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Review Article

Cetaceans and Marine Debris: The Great Unknown

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Plastics and other marine debris have been found in the gastrointestinal tracts of cetaceans, including instances where large quantities of material have been found that are likely to cause impairment to digestive processes and other examples, where other morbidity and even death have resulted. In some instances, debris may have been ingested as a result of the stranding process and, in others, it may have been ingested when feeding. Those species that are suction or "ram" feeders may be most at risk. There is also evidence of entanglement of cetaceans in marine debris. However, it is usually difficult to distinguish entanglement in active fishing gear from that in lost or discarded gear. The overall significance of the threat from ingested plastics and other debris remains unclear for any population or species of cetaceans, although there are concerns for some taxa, including at the population level, and marine debris in the oceans continues to grow. Further research including the compilation of unpublished material and the investigation of important habitat areas is strongly recommended.

1. Introduction and Background

Marine litter has been characterized as an environmental, economic, human health and aesthetic problem, posing a complex and multidimensional challenge with significant implications for the marine environment and human activities all over the world [1]. Much has been written about this pervasive pollution problem in recent years, and there are various international initiatives now striving to address it, including the United Nations Environment Program (UNEP) Global Initiative on Marine Litter. Part of the problem derives from the accumulation and fragmentation of plastics, "one of the most ubiquitous and long-lasting recent changes to the surface of our planet" [2]. In the marine environment, typically 40–80% of the larger categories of marine debris items are plastic. Much of this is packaging, carrier bags, footwear, cigarette lighters and other domestic items and much originates from land, as a recent study in Central and South America showed [3]. Lost or discarded fishing gear can also be important, particularly along continental shelves and remote islands.

Thirty-one species of marine mammals have previously been reported to have ingested marine debris [4], and it has been suggested that even small ingested quantities can have large effects [5]. In addition to interference with alimentary processes, another effect could be that the plastics lodged somewhere in the alimentary tract could facilitate the transfer of pollutants into the animals' bodies. The chemicals contained within plastics debris include polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, petroleum hydrocarbons, organochlorine pesticides (2,2′-bis(*p*-chlorophenyl)-1,1,1-trichloroethane, hexachlorinated hexanes), polybrominated diphenyl ethers, alkylphenols, and bisphenol A, at concentrations from sub $\mathrm{ng\,g^{-1}}$ to $\mu\mathrm{g\,g^{-1}}$ [6]. Some of these compounds are added during plastics manufacture, while others are adsorbed from the surrounding seawater. Concentrations of these absorbed contaminants showed distinct spatial variations, reflecting global pollution patterns. Model calculations and experimental observations consistently show that polyethylene accumulates more organic contaminants than other plastics such as polypropylene and polyvinyl chloride.

"Microplastics" are a related concern and defined by the United States' National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program as plastic debris pieces in the size range of 0.3–5 mm. "Primary microplastics"

are either intentionally produced for direct use, such as scrubbers in cleaning products, or as precursors to other products, such as preproduction plastic pellets. "Secondary microplastics" are formed from the breakdown of larger plastic materials. These small pieces of plastic are difficult to remove from the environment, and, because they have the potential to be ingested by a wider range of organisms than larger pieces microplastics may clog the feeding apparatuses or the digestive systems of a variety of species. Microscopic pieces may also be taken up from the gut into other body tissues [2].

In 2003, UNEP established a "Global Initiative on Marine Litter" to facilitate international cooperation on marine litter. This is coordinated by UNEP's Regional Seas Programme (RSP) and the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). Most recently, in March 2011, UNEP and NOAA organized the Fifth International Marine Debris Conference in Honolulu, Hawai'i. This meeting, which brought together 440 participants representing 38 countries, agreed the Honolulu Commitment, which outlines 12 actions to reduce marine debris and also produced the *Honolulu Strategy*, a comprehensive global framework strategy to prevent, reduce, and manage marine debris [10].

An investigation was made of the published scientific and other literature in order to assess the current state of knowledge with respect to cetaceans. This review focuses on incidents recorded after the review authored by Laist in 1987, when he first raised substantive concerns about this threat for marine wildlife [8].

2. The Behaviour of Debris at Sea

Many studies have been carried out across the world to try to quantify marine debris, and most of these have focused on large (macro) debris. These studies show that marine debris is ubiquitous in the world's oceans and on its shorelines [4]. Many plastics are buoyant, and plastic items are commonly found at the sea surface or washed up on the shoreline [2]. Distribution at sea is affected by local wind and current conditions, coastal geography and point of entry; enclosed seas tend to have higher concentrations.

Higher quantities are found in the mid-latitudes and tropics, with particular concentrations associated with shipping lanes, fishing areas, and ocean convergence zones. About 2000 items of anthropogenic debris are found on north Atlantic shores per linear km per year and 500 per linear km per year on south Atlantic shores. More than half of this debris is plastic. By comparison, more than six times as much plastic has been reported washing ashore annually in the Mediterranean Sea. Observed global trends include a sustained and considerable increase over time and an increase in the associations of macroplastics with some wildlife (e.g., in bird nests and stomachs, and entangling seals) [2].

Some plastics sink when they first enter the water column, and others do so after accumulating a layer of fouling organisms and sediment. Considerable spatial variability affects plastic debris below the sea surface, and distribution is strongly affected by hydrodynamics, geomorphology, and human factors [2]. Plastics have now been found on the seabed of all seas and oceans across the planet, although macrodebris is still very rare in the Southern Ocean. It is now apparent that even those species that typically feed at significant depth will not avoid exposure to plastic debris, indeed they may actually be exposed in some areas to very high concentrations. Submersibles conducting investigations at depths beyond the continental shelf have encountered substantial quantities of debris, including high densities in coastal canyons (up to 112 items per kilometer, of which 70% were plastics) [2].

Concentrations of marine debris may occur in areas that are important for cetaceans, such as convergence zones where prey may be abundant. For example, in 1997 and 2000, surveys were conducted on the floating debris in the Ligurian Sea, a subbasin of the Mediterranean Sea which includes the Ligurian Cetacean Sanctuary [11]. Debris densities were determined to be 15–25 objects/km^2 in 1997 and 1.5–3 objects/km^2 in 2000. The authors noted that there was a difference in sampling methodology between the two surveys but also suggested that meteorological factors played a role in creating real differences in the densities reported and noted that the factors affecting distribution need to be better understood.

Williams et al. [12] have recently mapped the at-sea distributions of both marine debris and eleven marine mammal species in the waters of British Columbia to identify areas of overlap. They commented that such areas were often far removed from urban centers, and this suggested that the extent of marine mammal-debris interactions would be underestimated from opportunistic sightings and stranding records. They urged that high-overlap areas should be prioritized by stranding response networks.

There are two primary types of impact for marine wildlife: entanglement and ingestion and whilst cetaceans, pinnipeds, turtles and seabirds are all known to suffer from entanglement, it has been suggested that pinnipeds are particularly affected [4]. Entanglement in marine debris is also well established as a health problem for some marine birds and turtles [5]. Entanglement may be confused with bycatch, which is the ensnaring of nontarget animals in active fishing apparatus. It may be difficult to diagnose from retrieved bodies whether they were caught in active gear or lost gear, and marks on bodies may be misidentified as net marks when they are actually the result of entanglement in marine debris.

3. Ingestion

3.1. Odontocetes. Walker and Coe made an extensive survey of foreign body ingestion by odontocetes [7]. They commented that the pathologic effects on foreign body ingestion on captive cetaceans are well known and provide details of materials ingested in captivity. They also investigated the situation for wild cetaceans and solicited information from relevant institutions covering the period between 1963 and 1986. Due to variations in data recording and pathology techniques, they were unable to determine frequency of

occurrence of debris ingestion, but they did identify 43 examples of ingestion in stranded animals primarily from the east and west coasts of North America. Table 1 summarizes the incidents reported by Walker and Coe in 1990, including some records where ingestion of debris might have been of health significance [7]. Plastic bags and plastic sheeting were the most common items ingested (62.5% of ingested materials) [7]. Other miscellaneous plastic items such as drinking straws, bottle caps, discarded fishing net, synthetic rope, and a small container occurred in 17.5% of cases.

Walker and Coe concluded that odontocete cetaceans were affected to an unknown degree by the ingestion of oceanic debris but that the sperm whale, *Physeter macrocephalus*, seemed to be particularly affected. They suggested that mistaken ingestion of debris due to its resemblance to prey is unlikely in odontocetes because of their echolocation skills and that for these species at least, ingestion happens incidentally to feeding or may be part of the stranding syndrome. They also commented that "naturally occurring disease factors may predispose" some animals to ingest abnormal items [7].

A number of other authors have reported more recently on incidents of ingestion. For example, the first account of ingestion causing mortality in sperm whales was recently published: in 2008, two male sperm whales stranded along the northern California coast with large amounts of fishing net scraps, rope, and other plastic debris in their stomachs [5]. One animal had a ruptured stomach, the other was emaciated, and gastric impaction was suspected as the cause of both deaths. There were 134 different types of nets in these two animals, all made of floating material, varying in size from 10 cm^2 to about 16 m^2. The researchers concluded that the variability in size and age of the pieces suggested that the material was ingested from the surface as debris. They also mentioned several other incidents of ingestion including two pygmy sperm whales, *Kogia breviceps*, with stomachs occluded by pieces of plastic bags and three bottlenose dolphins, *Tursiops truncatus*, asphyxiated by laryngeal entrapment by ingested fishing lines.

In November 1993, an emaciated juvenile female pygmy sperm whale was found stranded in Great Inlet, Longport, New Jersey, and taken into a rehabilitation facility [13]. The whale survived and exhibited various symptoms over a 42-day period. These included being unable to submerge successfully and indications that it had a digestive problem which led to a gastroscopic investigation. Foreign material was observed and, over a six-week period, using endoscopic procedures, a 20 cm × 22.5 cm sheet of black plastic, a portion of a plastic garbage bag, a cellophane wrapper, cigarette box wrapper, portion of a mylar balloon, and some other small pieces of plastic were extracted. The animal's appetite then improved, it put on weight and was ultimately released, tracked for several days, and appears to have survived.

In December 2009, a pod of seven male sperm whales stranded on the Adriatic Coast of southern Italy [14]. Stomach contents consisted mainly of highly digested cephalopod beaks and foreign bodies, including fishing gear and hooks, ropes, and several plastic objects. No evident obstruction or perforation of the alimentary tract was noted.

Beaked whales have also been suggested to be especially vulnerable [15]. Walker and Coe in 1990 reported debris from Baird's beaked whales, *Berardius bairdii,* taken at two localities in the Pacific coastal waters of Japan [7]. In these animals, the incidence of debris in 86 stomachs was 26.7% and off northern Hokkaido, in the southern Okhotsk Sea, incidence of debris in 20 stomachs was 15.0%. Prey data indicated that the lower frequency of debris ingestion reflected differences in feeding strategy. The high vulnerability of beaked whales may result from their reliance on suction-feeding for prey capture and some species in some regions, such as Cuvier's beaked whales, *Ziphius cavirostris,* in the northeast Atlantic, seem to have particularly high incidences of ingestion of and death from plastic bags [15]. MacLeod commented that "currently plastic bags are known to affect beaked whales at the individual level and may be of sufficient prevalence to affect some species at the local aggregation and population levels. As yet, it does not seem likely that plastic bag ingestion affects any beaked whales at the species level. However, this may be a possibility for some species with limited geographic ranges close to high concentrations of humans" [15].

An immature male Cuvier's beaked whale that stranded at Biscarrosse, Landes, France, on January 29, 1999 was found to be emaciated, with a blubber layer almost half that expected for an animal of its age, sex, and size [16]. The stomach was found to be full of plastic, weighing approximately 33 kg when wet, and estimated to consist of 378 separate plastic items. A subsample of the plastic (786 g) consisted of seven supermarket plastic bags and two plastic sheets. A small number of cephalopod and fish remains were also found in the stomach, but no fresh prey. The debris was covered with dark viscous fluid, possibly from erosion of the stomach lining and resulting hemorrhaging, which was suggested as the cause of death.

Santos et al. report on the stomach contents of three Cuvier's beaked whales, two of which stranded in Galicia, northwest Spain, in 1990 and 1995 and the other in North Uist, Scotland, in 1999 [17]. Both the whales that stranded in Galicia had plastic remains in their stomachs, and the Scottish animal contained the remains of at least six plastic bags or refuse sacks, one of which was recorded as "tightly screwed up and apparently jammed in the entrance to the stomach."

Santos et al. [18] later analyzed stomach contents from another group of beaked whales which mass-stranded shortly after a naval exercise conducted in the Canary Islands in September 2002. Samples from seven Cuvier's beaked whales, a single Blainville's beaked whale, *Mesoplodon densirostris*, and a single Gervais' beaked whale, *Mesoplodon europaeus*, were examined. All the whales were reported to have appeared to have been in good body condition with the exception of one of the male Cuvier's beaked whales. This animal was "visibly emaciated," and necropsy showed a high nematode parasite burden load in the stomach and also a plastic sheet. The stomach of this specimen was also the only one that did not contain fresh food remains.

The stomach contents of 23 cetaceans stranded in the Canary Islands between 1996 and 2006 were examined,

Table 1: Summary of incidents of ingestion by cetaceans of plastics and other debris reported in Walker and Coe between 1963 and 1986 with notes indicating where ingestion was indicated to be of significance [7].

Species	Number of incidents	Locations	Notes
Sperm whale, *Physeter macrocephalus*	3	Florence, OR, New Jersey and Newfoundland	One animal of 38 examined from a mass stranding in Oregon had one liter of tightly packed trawl net in its stomach
Dwarf sperm whale, *Kogia sima*	1	Corolla, NC	
Pygmy sperm whale, *Kogia breviceps*	3	Sullivan's Island, SC, Galveston, TX, and Brevard Co., Florida	The Texas animal had "pounds of plastic bags clogging its stomach chambers"
Cuvier's beaked whale, *Ziphius cavirostris*,	3	San Diego, CA, Assawoman, VA and Seaford, VA	
Blainville's beaked whale, *Mesoplodon densirostris*	1	East Hampton, NY	
Gervais' beaked whale, *Mesoplodon europaeus*	2	Hatteras Island, NC and Cape May, NJ	The NJ animal had its stomach full of plastic
Short-finned pilot whale, *Globicephala macrorhynchus*	1	Corolla, NC	
Rough-toothed dolphin, *Steno bredanensis*	3	Maui, HI and 2 from Sandbridge, VA	
Pacific white-sided dolphin, *Lagenorhynchus obliquidens*	4	Three from Santa Monica, CA, one from Long Beach, CA	The forestomach of the Long Beach animal was half full of four plastic bags, two plastic bottle caps, and various organic materials
Common dolphin, *Delphinus delphis*	4	Two from Los Angeles County, CA, one from Malibu, CA, and the other from Hermosa Beach, CA	The LA County animal had one partial red balloon (3×13 cm), one piece of clear plastic (8×13 cm), and kelp fronds in its stomach
Bottlenose dolphin, *Tursiops truncatus*	9	All from the California coastal population—stranded on various CA shores	Along with other organic and plastic debris, three of the animals contained hooks
Risso's dolphin, *Grampus griseus*	2	Martha's Vineyard, MA and Manhattan Beach, CA	The animal from MA was recorded as having a plastic bag in its throat
Striped dolphin, *Stenella coeruleoalba*	1	Cape Point, NC	
Northern right whale dolphin, *Lissodelphis borealis*	2	Los Angeles County, CA and Santa Monica, CA	
Harbour porpoise, *Phocoena phocoena.*	1	Corolla, NC	
Dall's porpoise, *Phocoenoides dalli*	3	Venice Beach, CA, and two from Santa Barbara, CA	The Venice Beach animal had its stomach "jammed with debris" including 13 pieces of clear plastic sheet, 3 heavy clear plastic bags, 2 plastic bread bags, and two plastic sandwich bags

and five of the animals examined had plastic debris in their stomachs with big plastic items being taken by deep diving teuthopagus whales [19]. The sample set comprised 5 sperm whales, 2 pygmy sperm whales, 1 Gervais' beaked whale, 1 Risso's dolphin, *Grampus griseus*, 2 short-finned pilot whales, *Globicephala macrorhynchus*, 1 Fraser's dolphin, *Lagenodelphis hosei*, 3 Atlantic spotted dolphins, *Stenella frontalis*, 3 striped dolphins, *Stenella coeruleoalba*, 1 bottlenose dolphin, 1 rough-toothed dolphin, *Steno bredanensis*, 3 common dolphins, *Delphinus delphis* and 1 Cuvier's beaked whale. One of the sperm whales had a plastic bag in its stomach. One of the pygmy sperm whales contained a plastic filament. One of the Gervais' beaked whales had a complete plastic bag (44×24 cm) and pieces of another two in its stomach. The Frazer's dolphin contained some small plastic pieces, and finally one of the striped dolphins had ingested a plastic filament around 10 cm long. All the animals that had ingested plastic also had food remains in their stomachs. In addition, in February 2004, a Cuvier's beaked whale was found washed ashore on the Isle of Mull, Scotland. The entrance to this animal's stomach was found to be completely blocked by a cylinder of tightly packed shredded black plastic bin liner bags and fishing twine [20].

A North Atlantic bottlenose whale, *Hyperoodon ampullatus*, which stranded in August 2006 in Skegness, UK, was found to have ingested some plastic [21]. The fundic stomach

contained copious brownish watery fluid, a piece of plastic, and a section of some green netting (resembling fishing gear). The mucosal lining at the base of the stomach (area in direct contact with the plastic) was reddened and haemorrhagic in appearance, and a single round mucosal ulcer with a red haemorrhagic base (measuring 1–1.5 cm diameter) was noted towards the entrance to the stomach. The UK Cetacean Strandings Investigation Programme (CSIP) examined 18 stranded whales from the Ziphiid family between 2005 and 2010. Two (a North Atlantic bottlenose whale and a Sowerby's beaked whale, *Mesoplodon bidens*) had ingested debris [21].

Accounts of plastic ingestion by beaked whales outside of the North Atlantic also exist. For example, there is a published report on a Blainville's beaked whale washed ashore in Brazil with a blueish bundle of plastic threads occupying a large part of its main stomach chamber [22]. This whale had not fed for some time. In addition, a Gervais' beaked whale stranded on the southeastern coast of Puerto Rico was recently found to have more than ten pounds (4.5 kilos) of twisted plastic inside its stomach, and its death was attributed to the plastic preventing it obtaining adequate nutrition [23].

There are scattered reports of ingestion of marine debris by other odontocete cetaceans. For example, in September 1997, a small harbour porpoise, *Phocoena phocoena*, (probably not yet weaned) was found dead near Pictou, Nova Scotia. It was visibly emaciated and its stomach and intestines were empty, apart from small amounts of bile-stained liquid [24]. Upon examination of the oesophagus, a balled-up piece of black plastic (about 5 by 7 cm) was found adjacent to the junction with the stomach. Cranially to this was a mass of fish bones and flesh and three intact fish. The authors noted two earlier published reports of plastic ingestion by this species and several other unpublished records of the same. CSIP has recorded 10 out of 459 harbour porpoises examined between 2005 and 2010 had ingested marine debris [21].

The stomach contents of 42 harbour porpoises that were either bycaught or stranded between April and June in 2002 and 2003, on the Turkish western Black Sea coast, were examined [25]. Plastic debris was found in five stomachs and in one of these, a bycaught female 130 cm long, this consisted of plastic bags and sheeting with dry weight of 40.9 g.

An adult male rough-toothed dolphin, *Steno bredanensis*, that stranded alive on Poço da Draga Beach, Fortaleza, Ceará State, northeastern Brazil, was found to have ingested two plastic bags, and four pieces of sea sponges were found in the forestomach chamber, where the mucosa had several ulcers [26].

CSIP has also reported marine litter ingestion by 3 out of a sample of 128 short beaked common dolphins stranded in the UK [21].

Plastic debris ingestion was examined in a large sample of Franciscana, *Pontoporia blainvillei*, incidentally captured in the artisanal fisheries of the northern coast of Argentina [27]. Twenty-eight percent of the 106 dolphins sampled had plastic debris in their stomachs, but no ulcerations or obstructions were recorded. Plastic ingestion was more frequent in the dolphins using an estuarine environment rather than those living in a fully marine environment, but the type of debris was similar in both. Packaging debris (cellophane, bags, and bands) was found in 64.3% of the dolphins which had ingested plastics, with a lesser proportion (35.7%) ingesting fishing gear fragments (monofilament lines, ropes, and nets). Twenty-five percent had ingested plastics from unknown sources. No obstructions or ulcers were found in any of these animals, and the researchers commented "that the small number and size of the fragments found in healthy dolphins suggest that this material is not lethal… [but] cannot be ruled out as a potential cause of death." They also noted that sublethal effects, such as partial obstruction of the gastrointestinal tract and reduction of feeding stimulus might occur. This large sample size also revealed that there is a potential relationship between age and plastic ingestion. The Franciscana of north Argentina are weaned between 2 and 7 months of age, and it is suggested that the sharp increase of plastic ingestion that occurs during the weaning phase could be a consequence of the learning process in the young animals as they start to catch prey by themselves [27].

3.2. Mysticetes. In 2000, a Bryde's whale, *Balaenoptera edeni*, was found on the shore in Cairns, Australia with a considerable amount of plastic in its stomach including 30 whole plastic bags and three lengths of plastic sheeting [28]. The plastic when stretched out was reported to cover an area of 6 m^2.

In April 2002, a dead minke whale, *Balaenoptera acutorostrata*, washed up on the Normandy Coast of France, was found to have 800 kg of plastic bags and packaging, including two English supermarket plastic bags in its stomach [29].

CSIP has not reported ingestion of plastic in any of the 13 baleen whales examined in the UK between 2005 and 2010 [21].

4. Entanglement

The first comprehensive review of the impacts of marine debris globally was undertaken by Laist [8], and he revisited this issue ten years later [9], when he was of the opinion, based on the available data, that entanglement was a greater threat to marine mammals than ingestion. Laist reported that fishing gear (monofilament line, nets, and ropes) was found to be the most significant source of entanglements in all documented records regarding sea turtles, coastal and marine birds, marine mammals, fish, and crabs. Most of this material originated from commercial fishing operations, although recreational fishing and cargo ships were also considered potential sources. He estimated that 100,000 marine mammals died every year from entanglement or ingestion of fishing gear and related marine debris. Laist's reviews are summarized here in Table 2 alongside the literature compiled here. One hundred and thirty-six marine species have been reported in entanglement incidents in the wider United States area, including 6 species of sea turtles, 51 species of seabirds, and 32 species of marine mammals [30].

Lambertsen et al. commented on the "imperfect nature of our understanding of the impact of marine debris on mysticete species" whilst also theorizing that fouling of

Table 2: Overview of entanglement and ingestion in cetaceans.

Species	Laist 1987 [8]	Laist 1997 [9]	This review
Mysticete whales			(Ingestion only)
Balaena mysticetus (bowhead whale)		I/E	
Eubalaena glacialis (northern right whale)	E*	E*	
Eubalaena australis (southern right whale)		E*	
Megaptera novaeangliae (humpback whale)	E*	E*	
Eschrichtius robustus (gray whale)		E*	
Balaenoptera physalus (fin whale)	E*		
Balaenoptera acutorostrata (minke whale)	E*	I/E*	I
Balaenoptera edeni (bryde's whale)			I
Odontocete whales			
Physeter macrocephalus (sperm whale)	I	I/E*	IM
Kogia sima (dwarf sperm whale)		I	
Kogia breviceps (pygmy sperm whale)	I	I	I
Berardius bairdii (Baird's beaked whale)		I	
Ziphius cavirostris (Cuvier's beaked whale)	I	I	I?M
Mesoplodon europaeus (Gervais' beaked whale)		I	IM
Mesoplodon densirostris (Blainville's beaked whale)		I	I
Globicephala macrorhynchus (short-finned pilot whale)		I	I
Globicephala melas (long-finned pilot whale)		I	
Steno bredanensis (rough-toothed dolphin)	I	I	I
Pseudorca crassidens (false killer whale)		I	
Orcinus orca (orca or killer whale)		E*	
Lagenorhynchus obliquidens (Pacific white-sided dolphin)		I	
Delphinus delphis (common dolphin)		I	I
Tursiops truncatus (bottlenose dolphin)		I/E*	I
Grampus griseus (Risso's dolphin)		I	
Stenella coeruleoalba (striped dolphin)		I	I
Lissodelphis borealis (northern right whale dolphin)		I	
Phocoena phocoena (harbour porpoise)		I/E*	I
Phocoenoides dalli (Dall's porpoise)		I/E	
Pontoporia blainvillei (Franciscana)		I	I
Sotalia fluviatilis (tucuxi dolphin)		I	
Stenella frontalis (Atlantic spotted dolphin)			I
Lagenodelphis hosei (Fraser's dolphin)			I
Hyperoodon ampullatus (North Atlantic bottlenose whale)			I
Mesoplodon bidens (Sowerby's beaked whale)			I

Key: I: ingestion recorded; E: entanglement recorded; IM: mortality reported as associated with ingestion; I?M: mortality resulting from ingestion likely.
*Entanglement in fishing gear where it is not clear if it was in use or lost at the time of entanglement.

the baleen may prove lethal, as it could interfere with the particular feeding mechanism used by these animals [31]. They added that this may be a significant factor in the declining survival probability of the northern right whale, *Eubalaena glacialis*, because as continuous ram feeders, they face a higher risk than rorquals of encountering various forms of marine debris with their mouths open.

As a means of trying to quantify entanglement, there have been a number of studies of nonlethal entanglements of whales using the pattern of scarification photographed on their bodies. For example, Neilson et al. found that 52–78% of humpback whales, *Megaptera novaeangliae*, in the northern part of southeastern Alaska had been nonlethally entangled at some point in their lives [32]. Calves were less likely to have entanglement scars than older whales, and males may be at higher risk than females. Entanglement of marine mammals in fishing gear has been documented widely and may affect a significant proportion of some populations of baleen whales (e.g., [32–35]). However, it remains unclear as to what percentage of entrapment arises from marine debris as opposed to entrapment from fishing gears, that were still in active commercial use. This seems to be general and significant problem in terms of determining the source of impacts.

In a similar study to that of Neilsen et al., nine minke whales from a photo catalogue of 74 known individuals which were known to regularly return to the waters in the west of Scotland were observed entangled, or with scars suggesting previous entanglement in marine debris, including pieces of discarded or "ghost" net [36]. Two whales, photographed in May 1997 and May 1999, had plastic packing straps wrapped around their rostrums. These plastic strips were trapped in the baleen in the upper jaws and appeared to be cutting into the whale's skin. Another whale, photographed in September 1999, had a white scar thought to be caused by a packing strip or twine. Three minke whales appeared to have evidence of creel ropes wrapped around their heads, and it was suggested that some of the other wounds seen on the whales were probably caused by marine debris. These investigations by Gill et al. provide a rare example where debris can be categorically shown to be causing entanglement. By contrast, there is a considerable literature on entanglement of cetaceans in fishing gear but given the problem of determining whether the gear was in use or not, entanglement is not further reviewed here or included in the third column of Table 2.

5. Conclusions

It has long been held that marine wildlife entanglement in and ingestion of synthetic marine debris are insidious and cryptic threats [8]. As Williams et al. put it "if death from debris entanglement or ingestion occurs at sea, documentation of the event generally requires the carcass to come close to shore to be detected by a person, reported to the competent authority, and subjected to a full necropsy before the carcass decays" [12]. There are, therefore, several processes at work that reduce the likelihood of the event being detected, and this may be further exacerbated by the probability that some of the deeper sea dwelling whales (i.e., the ziphiids) are particularly impacted. Then there are diagnostic problems, such as the fact that some ingestion of pebbles, sand, and debris seems to be part of the stranding process [37, 38] and the issue of trying to determine the extent to which entangled animals have become ensnared by operational rather than lost fishing gear.

It is difficult to attribute any trends to the published literature because of differences in sampling procedures and other factors such as the changes over time and variations that may exist for difference regions and cetacean populations. Table 2 shows that ingestion of debris is now known for several more species than when last reviewed, and there are incidents where it has clearly caused mortality. Deep diving whales are also strongly represented in the reports. More records from surfacing dwelling dolphin species might be indicative of a growing problem for them, but this may also be affected by sampling effort.

Nonetheless, it is clear that marine debris is an increasing problem, and there is growing evidence of impacts on cetaceans. There are now numerous recorded incidents where ingested debris has caused pathology and a growing concern especially for deep water suction feeders and arguably ram feeders as well, noting that marine debris has also been proposed as significant threat for the critically endangered northern right whale. Whilst it is strongly suggested in the literature that the small cetaceans living in surface waters are less likely to ingest harmful materials than other species, it is also apparent that this may change where there is substantial debris at the surface, as reported off northern Argentina.

However, apart from a small number of systematic surveys involving larger numbers of animals, the relevant data are generally scattered and rather scant. During research onto this topic, it became apparent that many cetologists and some institutions around the world hold some records of ingestion or entanglement in marine debris but, as these are frequently observations on one or just a few individual animals, they rarely bring them forward for publication. Nonetheless, if such records were compiled, they would probably help us better understand the scale and significance of this problem, and this may also help to pinpoint particular problem areas or populations that are being particularly impacted. The importance of appropriate pathology of stranded and bycaught cetaceans in order to investigate this issue is also apparent and likewise the desirability of developing approaches to determine if fishing gear was active or discarded when entanglement occurred.

Further consideration of where vulnerable cetaceans and marine debris may be converging—for example, the deep water canyons used as core habitat by beaked whales—is also recommended. Overall, in comparison to the level of understanding that exists for some other marine species such as turtles and albatrosses, the current level of understanding of the threat posed by marine debris to cetaceans is poor, and it is strongly recommended that this be addressed.

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