individual level but it is difficult to determine the wider implications of debris interactions at a population level. The number of recorded instances of debris interactions involving cetaceans, although increasing, remains relatively low, comprising a total of 303 cases of ingestion of debris and 38 cases of entanglement in debris over the last fifty years (Appendix A, Table 1). If taken at face value, such numbers of debris interactions, and the resulting mortality rates, would represent an insignificant threat to cetacean populations. However, the vast majority of published cases are derived from opportunistic strandings data. Such data likely represent a low proportion of actual mortalities. It has been estimated that only 2-6% of individuals dying at sea are likely to strand and be recovered (Fisheries and Oceans Canada, 2008; Williams *et al*., 2011). Thus, as Williams *et al.* (2011) extrapolate, "the true death toll could be 50 times the number of carcasses recovered".

Not only is there an initial small likelihood of animals stranding and being recovered but detection of a debris interaction event also depends upon animals stranding quickly and being subjected to a full necropsy while sufficiently fresh. Available data are further limited by geographic differences in shoreline coverage, carcass recovery and necropsy effort, lack of standardized reporting and storage of information, under-reporting and differential rates of publication. In entanglement cases, an added problem is that the origin of gear is not, or cannot, be determined. Even when entangling gear has been examined, the type of fishery responsible could not be determined in 20% of cases, and on the whole no conclusion is made as to whether gear was operational or derelict at the time of entanglement (Johnson *et al*., 2005; Laist, 1997). It is therefore highly likely that under-detection of entanglement in debris occurs due to mis-identification of derelict gear as operational gear.

Whilst the majority of publications document single stranding events, several notable studies have measured rates of debris interactions from larger sample sizes derived from strandings, bycatch and hunts (Appendix A: Table 3). Rates of debris interactions range from 2.2% in stranded UK harbour porpoises (Deaville & Jepson, 2010) to 31% in bycaught Franciscana dolphins in Argentina (Bastida et al., 2010). Samples from Franciscana dolphins have been consistently high, ranging from 17-31% (Appendix A: Table 3). Such studies suggest that debris interactions are far more frequent than strandings evidence would imply. Given that the widely adopted aim is to reduce anthropogenic mortality to below 2% of a population (IWC, 1995; ASCOBANS, 2000; Bergen Declaration, 2002), the high prevalence of debris interactions detected in some populations points to an urgent need for studies of the rate of interactions in different species and the resulting rates of mortality or other fitness-related pathology.

Meanwhile the frequency of microplastic ingestion remains unknown. Though this field is a new one, recent studies reveal the presence of leached plastic additives in Mediterranean fin whales (*Balaenoptera physalus*), indicating chronic exposure to toxins as a result of microplastic ingestion (Fossi *et al*., 2012). Microplastic ingestion may occur both directly or secondarily via prey species (Andrady, 2011; Fossi *et al*., 2012). Ingestion of microplastic has been confirmed in organisms throughout the food web, providing an additional mechanism for bioaccumulation and biomagnification of pollutant loads within the food chain (Teuten *et al*., 2007). Given the high contaminant load already observed in some cetacean populations, and its potential links to cancer, immuno-suppression, endocrine disruption and reproductive failure, this additional vector for pollutants is a cause for concern (Martineau *et al.,* 2002). Quantities of micro-plastics have increased 100-fold over the last forty years, representing a significant additional source of pollutants for cetaceans (Barnes *et al*., 2009; Goldstein *et al*., 2012). They present an insidious threat due to the even greater difficulty of removal and their potential to enter the marine food chain at virtually all levels (Barnes *et al*., 2009; Goldstein *et al*., 2012).

Whilst ingestion of debris and entanglement in debris are the key mechanisms by which marine mammal populations are impacted, the impacts of marine debris on marine habitats and prey populations may have secondary repercussions for cetaceans. Debris can smother or damage flora and impede sediment gas exchange, altering community composition (Backhurst and Cole, 2000; Donohue, *et al*., 2001; Goldberg, 1997; Gregory, 2009; Katsanevakis and Verriopoulos, 2007). Similarly, ghost-fishing by derelict gear can reduce stocks of prey species (Laist, 1995). The implications of such indirect impacts for marine mammals have not been studied but in areas of debris accumulation there is the potential for impacts on their breeding, foraging and migratory habitats and the food supplies upon which they depend (Gregory, 2009).

This review indicates an increase in the number of species documented with debris interactions, a concerning increase in the number of ingestion and entanglement interactions reported per decade (Figure 1), and alarmingly high rates of debris interactions in certain species (Appendix A: Table 3). Despite international efforts and the introduction of multiple pieces of legislation over the last 35 years to reduce inputs of waste into the marine environment, evidence suggests that quantities of debris and debris interaction rates are continuing to increase (UNEP, 2005). The data currently available for cetaceans does not allow us to measure the impact that debris interactions are having on cetacean populations. In order to gain a more accurate measure of population level impacts information on (a) the rate of interactions and (b) resulting rates of mortality and other fitness-related pathology is urgently required. Better standardisation and availability of data from strandings would facilitate understanding of potential population level impacts whilst modelling approaches could also be used to help identify populations of high concern. Research should also focus on the potential toxicological impact of micro-plastic ingestion for cetaceans, a novel and growing threat.

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**Appendix A: Supplementary data**

Table 1: Number of reported instances of debris interactions in cetacean species

| Order | Family | Species | Number of instances | | Reference(s) |
|---|---|---|---|---|---|
| | | | Ingestion | Entanglement | |
| Mysticete | Balaenidae | Bowhead whale (*Balaena mysticetus*) | >0 | >0 | (Philo *et al*., 1992; Lowry, 1993) |
| | | North Atlantic right whale (*Eubalaena glacialis*) | 1 | >0 | (Kraus, 1990; Johnson *et al*., 2005) |
| | | Southern right whale (*Eubalaena australis*) | 0 | >0 | (Cawthorn, 1985) |
| | Balaenidae Total | | >1 | >0 | |
| | Balaenopteridae | Blue whale (*Balaenoptera musculus*) | 1 | 0 | (Baxter, 2009) |
| | | Bryde's whale (*Balaenoptera edeni*) | 1 | 0 | (Haines and Limpus, 2001) |
| | | Fin whale (*Balaenoptera physalus*) | 6 | 0 | (Sadove and Morreale, 1990; Fossi et al., 2012) |
| | | Humpback whale (*Megaptera novaeangliae*) | 0 | 5 | (Mate, 1985; Humpback Whale Recovery Team, 1991; Mattila and Lyman, 2006; Moore *et al.*,2009; Marcondes pers. comm. 13/04/12) |
| | | Minke whale (*Balaenoptera acutorostrata*) | 6 | 9 | (Cawthorn, 1985; Mate, 1985; Hare and Mead 1987, Tarpley and Marwitz, 1993; Gill *et al.*, 2000; Mauger *et al.*, 2002; De Pierrepont *et al.*,2005; Smithsonian Research Institute, pers. comm.. 17/01/13)) |
| | Balaenopteridae Total | | 14 | 14 | |
| | Eschrichtiidae | Gray whale (*Eschrichtius robustus*) | 1 | >0 | (Hare and Mead, 1987; Heyning and Lewis, 1990; Cascadia Research, 2010; Barboza, 2012) |
| | Eschrichtiidae Total | | 1 | >0 | |
| Mysticete Total | | | **>17** | **>14** | |
| Odontocete | Delphinidae | Bottlenose dolphin (*Tursiops truncatus*) | 26 | 5 | (Barros *et al.*,1990; Walker and Coe, 1990; Schwartz *et al.*,1991; Mann *et al.*,1995; Gorzelany, 1998; Ceccarelli, 2009; NEFSC, 2009; Levy *et al.*,2009; Gomerčić *et al.*,2009; Deaville and Jepson, 2010; FAU, 2012; Lelis, 2012; Nicolau pers. comm. 12/04/12; Smithsonian Research Institute, pers. comm.. 17/01/13) |

| **Order** | **Family** | **Species** | **Number of instances** | | **Reference(s)** |
|---|---|---|---|---|---|
| | | | **Ingestion** | **Entanglement** | |
| | | Common dolphin (*Delphinus delphis*) | 8 | 0 | (Deaville and Jepson, 2010; Walker and Coe, 1990; Nicolau pers. comm. 12/04/12) |
| | | False killer whale (*Pseudorca crassidens*) | >0 | 0 | (Barros *et al*., 1990) |
| | | Fraser's dolphin (*Lagenodelphis hosei)* | 1 | 0 | (Fernández *et al*., 2009) |
| | | Guiana river dolphin (*Sotalia guianensis)* | 1 | 0 | (Geise and Gomes, 1992) |
| | | Indo-pacific bottlenose dolphin (*Tursiops aduncus*) | 0 | >0 | (Chatto and Warneke, 2000; Bossley, 2005) |
| | | Irrawaddy dolphin (*Orcaella brevirostris*) | 2 | 0 | (Kreb, pers. comm. 25/01/13) |
| | | Killer whale (*Orcinus orca*) | 2 | >0 | (Cawthorn 1985; Baird and Hooker, 2000; Smithsonian Research Institute, pers. comm.. 17/01/13)) |
| | | Long-finned pilot whale (*Globicephala melas*) | 1 | 0 | (Laist, 1997) |
| | | Northern right whale dolphin (*Lissodelphis borealis*) | 2 | 0 | (Walker and Coe, 1990) |
| | | Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) | >4 | 0 | (Caldwell *et al.*,1965; Cowan *et al.*,1986; Walker and Coe, 1990) |
| | | Pantropical spotted dolphin (*Stenella attenuata)* | 1 | 0 | (Baird and Hooker 2000) |
| | | Risso's dolphin (*Grampus griseus*) | 4 | 1 | (Walker and Coe, 1990; Shoham-frider *et al.*,2002; Frantzis, 2007; Bermudez-Villapol *et al.*,2008) |
| | | Rough toothed dolphin (*Steno bredanensis*) | 4 | 0 | (Meirelles and Barros, 2007; Smithsonian Research Institute, pers. comm.. 17/01/13; Walker and Coe, 1990) |
| | | Short-finned pilot whale (*Globicephala macrorhynchus*) | 3 | 0 | (Walker and Coe, 1990; Barros *et al.*,1997; Carillo pers. comm. 02/05/12) |
| | | Striped dolphin (*Stenella coeruleoalba*) | 2 | 13 | (Walker and Coe, 1990; Frantzis, 2007; Fernández *et al.*,2009) |
| | | Tucuxi (*Sotalia fluviatilis)* | 1 | 0 | (Laist, 1997) |
| | | White-beaked dolphin (*Lagenorhynchus albirostris*) | 1 | 0 | (Baird and Hooker, 2000) |
| | Delphinidae Total | | >63 | 19 | |

| Order | Family | Species | Number of instances<br>Ingestion | <br>Entanglement | Reference(s) |
|---|---|---|---|---|---|
| | Kogiidae | Dwarf sperm whale (*Kogia sima*) | >1 | 0 | (Barros *et al*., 1990; Walker and Coe, 1990) |
| | | Pygmy sperm whale (*Kogia breviceps*) | 15 | 0 | (Walker and Coe, 1990; Sadove and Morreale, 1990; Tarpley and Marwitz, 1993; Laist *et al.*,1999; Stamper *et al.*,2006; Fernández *et al.*,2009; Jacobsen *et al.*,2010; Marcondes pers. comm. 13/04/12; Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | Kogiidae Total | | >16 | 0 | |
| | Phocoenidae | Dall's porpoise (*Phocoenoides dalli*) | 3 | 1 | (Degange and Newby, 1980; Jones and Ferrero, 1985; Walker and Coe, 1990) |
| | | Finless porpoise (*Neophocoena phocaenoides*) | 1 | 0 | (Baird and Hooker, 2000) |
| | | Harbour porpoise (*Phocoena phocoena*) | 20 | 4 | (Hare and Mead, 1987; Walker and Coe 1990; Kastelein and Lavaleije, 1992; Baird and Hooker, 2000; Tonay *et al.*,2007; Deaville and Jepson, 2010; Bogomolni *et al.*,2010; Northwest Straits Initiative Project, 2012) |
| | Phocoenidae Total | | 24 | 5 | |
| | Physeteridae | Sperm whale (*Physeter macrocephalus*) | 57 | >0 | (Mate, 1985; Martin and Clarke, 1986; Lambertsen, and Kohn, 1987; Sadove and Morreale, 1990; Walker and Coe, 1990; Lambertsen 1990; Viale *et al.*,1992; Spence, 1995; Laist, 1997; Evans and Hindell 2004; International Whaling Commission, 2008; NMFS, 2009; Fernández *et al.*,2009; Moore *et al.*,2009; Mazzariol *et al.*,2011; Carillo pers. comm. 02/05/12; Haelters pers. comm. 24/04/12; Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | Physeteridae Total | | 57 | >0 | |
| | Pontoporiidae | Franciscana dolphin (*Pontoporia blainvillei*) | 59 | 0 | (Pinedo, 1982; Bassoi, 1997; Bastida, 2000; Denuncio *et al*., 2011) |
| | Pontoporiidae Total | | 59 | 0 | |

| Order | Family | Species | Number of instances | | Reference(s) |
|---|---|---|---|---|---|
| | | | **Ingestion** | **Entanglement** | |
| | Ziphiidae | Baird's beaked whale (*Berardius bairdii*) | 31 | 0 | (Walker and Coe, 1990; Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | | Blainville's beaked whale (*Mesopledon densirostris*) | 4 | 0 | (Secchi and Zarzur, 1999; Smithsonian Research Institute, pers. comm. 17/01/13; Walker and Coe, 1990;) |
| | | Cuvier's beaked whale (*Ziphius cavirostris*) | 17 | 0 | (Foster and Hare, 1990; Walker and Coe, 1990; Fertl *et al.*,1997; Poncelet *et al.*,2000; Santos and Pierce 2001; Gomerčić *et al.*,2006; Santos *et al.*,2007; Kerem pers. comm. 12/04/12; Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | | Gervais' beaked whale (*Mesopledon europaeus*) | 4 | 0 | (Fernández *et al*., 2009; Walker and Coe, 1990; Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | | Ginkgo-toothed whale (*Mesoplodon ginkgodens*) | 1 | 0 | (IWC, 2012) |
| | | Hubb’s beaked whale (*Mesoplodon carlhubbsi*) | 1 | 0 | (Yamada *et al*., 2012a) |
| | | Longman’s beaked whale (*Indopacetus pacificus*) | 2 | 0 | (Yamada *et al.*, 2012b) |
| | | Northern bottlenose whale (*Hyperoodon ampullatus*) | 2 | 0 | (Baird and Hooker, 2000; Deaville and Jepson, 2010) |
| | | Sowerby's beaked whale (*Mesoplodon bidens*) | 1 | 0 | (Deaville and Jepson, 2010) |
| | | Shepherd’s beaked whale (*Tasmacetus shepherdi*) | 1 | 0 | (Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | | Stejneger's beaked whale (*Mesopledon stejnegeri*) | >2 | 0 | (Walker and Hanson, 1999; Yamada, 2012) |
| | | True’s beaked whale (*Mesopledon mirus*) | 2 | 0 | (Smithsonian Research Institute, pers. comm.. 17/01/13) |
| | Ziphiidae Total | | >68 | 0 | |
| Odontocete Total | | | **287** | **24** | |
| Cetacea Total | | | **303** | **38** | |

Table 2: Number of species per family and order reported with debris interactions.

| **Sub-order** | **Family** | **Ingestion** | | **Entanglement** | |
|---|---|---|---|---|---|
| | | **Number of species** | **Proportion of family/order (%)** | **Number of species** | **Proportion of family/order (%)** |
| Mysticetes | Balaenidae | 2 | 50 | 3 | 75 |
| | Balaenopteridae | 4 | 50 | 2 | 25 |
| | Eschrichtiidae | 1 | 100 | 1 | 100 |
| | **Sub-total for sub-order** | **7** | **50** | **6** | **43** |
| Odontocetes | Delphinidae | 17 | 47 | 5 | 14 |
| | Kogiidae | 2 | 100 | 0 | 0 |
| | Phocoenidae | 3 | 43 | 2 | 29 |
| | Physeteridae | 1 | 100 | 1 | 100 |
| | Pontoporiidae | 1 | 100 | 0 | 0 |
| | Ziphiidae | 12 | 57 | 0 | 0 |
| | **Sub-total for sub-order** | **36** | **49** | **8** | **11** |
| **Cetacea Total** | | **43** | **49** | **14** | **16** |

Table 3: Documented rates of debris interactions in different species and regions.

| Species | Country/Sea | Number of animals recorded ingesting debris | Sample size | Prevalence | Type of record | Date | Reference |
|---|---|---|---|---|---|---|---|
| Harbour porpoise | Turkish western Black Sea | 5 | 42 | 11.9% | Bycatch (40 of 42) and strandings (2 of 42) | 2002-2003 | Tonay et al., 2007 |
|  | UK | 10 | 459 | 2.2% | Strandings | 2005-2010 | Deaville & Jepson, 2010 |
| Short-beaked common dolphin | UK | 3 | 128 | 2.3% | Strandings | 2005-2011 | Deaville & Jepson, 2010 |
| Bottlenose dolphin | UK | 1 | 18 | 5.6% | Strandings | 2005-2012 | Deaville & Jepson, 2010 |
| Northern bottlenose whale | UK | 1 | 11 | 9.1% | Strandings | 2005-2013 | Deaville & Jepson, 2010 |
| Baird's beaked whale | Okhotsk Sea | 6 | 20 | 30.0% | Hunted | 1988-1989 | Walker & Coe, 1990 |
|  | Pacific coast, central Japan | 25 | 86 | 29.1% | Hunted | 1985-1987 | Walker & Coe, 1990 |
| Sperm whale | U.S. west coast | 1 | 38 | 2.6% | Strandings | 1979 | Mate, 1985 |
|  | southern Australia | Unknown | 36 | 11.1% | Strandings | 1998 | Evans & Hindell, 2004 |
| Fin whale | Iceland | 6 | 82 | 7.3% | Hunted | 1985 | Sadove & Morreale, 1990 |
| Franciscana dolphin | Southern Brazil | Unknown | 36 | 17.0% | Bycatch | Unknown | Bassoi, 1997 |
|  | Northern Argentina | Unknown | 68 | 31.0% | Bycatch | Unknown | Bastide et al. 2000 |
|  | Argentina | 30 | 106 | 28.3% | Bycatch | 2007-2010 | Denuncio et al. 2011 |

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