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Fin whales and microplastics: The Mediterranean Sea and the Sea of Cortez scenarios

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A B S T R A C T

The impact that microplastics have on baleen whales is a question that remains largely unexplored. This study examined the interaction between free-ranging fin whales (*Balaenoptera physalus*) and microplastics by comparing populations living in two semi-enclosed basins, the Mediterranean Sea and the Sea of Cortez (Gulf of California, Mexico). The results indicate that a considerable abundance of microplastics and plastic additives exists in the neustonic samples from Pelagos Sanctuary of the Mediterranean Sea, and that pelagic areas containing high densities of microplastics overlap with whale feeding grounds, suggesting that whales are exposed to microplastics during foraging; this was confirmed by the observation of a temporal increase in toxicological stress in whales. Given the abundance of microplastics in the Mediterranean environment, along with the high concentrations of Persistent Bioaccumulative and Toxic (PBT) chemicals, plastic additives and biomarker responses detected in the biopsies of Mediterranean whales as compared to those in whales inhabiting the Sea of Cortez, we believe that exposure to microplastics because of direct ingestion and consumption of contaminated prey poses a major threat to the health of fin whales in the Mediterranean Sea.

1. Introduction

Litter enters the sea from land-based sources, maritime activities and sea-based infrastructure, among other sources, and can travel long distances (Eriksen et al., 2014). At the global scale, the highest percentage (~80%) of marine litter consists of plastic (Thompson et al., 2009). As larger pieces of plastic debris fragment into smaller pieces, the abundance of microplastics (plastic fragments smaller than 5 mm; Thompson et al., 2004) in marine habitats increases, outweighing larger debris. Plastic debris accumulates in semi-enclosed basins, such as the Mediterranean Sea, to a greater degree than in the open oceans. The Mediterranean Sea has been considered for centuries as “the cradle of civilization” and a medium for cohesion among different cultures. Over the past century, however, it has also become a dumping ground for the anthropogenic waste generated by the 22 countries (and 450 million people) bordering its shores. As a result of one of the highest levels of per-capita solid-waste production annually (208–760 kg/year), the Mediterranean Sea has become highly polluted with litter (Eriksen et al., 2014; Cózar et al., 2015). It has been estimated that 62 million items of macro-litter are floating on

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the surface of the Mediterranean Basin at any given time (Suaria and Aliani, 2014). The mean densities of floating microplastics in the Mediterranean Sea (more than 100,000 items/km^2) demonstrate the importance of this threat to the health of the basin (Collignon et al., 2012). Despite the ratification of the Marine Litter Action Plan by the Barcelona Convention in the 2013 Conference of the Parties, production trends, improper waste management, and the lack of mitigation actions and governance on the basin scale may lead to greater hazards for both marine wildlife and seafood safety (Seltenrich, 2015). Conversely, little data have been reported on the average density of microplastics in Mexico's Sea of Cortez (Gulf of California), a semi-enclosed body of water that is considered to be one of the more pristine areas in the world's oceans.

Research on the impact of microplastics on the biota of semi-enclosed marine ecosystems (Deudero and Alomar, 2015) and their potential toxicological effects on the large filter-feeding species that inhabit these environments, such as baleen whales, is still in its infancy (Fossi et al., 2012); to date, this research has been performed solely on a single stranded organism from Atlantic Ocean (Besseling et al., 2015). Cózar et al. (2014) estimated the global load of plastic at the ocean surface to be on the order of tens of thousands of tons, a level far lower than expected; these data were later confirmed by an assessment of plastic pollution in the world's oceans (Eriksen et al., 2014). The difference between the estimates and what was expected may be due to a combination of nano-fragmentation of microplastics along with their transfer to the ocean biomass through food webs. Intriguingly, the missing proportion of microplastics has about the same size interval as that of zooplankton (Cózar et al., 2014; Collignon et al., 2014). Zooplanktivorous predators, such as mesopelagic fish and large filter-feeding species (including baleen whales and some sharks), represent an important trophic component in the oceans and seas and they are at risk of exposure to microplastics in the water column. It is known that accidental ingestion of plastic occurs directly during feeding activities and indirectly via the consumption of zooplankton that previously ingested microplastics (Desforges et al., 2015; Farrell and Nelson, 2013; Setälä et al., 2014; Besseling et al., 2015; Romeo et al., 2015). Zooplankton and zooplanktivores may play a major role in capturing plastic at the millimeter scale (Cózar et al., 2014; Cole et al., 2013). Moreover, marine organisms may bioaccumulate toxic chemicals through the consumption of contaminated prey, large plastic debris and even microplastics. The major toxicological impact related to microplastic ingestion by filter-feeding organisms is the role that microplastics may play in persistent, bioaccumulative, and toxic (PBT) chemicals and in the leaching of plastic additives. Because PBT chemicals have low solubility in seawater, they tend to concentrate in the sea-surface microlayer, where they can be absorbed by microdebris, and thus may bioaccumulate in organisms that can ingest microplastic particles (Engler, 2012). However, modelling studies indicate that microplastics may act as a cleansing mechanism for PBT chemicals with log KOW between 5.5 and 6.5 (Gouin et al., 2011).

The more direct toxicological effects of microplastics are related to the leaching of plastic additives, such as bisphenol A, brominated flame retardants and phthalates, that enhance the performance of the plastic (Teuten et al., 2009). Phthalates, in particular, are a class of chemicals commonly used to soften rigid plastics. Di-(2-ethylhexyl) phthalate (DEHP), the most abundant phthalate in the environment, is rapidly metabolized in organisms to its primary metabolite MEHP (mono-(2-ethylhexyl) phthalate) (Barron et al., 1989). MEHP can be used as a marker of exposure to DEHP. Most of the chemicals that are absorbed by (PBTs) or added to (phthalates) plastics can negatively affect marine organisms through such means as endocrine disruption and subsequent population viability (Teuten et al., 2007). As such, organochlorines and phthalates are used in this paper as indirect (absorbed contaminants) and plastic-related (constituent contaminants) tracers of the microplastics in the baleen whale food chain.

This paper focus on the fin whale (*Balaenoptera physalus*), the second-largest filter feeder inhabiting two semi-enclosed marine basins, the Mediterranean Sea and Mexico's Sea of Cortez (or Gulf of California). Despite its global distribution, fin whales are listed as “Endangered” worldwide (including in the Sea of Cortez) and “Vulnerable” in the Mediterranean Sea on the IUCN Red List of Threatened Species. Fin whales forage on dense aggregations of krill in the water column during the daytime and near the surface during both the day and night in some areas in the Mediterranean (Croll et al., 2005), engulfing an average of 71 m^3 of water per mouthful (Goldbogen et al., 2007). As a result, fin whales are exposed to a high potential risk of microplastic ingestion in their feeding grounds, both at the sea surface and throughout the water column.

Fin whales, the only resident mysticete in the Mediterranean, aggregate during the summer months on the feeding grounds of the Pelagos Sanctuary for Mediterranean Marine Mammals (hereafter referred to as “Pelagos Sanctuary”; Notarbartolo di Sciara et al., 2003) and presumably migrate to the southern Mediterranean Sea during winter (Panigada et al., 2011). The Pelagos Sanctuary, which is located in the northwestern Mediterranean Sea and encompasses 87,500 km^2 (Fig. 1a), is one of the Special Protected Areas of Mediterranean Interest (SPAMI) under the Barcelona Convention. This area is characterized by high offshore primary productivity, which attracts a variety of predators, including eight cetacean species and many large marine vertebrates (Notarbartolo di Sciara et al., 1993; Coll et al., 2012). This remarkable biodiversity coexists with extremely high human pressure (e.g. coastal tourism, recreational/commercial fishing, maritime traffic) and, consequently, is subject to a considerable amount of pollution (Fossi et al., 2013), including large amounts of plastic debris and microplastics (Collignon et al., 2012; Cózar et al., 2015).

Mexico's Sea of Cortez (Fig. 1b) presents a different scenario. It covers approximately 260,000 km^2, is extraordinarily productive (Carvajal et al., 2010), and features a high endemic biodiversity (857 endemic species, including the endangered vaquita, *Phocoena sinus*). However, the impact of pollution in the Sea of Cortez stemming from human coastal activities amplifies the conservation priorities in this coastal ecosystem, where marine debris and microplastic impact have not yet been investigated. Fin whales are resident in the Sea of Cortez and are genetically isolated from other populations (Bérubé et al., 1998).

In order to shed light on the under explained impact of microplastics on baleen whales, we followed up on previous studies on the use of phthalates as tracers of microplastic ingestion in stranded fin whales (Fossi et al., 2012) and the first evidence of direct ingestion of microplastics in a stranded humpback whale (Besseling et al., 2015) by investigating the potential toxicological effects of microplastics and their related contaminants on free-ranging fin whale populations in two separate basins with different levels and forms of human pressure and abundance of plastic debris. The study consists of two experimental steps: 1) counting microplastics, and mapping and detecting phthalates via zooplankton/microplastic sampling in two areas of the Pelagos Sanctuary and in the Sea of Cortez (preliminary sampling); and 2) performing genetic analysis and detection of phthalates, PBT chemicals and biomarker responses via biopsies of skin samples collected from fin whales, collected at three different times (July, August and September) in the Pelagos Sanctuary and in the Sea of Cortez, to investigate the temporal and geographical differences in microplastic-related pollutants.