



Cetaceans as Ocean Health Indicators of Marine Litter Impact at Global Scale

Maria Cristina Fossi^{1*}, Matteo Baini¹ and Mark Peter Simmonds^{2,3}

¹ Department of Physical, Earth and Environmental Sciences, University of Siena, Siena, Italy, ² School of Veterinary Science, University of Bristol, Bristol, United Kingdom, ³ Humane Society International c/o HSI-UK, London, United Kingdom

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*Correspondence:

Maria Cristina Fossi
fossi@unisi.it

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Marine litter is a growing concern for marine animals, including cetaceans for which there is a developing body of evidence showing impacts of both entanglement and ingestion. Better understanding is needed of the current and predicted scales of impacts on cetacean species of both macro- and micro-litter. Some emerging methodological approaches, such as the “threefold approach,” will help address data gaps. The relationship between this form of pollution and some cetaceans is strong and the particular feeding habits, and widespread distribution of two whale species means that they can be proposed as ocean health indicators for macro- and micro-litter impacts at global scales, helping steer research. The species concerned are sperm whales (*Physeter macrocephalus*), for macro-litter at depth, and fin whales (*Balaenoptera physalus*), for micro-debris. Once appropriate techniques have been fully developed for non-lethal assessment, other whale species might also be used as indicators of litter pollution in their specific feeding zones.

Keywords: cetaceans, marine litter, microplastics, ocean health, indicators, research perspectives

INTRODUCTION

The effects of marine debris on marine wildlife have been documented since the 1960’s (CBD, 2016; Germanov et al., 2018). However, the production of plastics and associated pollution has subsequently increased greatly, and marine debris is now been recognized as a global problem (CBD, 2016), with more than 800 species known to have been adversely affected (Fossi et al., 2018c; Kühn and van Franeker, 2020). For cetaceans, impacts from entanglement or ingestion can be acute or chronic (Laist, 1997, IWC., 2020). Almost two-thirds of cetacean species have been found to have ingested plastic macro-litter (2.5 cm+) and this affects species across many different habitats and which exhibit differing feeding techniques (Walker and Coe, 1990; Laist, 1997; Katsanevakis, 2008; Cornish et al., 2011; Simmonds, 2011, 2012; Baulch and Perry, 2014; Fossi et al., 2018b, IWC., 2020, Kühn et al., 2015). This paper focuses on ingested materials and plastic items are the most recorded type of ingested debris, including large pieces of netting and sheets of plastic.

In December 2019, the International Whaling Commission (IWC) held its third international workshop on cetaceans and marine litter (IWC., 2020) and took an in-depth look at the relationship between cetaceans and marine litter. Alongside other aims the workshop sought to review the latest evidence on interactions with cetaceans and identify best protocols for gross pathology, including

for micro-debris. Based on its review of both published and unpublished sources, the workshop agreed that “the scale of the actual and projected increase in plastics” was “alarming,” noting that cetaceans can be killed by ingestion because of gastric impaction/occlusion and perforation or as a result of the associated lesions. It was also noted that chronic health concerns could result if plastics persisted in the gastrointestinal tract (GIT) where they might reduce the space for food, adversely affecting nutrition and ultimately the animal’s condition. Ingested plastic debris can also cause inflammatory changes and act as a vector of pathogens or pollutants.

The 2019 IWC workshop also considered entanglement, noting that ~640,000 tons of Abandoned, Lost and otherwise Discarded Fishing Gear (ALDFG) arrives in the oceans annually. Among its recommendations, the workshop highlighted how important long-term studies are and the need for uniformity in post-mortem studies. At the present time, the most universally used method to examine effects and occurrence in cetaceans is the examination during necropsy of the GI tract of stranded individuals. This can demonstrate the type of exposure of the species but has limitations in terms of identifying all the adverse effects on both the individual and at the population level. Problems with this approach include that:

- i few bodies are retrieved;
- ii of these, even fewer are in good enough condition to be examined; and
- iii an apparently low associated rate of reporting.

In our experience, obtaining accurate samples from necropsies is also often problematic and so are the practical issues that arise from analyzing the large quantities of material from the GI tract of the larger whales. Studies on microplastics are notably rare, although they have been systematically determined in seven small cetaceans to date: *Tursiops truncatus*, *Delphinus delphis*, *Stenella coeruleoalba*, *Phocoena phocoena*, *Orcinus orca*, and *Ziphius cavirostris* (Lusher et al., 2018; van Franeker et al., 2018) and one stranded humpback whale (*Megaptera novaeangliae*) (Besseling et al., 2015).

Microplastic uptake by cetaceans can occur by various mechanisms, including:

- i ingestion when feeding;
- ii inhalation when taking a breath at the surface; or
- iii transfer via prey items (IWC., 2013).

Planktivorous (Collard et al., 2015), pelagic and demersal fish have all been shown to uptake microplastics (Lusher et al., 2013; Murphy et al., 2017), as have copepods and euphausiids, some of which are common prey species for baleen whales (Desforges et al., 2015). Uptake has also been demonstrated in some shellfish and other benthic organisms (e.g., Pellini et al., 2018), potentially providing a further contaminated link in the food chain to other species that feed on the seabed.

Here we report on the scientific evidence and discuss the emerging gaps in understanding related to both filter feeder baleen whales (such as fin whales, *Balaenoptera physalus*) and deep diving odontocetes (such as sperm whales, *Physeter*

macrocephalus) in relation to, respectively, micro- and macro-litter impacts, including their related toxicological effects. We also consider emerging methodological approaches and, in particular, the threefold approach, which can contribute to new diagnostic tools. Finally, we propose these species as potential ocean health indicators of macro- and micro-litter impact at a global scale.

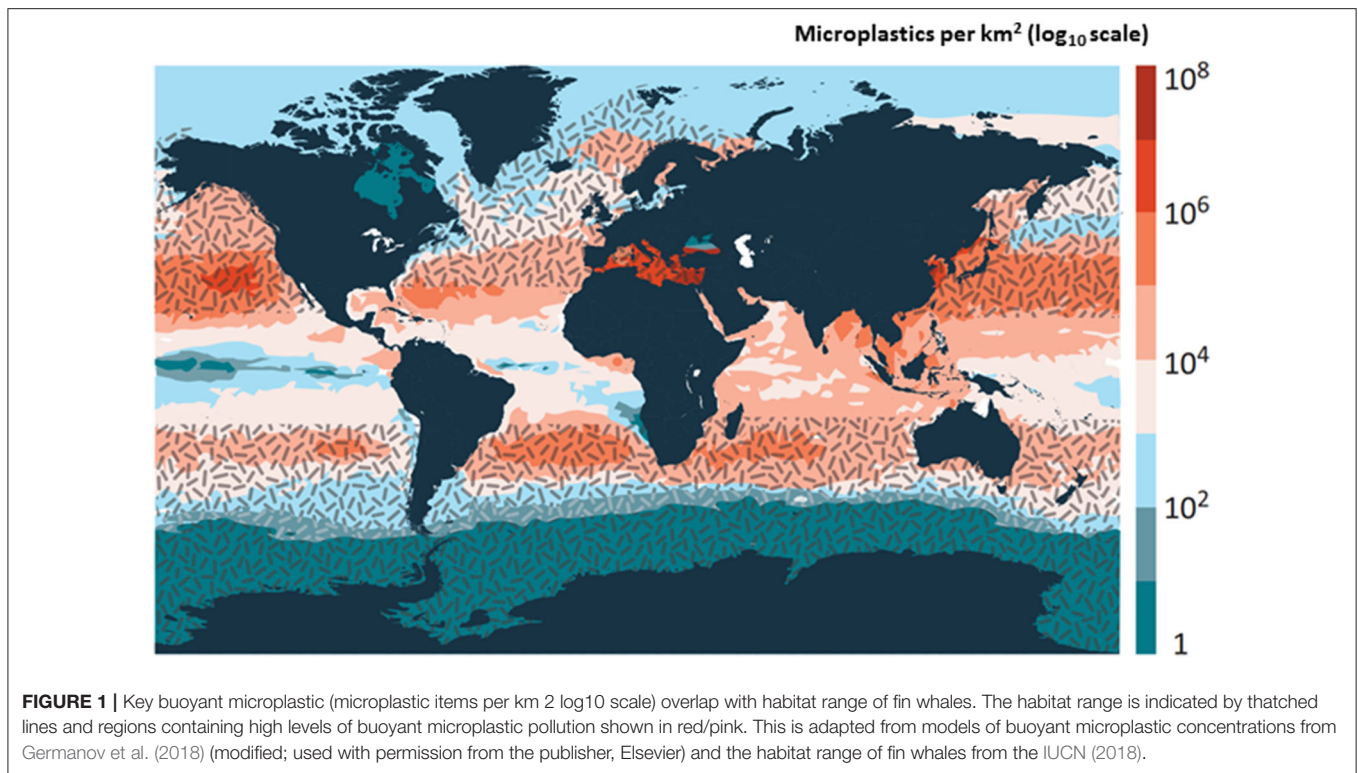
EMERGING METHODOLOGICAL APPROACHES TO DETECT THE IMPACT OF PLASTIC POLLUTION AND PLASTIC ADDITIVES IN CETACEANS

Investigating the impacts of plastic pollution on cetaceans presents several significant challenges, including access to materials (which need to be in an appropriate condition to be examined), having adequate knowledge about the biology and distributions of the species concerned and also the multiple potential physical and ecotoxicological effects of marine debris interactions. The challenge of finding carcasses in a good state of preservation and the difficulties inherent in conducting strict ecotoxicological investigations in the field are leading to the development of novel integrated approaches such as the new threefold approach. This approach can add to the data on both the rate of ingestion in cetaceans and the multiple sublethal stresses that marine debris ingestion can cause in the short and long terms. Each of the three levels of investigation tools that make up the threefold approach can be applied independently or simultaneously and whether the animals concerned are stranded or free ranging (Fossi et al., 2018a).

The threefold approach consists of:

- a) **GI content analysis:** the rate of occurrence of ingested litter (with a focus on plastics and micro-debris) and associated lesions determined from stranded or bycaught cetaceans;
- b) **Plastic additives analysis:** in theory, tissue concentrations of plastic additives and associated Persistent Bioaccumulative and Toxic (PBT) compounds could be used as a proxy for ingestion via the examination of samples, from stranded or bycaught animals, or biopsies, from live ones. This approach requires considerable ground-truthing, including because such compounds can be ingested from other sources, although promising progress has been made.
- c) **Ecological end-point analysis:** which would apply biomarkers (for example, gene expression biomarkers, CYP1A and CYP2B expression, or endocrine disrupters end-points) to look at the toxicological effects of additives or PBT in stranded or bycaught animals (within a few hours of death) or wild ones (again via biopsies) (Fossi et al., 2016).

The further development of the threefold approach will allow a fuller consideration of the sublethal effects of ingestion. This approach and its development is further discussed in Fossi et al. (2018a) and it can be applied to the indicator species that we describe below.



FIN WHALES: A OCEAN HEALTH INDICATOR OF MICRO-LITTER IMPACT AT GLOBAL SCALE

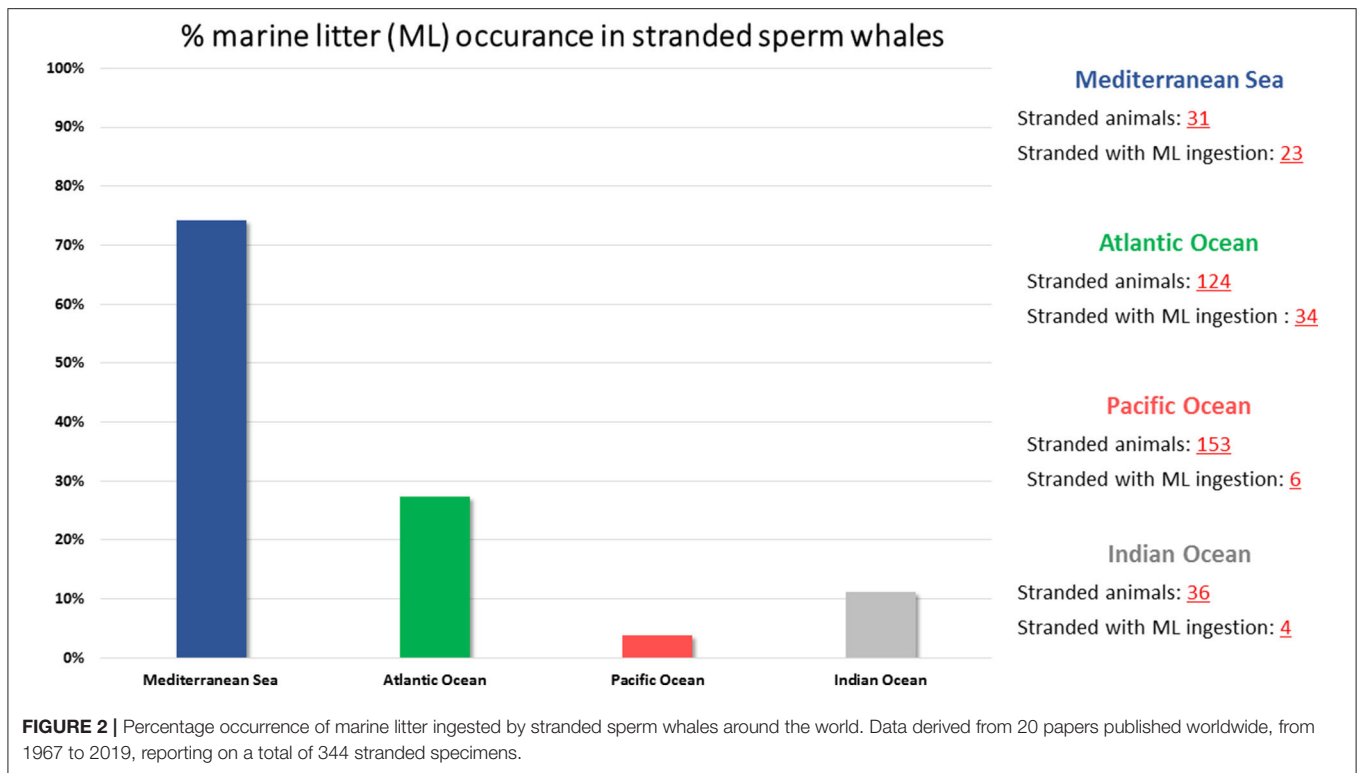
In this, and the following section, we explore how two large and wide-ranging species might be used as indicators of marine debris at a global scale and the available information that underpins this. We think that the development of their use in this way will assist global assessment of the impacts of marine debris, although we also accept that further research is needed to help underpin this idea.

The fin whale (*Balaenoptera physalus*) occurs across all oceans and is the second biggest whale species, weighing from 40 to 80 tons and reaching up to 85 feet in length (NOAA Fin whale, 2020). Fin whales, like all large whales, were hunted commercially and especially during the mid-1900's, when hundreds of thousands were killed. The species remains “endangered” according to the United States Endangered Species Act (ESA) and the US Marine Mammal Protection Act (MMPA) has it as “depleted.” The IUCN re-classified it as “vulnerable” in 2018, having listed it previously as “endangered” in 2008 (Cooke, 2018), and there are thought to be in the region of 100,000 mature individuals alive. Fin whales typically feed in the warmer months of the year on small schooling fish (such as sand lance, herring, and capelin), squid and krill. They engulf prey, filtering their prey out from the water using the 260–480 baleen plates which hang down from their upper jaws. They may mainly fast in the winter when some make migrations to warmer waters. Currently,

only a few studies on marine litter impact on fin whales have been published. Two papers report ingestion in individuals from North Atlantic water (Lusher et al., 2018) and from the sea off East Asia (Im et al., 2020).

More comprehensive studies on the accumulation of micro-litter by this species have so far been focused on two populations in the Mediterranean and the Sea of Cortez and, hence, our evidence of micro-debris accumulation comes from these regions. The emergent threat of micro-litter for large filter-feeding marine animals was recognized by Fossi et al. (2012, 2014, 2017) for baleen whales and later for whale sharks (*Rhincodon typus*) and basking sharks (*Cetorhinus maximus*) (Fossi et al., 2012, 2014, 2017). Fossi et al. (2014) found organochlorines and a phthalate metabolite were higher in a stranded Mediterranean fin whale than in a basking shark, suggesting that fin whales are more heavily impacted by micro-litter and therefore a stronger candidate as an indicator species than other filter feeders. These marine animals are susceptible to high levels of microplastics ingestion and potential exposure to associated toxic compounds due to their feeding strategies and the overlap between their habitats and microplastic hot spots. For example, the SPAMI Pelagos Sanctuary in the Mediterranean Sea is a site where high concentrations of microplastics and cetaceans co-occur and specific end-point responses have been found in skin biopsies taken there [this is further discussed in Fossi et al. (2016), Baini et al. (2017), Fossi et al. (2017, 2018b)].

Filter-feeding cetaceans in areas, such as the Pelagos Sanctuary, need to sieve thousands of liters of water each day to obtain



their food and will, unfortunately, simultaneously ingest plastics and other debris. The high plastic/plankton ratio in the Mediterranean Sea means that a fin whale there will ingest some 3,000 pieces of microplastic each day (Fossi et al., 2014). The region of the Mediterranean known as the Ligurian Sea, where fin whales feed, has very high microplastic contamination which is comparable to that recorded in the North Pacific Gyre (Fossi et al., 2017).

A comparison of micro-debris contamination between the Sea of Cortez and the Mediterranean, which are both semi-enclosed basins, showed higher plastics pollution in zooplankton in the latter, with associated higher biomarker responses and plastic additives and PBT contamination (Fossi et al., 2016). The potential threat to fin whale health and its potential as an indicator species for this form of contamination around the world (Figure 1) have been highlighted in previous work (Fossi and Panti, 2017; Fossi et al., 2018b) and were supported by the recent IWC workshop (IWC., 2020). Further research into microplastic contamination in this species around the world should take into account feeding grounds and possible differences in feeding between ages and sexes.

SPERM WHALES: A OCEAN HEALTH INDICATOR OF MACRO-LITTER IMPACT IN THE DEEP SEA AT A GLOBAL SCALE

The sperm whale (*Physeter macrocephalus*) is another large whale and is amongst the most cosmopolitan of cetaceans with populations in all deep oceans (NOAA Sperm Whale, 2020). Mature females weigh some 15 tons, and are around

40 feet in length, and males weigh around 45 tons, reaching 52 feet in length. Sperm whales can live for up to sixty years. Heavily hunted for their oil in preceding centuries, the species is categorized as “endangered” by the ESA and “depleted” by the MMPA. The IUCN categorizes it as vulnerable, noting that its population trend is unknown (IUCN., 2019). Sperm whale dives can take them to depths of more than 1,200 m (Amano and Yoshioka, 2003) and they prey on deep sea fish, including sharks and skates, and also squid. The feeding mechanism of sperm whales is not fully understood. Their relatively small lower jaw and large peg-like teeth that fit into sockets on the upper jaw reflect the fact that they can grasp items, including prey, but suction is also very probably involved (Fais et al., 2016), which may explain their seemingly high levels of ingestion of marine debris. In other words, they cannot avoid such ingestion where plastics are in the water column alongside prey. Part of their hunting range will include marine canyons, which have been widely recognized globally as among the areas of maximum marine litter accumulation (Angiolillo et al., 2015; Fischer et al., 2015; Peng et al., 2020), and there is also evidence that plastics are accumulating in deep sea trenches (e.g., the Mariana trench, Marceau Trench, and New Britain Trench). This suggests that hadal trenches may be the ultimate sink for a significant proportion of the plastics entering the ocean (Peng et al., 2020).

Mediterranean sperm whales appear to be especially badly affected (e.g., Roberts, 2003; Mazzariol et al., 2011; IUCN., 2012; de Stephanis et al., 2013; Alexiadou et al., 2019) in comparison to other oceanic areas (e.g., Martin and Clarke, 1986; Evans and Hindell, 2004; Jacobsen et al., 2010; Unger et al., 2016), as shown in Figure 2, and this is likely to be because of the relatively

high level of marine litter contamination in this sea area. A quantitative assessment of debris on the Mediterranean seabed found fishing gear was the dominant type of debris present (89%) (Angiolillo et al., 2015) and this may therefore be a particular problem in this region for this species, although more research is needed. While other deep diving cetacean species, including for example Cuvier's beaked whales, *Ziphius cavirostris*, also seem to be highly susceptible to the ingestion of marine litter (e.g., Baulch and Perry, 2014; Fossi et al., 2018a; IWC., 2020), we propose that the long-lived sperm whales are the better indicator because they are more cosmopolitan, their bodies are probably more likely to be retrieved and their biology is better known. Hence, the Sperm Whale is proposed here as ocean health indicator of marine litter impact in deep seas at a global scale.

DISCUSSION AND CONCLUSION

Recently, the idea of cetaceans as indicators of oceans health has attracted the attention of the scientific community (as evidenced by the recent IWC workshop), other stakeholders and the media. Here we have emphasized the potential of some cetaceans to provide important information about marine litter impact at a global scale. Whale sharks and baleen whales are prone to microplastics ingestion and potentially exposed to associated toxic compounds due to their feeding strategies and habitat overlap with microplastic hot spots, as seen in the Mediterranean Sea. As noted by the IWC workshop, skim feeders, like right and bowhead whales (Balaenidae), might also be monitored for their potential susceptibility (IWC., 2020), but species with a wider distribution appear better candidates as global indicators. Humpback whales have also been promoted as possible candidates for this type of monitoring but are generally faithful to discrete feeding grounds, whereas fin whales are more wide-ranging in their foraging, except for some unique, segregated populations (for example in the Mediterranean and the Gulf of California). The gray whale (*Eschrichtius robustus*), which feeds almost exclusively on the seabed, could be a good candidate for monitoring microplastic impact from the benthos at appropriate depths (IWC., 2020).

As outlined, development of the threefold approach, which is based on the detection of new plastic tracers in tissues and the identification (through omics techniques) of the potential ecotoxicological effects caused by plastic debris ingestion in indicator species, is a promising new diagnostic methodology. More research is needed, including investigations into the potential ecotoxicological effects caused by the ingestion of plastics and consideration will also need to be given to the effects of potential differences in the feeding behavior of different cetacean age classes and sexes. We would also like to emphasize the importance of more coordinated effort on debris ingestion and entanglement in cetaceans, to aid

a better understanding of the issues that this presents both in terms of macro- and micro-debris. In this context, we reemphasise here the recommendations from the IWC workshop concerning standardised approaches to necropsies and recording and measuring plastics and other debris (IWC., 2020). This will allow better comparisons to be made between investigations around the world and this relates equally to whether the debris is ingested or is associated through entanglement.

In conclusion, we are increasingly concerned about the health, welfare and conservation implications of the growing amounts of marine debris entering the oceans for cetaceans and other species, and we recommend the development of appropriate programmes of research to further consider sperm whales as a global indicator of macro-litter at depth and fin whales as a global indicator of micro-debris.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MF participated in the sampling, conceived the study, and coordinated the writing of the manuscript. MB contributed to the analysis of the data. MS supported the writing of the manuscript and language revision of the ms. All authors contributed to the writing process, reviewed critically the drafts of the manuscript, and gave final approval for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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