



Impacts of Marine Plastic Pollution From Continental Coasts to Subtropical Gyres—Fish, Seabirds, and Other Vertebrates in the SE Pacific

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Anthropogenic Marine Debris (AMD) in the SE Pacific has primarily local origins from land-based sources, including cities (coastal and inland), beach-goers, aquaculture, and fisheries. The low frequency of AMD colonized by oceanic biota (bryozoans, lepadid barnacles) suggests that most litter items from coastal waters of the Humboldt Current System (HCS) are pulled offshore into the South Pacific Subtropical Gyre (SPSG). The highest densities of floating micro- and macroplastics are reported from the SPSG. An extensive survey of photographic records, unpublished data, conference proceedings, and published studies revealed interactions with plastics for 97 species in the SE Pacific, including 20 species of fish, 5 sea turtles, 53 seabirds, and 19 marine mammals. Sea turtles are most affected by interactions with plastics, underlined by the fact that 4 of the 5 species suffer both from entanglement and ingestion. Reports gathered in this review suggest that interactions along the continental coast are mostly via entanglement. High frequencies of microplastic ingestion have been reported from planktivorous fish and seabirds inhabiting the oceanic waters and islands exposed to high densities of microplastics concentrated by oceanic currents in the SPSG. Our review also suggests that some species from the highly productive HCS face the risk of negative interactions with AMD, because food and plastic litter are concentrated in coastal front systems. In order to improve the conservation of marine vertebrates, especially of sea turtles, urgent measures of plastic reduction are needed.

Keywords: anthropogenic marine debris, impacts, biota-litter interactions, entanglement, microplastic ingestion

INTRODUCTION

Marine plastic pollution is generating impacts on marine biota and ecosystems at many different levels (Ryan, 2016). Impacts are reported from a wide range of organisms, including microbiota, invertebrates, and vertebrates (Galloway et al., 2017; Law, 2017). An increasing number of reports document microplastic ingestion by marine invertebrates (Lusher, 2015); certain species also grow on large, floating plastic items, and can be transported to new habitats they had not previously inhabited (Kiessling et al., 2015). Interactions with vertebrates are best known, because vertebrates are larger and therefore more visible and recognizable than small marine invertebrates. Entanglement of seabirds and marine mammals in large plastic litter (nets, ropes, etc.) has been known since the early 1970s (Derraik, 2002). Similarly, ingestion of microplastics by fishes and seabirds is well known since about the same time period (Kenyon and Kridler, 1969; Carpenter et al., 1972; Ryan, 1987), and the number of affected species, such as seabirds (Wilcox et al., 2015), is continuously increasing.

The risk of interactions between marine organisms and plastics is not equal across the oceans. It depends on feeding biology and amount of plastic litter in the environment where the organisms are foraging. For example, seabird species feeding at the sea surface are more susceptible to plastic ingestion than diving species (Ryan, 1987). Species that ingest small microplastics, such as many fishes and surface-foraging seabirds might be at highest risk in areas where microplastics concentrate, such as the subtropical gyres, whereas species ingesting larger plastic items could potentially encounter these closer to the continental coasts where rivers and other human activities spill and accumulate large quantities of plastic litter (Rech et al., 2014, 2015; Di-Méglio and Campana, 2017; Fossi et al., 2017). Indeed, many reports of meso- and macroplastics ingestion include sea turtles and whales stranded on continental shores (Schuyler et al., 2014; Lusher et al., 2018). Similarly, the risk of entanglement for marine vertebrates is likely to be higher in areas with large amounts of derelict fishing gear, such as the North Pacific subtropical convergence zone (Pichel et al., 2007) or coastal areas where ghost nets accumulate (Wilcox et al., 2013).

These considerations suggest that the risk of harmful interactions with marine plastic pollution depends on (a) the biology of the species, and (b) the distribution and abundance of the different plastic types. To examine these predictions, herein we gather reports of interactions with plastic litter for marine vertebrates in the SE Pacific. We compare reports from the highly productive Humboldt Current System (HCS) with those from the oligotrophic open ocean, in particular the Easter Island ecoregion close to the South Pacific Subtropical Gyre (SPSG) accumulation zone (for methodological details see Supplement 1).

PLASTIC LITTER IN THE SOUTH-EAST PACIFIC

Litter Sources and Pathways in the South-East Pacific

In the South Pacific Ocean, anthropogenic marine debris (AMD) originates from the surrounding landmasses and oceanic sources (Thiel et al., 2003, 2013; Kiessling et al., 2017). Especially in

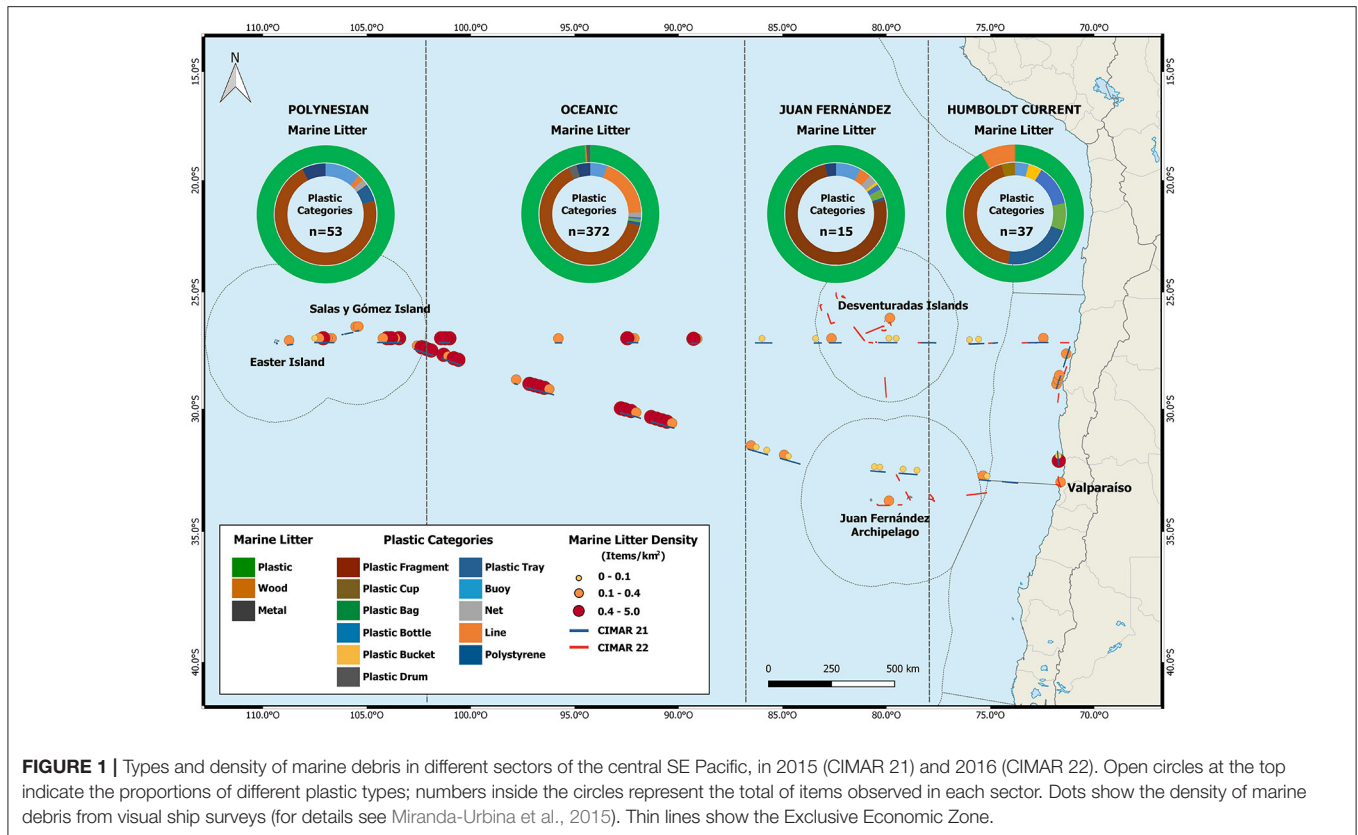
the eastern part of the S Pacific, litter pollution comes from land sources (e.g., Hidalgo-Ruz et al., 2018), beach-goers (Bravo et al., 2009), and marine activities including aquaculture (Astudillo et al., 2009; Hinojosa and Thiel, 2009), coastal (Perez-Venegas et al., 2017) and high seas fisheries (Kiessling et al., 2017). Rivers also contribute large amounts of macro- and microplastics (Rech et al., 2014, 2015).

The majority of the litter from land sources is probably trapped in coastal waters or on shores very close to its sources (Hinojosa and Thiel, 2009; Thiel et al., 2011; Rech et al., 2014). The low incidence of marine organisms growing on marine litter stranding on the continental coasts of the SE Pacific suggests that this fouling-free litter has likely passed very little time (if at all) at sea. On the other hand, strong offshore currents within the HCS are thought to move floating plastics quickly to the open ocean, where they become trapped in the SPSG (Martinez et al., 2009).

Floating Macro- and Microplastics in the SE Pacific

Given the multiple sources and transport dynamics of floating AMD in the SE Pacific, the density of macroplastics is high in immediate coastal waters, but rapidly decreases further away from the continental coast (Thiel et al., 2003; Miranda-Urbina et al., 2015). When approaching the center of the SPSG, densities of floating AMD reach very high abundances, as also reflected in recent data taken in two surveys conducted in 2015 and 2016 (Figure 1). A total of 477 items of floating AMD were observed across both surveys, the majority corresponding to 2015 when a major area including the Easter Island ecoregion was surveyed (Figure 1). Of the total floating AMD, 77% were macroplastics, most of which were large plastic fragments (95.4%). Other items included lines (17.7%), buoys (7.6%), plastic trays (4.9%), and plastic bags and nets (2.5 and 2.2%, respectively) (Figure 1). Accounting for the total number of AMD in both years, it seems that the distribution of floating AMD is comparable to patterns previously determined for the SE Pacific (see Miranda-Urbina et al., 2015). Out of the total (477 items), 8% were found in the HCS, only 3% occurred around Juan Fernandez and Desventuradas Islands, while 78 and 11% of all floating AMD were concentrated in the Oceanic and Polynesian sector, respectively. Large numbers of marine litter accumulate on beaches of Rapa Nui (Easter Island) and the uninhabited island Salas and Gómez in the Polynesian sector (Kiessling et al., 2017). Furthermore, marine litter on Salas and Gómez imposes a severe risk of entanglement for several seabird species breeding on the island (Miranda-Urbina et al., 2015).

The distribution of floating microplastics in the SE Pacific shows the typical distribution documented for other ocean basins (Eriksen et al., 2014; Law, 2017), with highest concentrations in the subtropical gyre (Eriksen et al., 2013, 2018). Microplastic densities in the HCS generally remain far below the densities reported from the gyre (Figure 2; NO, unpublished data). This distribution pattern is also well reflected in concentrations of small plastics from sandy beaches in the SE Pacific, where beaches along the HCS feature moderate densities, while sandy beaches on Rapa Nui have very high densities (Hidalgo-Ruz and Thiel, 2013). This pattern, with the abundances of microplastics increasing with distance from the continental coast (Figure 2),



is also suggestive of progressive fragmentation of large plastics during their journey toward the SPSG.

Interactions of Marine Vertebrates From the SE Pacific With Plastic Litter

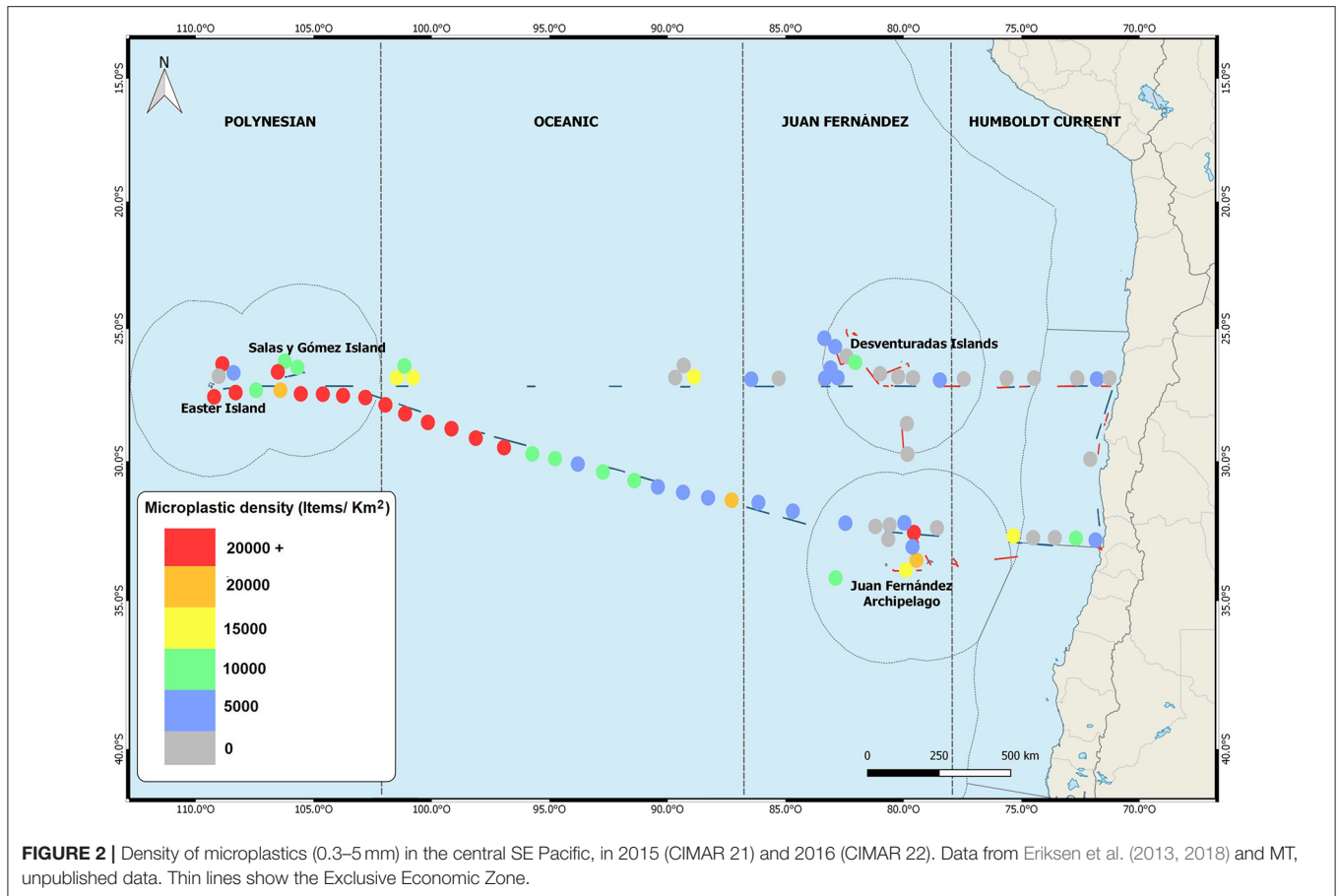
A large number of marine vertebrate species from the SE Pacific were documented to have interacted with marine litter, including fishes, seabirds, sea turtles, and marine mammals (Thiel et al., 2011; Miranda-Urbina et al., 2015; Ory et al., 2017). In revising and compiling information from diverse sources we found that marine litter affects at least 97 different species (see **Table 1** and text below for details). These reports comprise those of entanglement (including incorporation of plastics in seabird nests) and the ingestion of plastics.

Fishes

The few studies documenting the interaction of microplastics with fishes in the SE Pacific revealed a high incidence of microplastics in planktivorous fish from the coast of Rapa Nui, located within the SPSG: 80% of the examined individuals of the amberstripe scad *Decapterus muroadsi* (Ory et al., 2017) and 14% of the flying fish *Cheilopogon rapanouiensis* (Chagnon et al., unpublished data) had ingested microplastics, many of which were similar in size and color to blue-pigmented planktonic organisms (copepods, crustacean larvae), which are common prey of these fish (**Figure 3B**). These findings suggest that visually-oriented planktivorous fish mostly ingest microplastics

resembling their prey. The study of the digestive tracts of 7 planktivorous fish species from the HCS revealed that, overall, few of the fish analyzed (~2%) had ingested microplastics (Ory et al., 2018). Microplastics were also found more often (23% of all individuals analyzed) in herbivorous fish from Rapa Nui than in bottom-dwelling carnivorous and herbivorous fish species from the HCS (**Table 1**; NO, unpublished data). Such contrasting ingestion of microplastics well reflects the observed gradient of low microplastic densities in surface waters along the SE Pacific continental coast and high densities within the SPSG (Eriksen et al., 2013, 2014, 2018), and in particular along the Rapa Nui coast (Ory et al., 2017; Eriksen et al., 2018).

Apex predators play an important role in the exchange of energy between upper trophic levels in the marine environment (Markaida and Sosa-Nishizaki, 2010). However, little is known about the interaction of these species with AMD (Choy and Drazen, 2013). Plastics have been documented in the stomachs of tuna from Rapa Nui (**Table 1**), but little is known about plastic ingestion by other piscivorous fish from the open ocean. Publications on the diet of piscivorous fishes from the continental coast have not reported plastics (Fariña and Ojeda, 1993; Fariña et al., 2000), which indeed have not been found in the stomach contents of the investigated fish species (Jose Miguel Fariña, personal comment). Similarly, plastic ingestion by oceanic sharks seems to be very rare, estimated to occur in <1% of all analyzed stomachs (Sebastian Klarian, personal comment). Plastics found in sharks were PVC fragments in deep-sea species, and (positively



buoyant) bottle and pen caps in coastal species (S. Klarian, personal comment; **Figure 3D**).

Reports on entangled fish are scarce, but there are three notable exceptions. In December 2016, an entangled Pacific chub *Kyphosus sandwicensis* was observed in a derelict fishing net found floating in the SPSG (28°23'S, 105°42'W) (**Table 1**). There were several living chubs swimming around the mass of net and ropes, and it is likely that the individual was trapped and died while this raft floated in the gyre. On the coast of Rapa Nui a surgeon fish *Acanthurus leucopareius* was entangled in a fishing line (NL, personal observation). The other case of an entangled fish is of a juvenile Galapagos shark *Carcharhinus galapagensis* that was documented in the waters around Rapa Nui. In June 2017 one specimen (about 160 cm in total length) of *C. galapagensis* was recorded swimming in shore waters with a plastic collar-like debris obstructing its gill region (**Figure 4A**). The animal appeared otherwise healthy, presenting an active feeding behavior. It showed initial tissue damage, which indicates that the collar recently became attached to the animal; similar records have shown that the internal projections of plastic collars have the potential to severely damage the tissue by affecting normal feeding and ventilation (Sazima et al., 2002), followed by body deformations as the animal grows (Wegner and Cartamil, 2012). The plastic ring attached to the animal was identified as the screwing part of a plastic barrel; this type of plastic debris is

most likely coming from the industrial fishery that operates in the S Pacific and is an important source of recognizable plastic litter stranding on the shores of Rapa Nui (Kiessling et al., 2017).

Continental coastal species of Chondrichthyes are also known to interact with marine litter. Oviparous species like cat sharks (Scyliorhinidae) and skates from the genus *Sympterygia* lay egg capsules with long tendrils (Oddone and Vooren, 2002, 2008; Hernández et al., 2005; Flammang et al., 2007; Concha et al., 2013). These long tendrils are used to entangle the egg capsule to different substrata in order to maintain the vertical positioning and facilitate oxygen flow (Flammang et al., 2007). Along the central coast of Chile, dense multispecies coils of capsules are commonly found firmly attached to algae and/or plastic debris floating close to the coast or stranded on the shores after storms (MT and NM, personal observations).

Sea Turtles

Sea turtles are exposed to a variety of anthropogenic stressors, including marine plastic pollution, because of their use of diverse habitats, migratory behavior, and complex life histories (Nelms et al., 2016). Indeed, litter ingestion and entanglement in plastic debris have been recognized as serious threats to these species worldwide (Nelms et al., 2016; Clukey et al., 2017; Duncan et al., 2017). Five sea turtle species inhabit the SE Pacific (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*,

TABLE 1 | Reports on entanglement with macroplastics or plastic ingestion by marine vertebrates from open ocean (OO) and continental coastal (CC) (<5 nm from the land) waters of the southeast Pacific, based on literature, or anecdotal reports.

Species	Diet	Environment	Effect		Source
			Ent	Ing	
FISHES					
<i>Acanthurus leucopareus</i>	H	OO	+		Video by Nicolas Luna
<i>Apodactylus punctatus</i>	H	CC		+	Nicolas Ory, unpubl. data
<i>Auchenionchus microcirrhis</i>	C	CC		+	Mizraji et al., 2017
<i>Brama australis</i>	P	CC		+	Nicolas Ory, unpubl. data
<i>Carcharhinus galapagensis</i>	C	OO	+		Video by Naiti Morales
<i>Cetengraulis mysticetus</i>	P	CC		+	Ory et al., 2018
<i>Cheilodactylus variegatus</i>	C	CC		0	Nicolas Ory, unpubl. data
<i>Cheilopogon rapanouiensis</i>	P	OO		+	Chagnon et al., unpubl. data
<i>Decapterus muroadsi</i>	P	OO		+++	Ory et al., 2017
<i>Engraulis ringens</i>	P	CC		+	Ory et al., 2018
<i>Girella laevis</i>	O	CC		+	Mizraji et al., 2017
<i>Graus nigra</i>	C	CC		+	Mizraji et al., 2017
<i>Helcogrammoides chilensis</i>	C	CC		+	Mizraji et al., 2017
<i>Kyphosus sandwicensis</i>	H	OO	+		Photo by Tim Kiessling
<i>Kyphosus sandwicensis</i>	H	OO		++	José Abalos, unpubl. data
<i>Odontesthes regia</i>	P	CC		+	Ory et al., 2018
<i>Opisthonema libertate</i>	P	CC		+	Ory et al., 2018
<i>Pinguipes chilensis</i>	C	CC		0	Nicolas Ory, unpubl. data
<i>Prionace glauca</i>	C	OO		+	Photo by Carlos Canales-Cerro
<i>Sardinops sagax</i>	P	CC		0	Ory et al., 2018
<i>Scarthichthys viridis</i>	H	CC		+	Mizraji et al., 2017
<i>Scomber japonicas</i>	P	CC		+	Ory et al., 2018
<i>Sebastes capensis</i>	C	CC		+	Nicolas Ory, unpubl. data
<i>Strangomera bentincki</i>	P	CC		0	Ory et al., 2018
<i>Thunnus albacares</i>	C	OO		+	Chagnon et al., unpubl. data
SEA TURTLES					
<i>Caretta caretta</i>	O	OO	+	0	Duncan et al., 2017; Photo by Camila González

(Continued)

TABLE 1 | Continued

Species	Diet	Environment	Effect		Source
			Ent	Ing	
<i>Chelonia mydas</i>	O	CC	+	++	Brito, 2001; IMARPE, 2011; Alemán, 2014; Duncan et al., 2017; Jiménez et al., 2017; Photo by Guerra-Correa et al., 2007
<i>Dermochelys coriacea</i>	O	OO	+	+	Brito, 2001; IMARPE, 2011; Duncan et al., 2017
<i>Eretmochelys imbricata</i>	O	CC	+	+	Brain et al., 2015; Duncan et al., 2017; Photo by Anita Espinoza
<i>Lepidochelys olivacea</i>	O	CC-OO	+	++	Brito, 2001; IMARPE, 2011; Alemán, 2014; Duncan et al., 2017; Photos by Miguel Angel Mansilla, Rubén Alemán
SEABIRDS					
<i>Ardenna griseus</i>	Pis	CC-OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Ardenna pacifica</i>	Pis	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Ardenna creatopus</i>	Pis	CC-OO		+	Cañoles et al., 2017; Photo by OIKONOS Chile
<i>Cinclodes nigrofumosus</i>	I	CC		+	Photo by Carolina Henríquez
<i>Daption capense</i>	Pis	OO		+	Ainley et al., 1990
<i>Fregata minor</i>	Pis	OO		n+	Miranda-Urbina et al., 2015; Luna Jorquera, unpubl. data
<i>Fregatta grallaria</i>	P	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Gygis alba</i>	Pis	OO		+	Spear et al., 1995
<i>Haematopus ater</i>	I	CC		+	Photo by Matías Portflitt-Toro
<i>Haematopus palliatus</i>	I	CC		+	Photo by Pedro Valencia
<i>Larosterna inca</i>	Pis	CC		+	Photo by Fernanda Barilari
<i>Larus belcheri</i>	Pis	CC		+	Photo by Ana García
<i>Larus dominicanus</i>	Pis	CC		+	Ludynia et al., 2005
<i>Larus dominicanus</i>	Pis	CC		n+	Thiel et al., 2011; Arce et al., 2014; Photo by Matías Portflitt-Toro, Pedro Valencia, Katherine Muñoz, Angélica Contador, Shannon Montecinos, Jorge Rivera Torres

(Continued)

TABLE 1 | Continued

Species	Diet	Environment	Effect		Source
			Ent	Ing	
<i>Leucophaeus modestus</i>	Pis/I	CC	+		Photo by Matías Portflitt-Toro, Andrés Puiggros
<i>Leucophaeus scoresbii</i>	C/Pis/I	CC	+		Photo by Cristian Larrere
<i>Macronectes</i> sp.	C/Pis/I	OO	+		Photo by Paulo Davalos—Revista Trile
<i>Nesofregatta fuliginosa</i>	P	OO		+	Miranda-Urbina et al., 2015; Luna Jorquera, unpubl. data
<i>Nesofregatta fuliginosa</i>	P	OO	n		Luna Jorquera, unpubl. data
<i>Oceanodroma leucorhoa</i>	P	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Oceanodroma markhami</i>	P	OO		+	Ainley et al., 1990; García-Godos et al., 2002
<i>Oceanodroma tethys</i>	P	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Onychoprion fuscatus</i>	P	OO		+	Spear et al., 1995
<i>Pachyptila belcheri</i>	P	OO		+	Ainley et al., 1990
<i>Pachyptila vittata</i>	P	OO		+	Matías Portflitt-Toro, unpubl. data
<i>Pelagodroma marina</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pelecanoides gamotii</i>	P	CC		+	Luna-Jorquera in: Thiel et al., 2011
<i>Pelecanoides urinatrix</i>	P	CC		+	Ryan, 1987
<i>Pelecanus thagus</i>	Pis	CC	n+		Thiel et al., 2011; Arce et al., 2014
<i>Phaethon rubricauda</i>	Pis	OO		+	Guillermo Luna-Jorquera, unpubl. data
<i>Phaethon rubricauda</i>	Pis	OO	n+		Miranda-Urbina et al., 2015
<i>Phalacrocorax atriceps</i>	Pis	CC		n	Photo by Jorge Navarro
<i>Phalacrocorax bougainvillii</i>	Pis	CC		+	Photo by Carlos Vallejos
<i>Phalacrocorax bougainvillii</i>	Pis	CC		+	Carlos Zavalaga, unpubl. data
<i>Phalacrocorax brasilianus</i>	Pis	CC		n+	Thiel et al., 2011; Arce et al., 2014; Photo by Víctor Ríos
<i>Phalacrocorax gaimardi</i>	Pis	CC		n	Fernández et al., 2011; Photo by Ivan Torres, Paola Araneda, Manuel Segovia
<i>Procellaria aequinoctialis</i>	I	OO		+	Ainley et al., 1990, Matías Portflitt-Toro, unpubl. data

(Continued)

TABLE 1 | Continued

Species	Diet	Environment	Effect		Source
			Ent	Ing	
<i>Procelsterna albivitta</i>	Pis	OO		+	Luna Jorquera, unpubl. data
<i>Procelsterna albivitta</i>	Pis	OO	n+		Luna Jorquera, unpubl. data
<i>Pseudobulweria rostrata</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma brevipes</i>	Pis/I	OO		+	Spear et al., 1995
<i>Pterodroma cervicalis</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma defilippiana</i>	Pis/I	OO		+	Ainley et al., 1990
<i>Pterodroma externa</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma leucoptera</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma longirostris</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma nigripennis</i>	I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma pycrofti</i>	I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Pterodroma ultima</i>	Pis/I	OO		+	Spear et al., 1995; Luna-Jorquera, unpubl. data
<i>Puffinus bulleri</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995
<i>Puffinus nativitatis</i>	Pis/I	OO		+	Ainley et al., 1990; Spear et al., 1995; Luna-Jorquera, unpubl. data
<i>Rynchops niger</i>	Pis	CC		+	Photo by Pedro Valencia
<i>Spheniscus humboldti</i>	Pis	CC		+	Photo by Matías Portflitt-Toro; Carlos Zavalaga unpubl. data
<i>Spheniscus humboldti</i>	Pis	CC	n		Arce et al., 2014
<i>Stercorarius longicaudus</i>	C/Pis/I	OO		+	Spear et al., 1995
<i>Sternula lorata</i>	Pis	CC		+	Thiel et al., 2011
<i>Sula variegata</i>	Pis	CC		+	Thiel et al., 2011; Photo by Issa Ramos
<i>Thalassarche chrysostoma</i>	Pis/I	OO		+	Cristian Suazo, unpubl. data
<i>Thalassarche chrysostoma</i>	Pis/I	OO	n		Cristian Suazo, unpubl. data
<i>Thalassarche melanophrys</i>	Pis/I	OO		+	Cristian Suazo, unpubl. data
<i>Thalassarche melanophrys</i>	Pis/I	OO	n		Photo by Cristian Suazo
MAMMALS					
<i>Arctocephalus philippi</i>	C	CC		+	Thiel et al., 2011, Photo by Lukas Mekis

(Continued)

TABLE 1 | Continued

Species	Diet	Environment	Effect		Source
			Ent	Ing	
<i>Balaeonoptera bonaerensis</i>	C	CC	+		Campbell et al., 2017, Photo by Aldo S. Pacheco
<i>Balaeonoptera edeni</i>	C	CC	+		Campbell et al., 2017
<i>Balaeonoptera musculus</i>	C	CC	+		Campbell et al., 2017
<i>Cephalorhynchus commersonii</i>	C	CC	+		Aguayo-Lobo, 1999
<i>Cephalorhynchus eutropia</i>	C	CC	+		Aguayo-Lobo, 1999
<i>Delphinus capensis</i>	C	CC	+		Mangel et al., 2013
<i>Eubalaena australis</i>	C	CC	+		Aguayo-Lobo, 1999
<i>Globicephala</i> spp.	C	CC	+		Mangel et al., 2013
<i>Grampus griseus</i>	C	CC-OO		+	Photo by Macararena Bravo Aguayo-Lobo, 1999
<i>Lagenorhynchus australis</i>	C	CC	+		Mangel et al., 2013
<i>Lagenorhynchus obscurus</i>	C	CC	+		Mangel et al., 2013
<i>Lissodelphis peronii</i>	C	CC	+		Aguayo-Lobo, 1999
<i>Lontra felina</i>	C	CC	+		Photo by Fernando Olivares, Juan Valqui
<i>Megaptera novaeangliae</i>	C	CC	+		Photo by Aldo S. Pacheco
<i>Otaria byronia</i>	C	CC	+		Photo by Claudio Godoy, Aldo Pacheco, Natalie Pozo, Mauricio Ulloa, ONG Vuelve al Océano
<i>Phocoena spinipinnis</i>	C	CC	+		Mangel et al., 2013
<i>Physeter macrocephalus</i>	C	CC	+		Campbell et al., 2017
<i>Tursiops truncatus</i>	C	CC	+		Mangel et al., 2013

Information based on photographic evidence is given together with the name of the author of the photograph or video; all photographers agreed that this information be included in this table and publication. Abundance categories: + present, ++ common, +++ very frequent. 0 means that the species was examined and no plastic items were found in its stomach; n = seabirds reported with plastics entangled in nests, n+ = individuals and nests with plastic entanglement; please, note that herein we consider incorporation of plastics in seabird nests also as a case of entanglement (see also Supplement 1). The Diet can be: C, Carnivorous; H, Herbivorous; I, Invertivorous; O, Omnivorous; P, Planktivorous; and Pis, Piscivorous.

Eretmochelys imbricata, and *Lepidochelys olivacea*); all are listed from vulnerable to critically endangered on the IUCN Red List (IUCN, 2018) and have documented interactions with marine litter.

The green turtle (*C. mydas*) is the species most commonly mentioned to have ingested plastic items, with a frequency ranging from 28% in the Ecuadorian part of the HCS (Alemán,

2014) to 56 and 91% in Peru (Alfaro-Shigueto et al., 2005; Jiménez et al., 2017). The olive ridley turtle (*L. olivacea*) also has a high incidence of plastic ingestion, reaching up to 43% in Ecuador (Alemán, 2014), but this species has a lower incidence in other parts of the HCS (8%), both in Peru and southern Chile (de Paz et al., 2005; Brito et al., 2007). Furthermore, specific cases of plastic ingestion have been reported for leatherback turtles (*D. coriacea*) from the HCS in southern Peru and central Chile (Bruto, 2001; IMARPE, 2011) and a hawksbill turtle (*E. imbricata*) in Rapa Nui (Brain et al., 2015).

Items most commonly found in stomachs or intestines of sea turtles are plastic pieces of intermediate size, including plastic bags, monofilament nylon, rope, and fishing nets (Bruto, 2001; Guerra-Correa et al., 2007; IMARPE, 2011; Jiménez et al., 2017; Figure 3C). Several authors suggested that plastic ingestion has been the cause of death of stranded turtles in Ecuador and Chile (Bruto et al., 2007; Silva et al., 2007; Alemán, 2014).

Even though many studies have focused on evaluating sea turtle bycatch rates (in active fishing gear) in the Pacific Ocean (Wallace et al., 2010), to date almost no reports exist on sea turtle entanglements (derelict fishing gear) in the region (Nelms et al., 2016). In fact, to our knowledge no peer-reviewed articles have informed incidents of entanglements from the SE Pacific. In Rapa Nui, a case of *C. caretta* with fishing line in both anterior flippers caused their amputation and subsequent death a few hours later (RAV, personal observation). In addition, several cases of entanglements of green and olive ridley turtles have been informed from Ecuador (Rubén Alemán, personal communication).

Seabirds

Many different seabird species have been reported to be entangled in marine debris or have ingested plastic (Table 1). Interestingly, for most fish-feeding species from the HCS, the incidence of individuals with microplastics in their stomachs is low, although these species face other threats to their conservation (Luna-Jorquera et al., 2012). We found 6 species in which plastic litter has been found in their stomachs, 3 of them (*Pelecanoides garnotii*, *P. urinatrix*, *Phalacrocorax bougainvillii*, and *Spheniscus humboldti*) being true diving species, and one a plunge diver (*Pelecanus thagus*). One species with relatively high frequency of plastic ingestion is the kelp gull *Larus dominicanus*, which is commonly observed feeding in fishing ports, at garbage containers, and on waste disposal facilities.

In addition to the low number of continental species with plastic in their stomach, it seems that the number of affected individuals per species is relatively low: 10 out of 450 examined individuals (2.2%) *S. humboldti*, 4 out of 103 (3.9%) *Pelecanoides garnotii*, and 12 out of 363 studied pellets (3.3%) of *Phalacrocorax bougainvillii* (CZ, unpublished data). The diet of the Humboldt penguin *S. humboldti* has also been examined in another study, but the authors did not mention any plastic items in the species' stomach contents (Herling et al., 2005). The tendency of low incidence of plastic ingestion in seabirds inhabiting the HCS is supported by several other studies. Jahncke et al. (1997) and García-Godos and Goya (2006) studied the diet of *P. bougainvillii*, *Sula variegata*, and *Pelecanoides garnotii*, and did

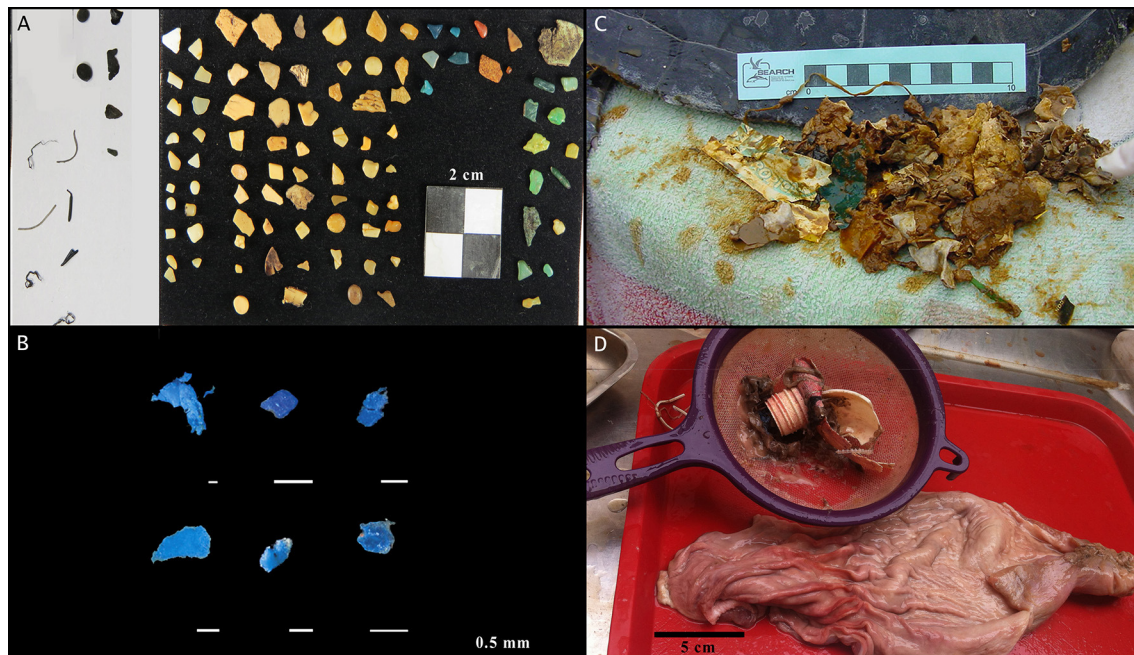


FIGURE 3 | Examples of ingestion of plastic litter by marine species. **(A)** Microplastics collected from the stomach of one Christmas shearwater *Puffinus nativitatis* found dead on Salas y Gómez Island; Image by Matías Portflitt Toro. **(B)** Blue microplastics found in the stomach of amberstripe scads *Decapterus muroadsi*, fished at Rapa Nui; Image by Nicolas Ory. **(C)** Meso- and macroplastics found obstructing the cloacal opening of a green turtle *Chelonia mydas* found near Antofagasta. After carefully taking out these items the turtle recovered and later was liberated by the Wildlife Rescue and Rehabilitation Centre (Centro de Rescate y Rehabilitación de Fauna Silvestre) from Universidad de Antofagasta, Chile; Photo by Guerra-Correa et al. (2007). **(D)** Meso- and macroplastics found in the stomach of a blue shark *Prionace glauca*; Image courtesy of Carlos Canales-Cerro.

not find any plastic artifacts in any of the examined individuals (I. García-Godos, personal communication).

In contrast to continental seabirds, oceanic species are severely affected (see **Table 1**). Of the 37 seabird species from the SE Pacific with reported ingestion of plastic, 31 are oceanic and the majority are Procellariiformes, which retain particles for several months before the particles are evacuated from the digestive system by regurgitation (Terepocki et al., 2017; **Figure 3A**). The high incidence of microplastic ingestion in the species listed in **Table 1** is very likely due to the high concentration of AMD observed in the Oceanic and Polynesian sectors of the SE Pacific (see **Figure 2**). Several harmful effects have been reported due to microplastic ingestion, ranging from stomach ulcers, intestinal obstruction, reduced body condition, and increased contaminant load (Derraik, 2002; Lavers et al., 2014).

Body injuries, severe negative effects on behavior, and even mortality, are typical consequences of seabird entanglement in floating or stranded marine litter. As opposed to the observed tendency of plastic ingestion, entanglement mostly affects continental species. Seventeen seabird species inhabiting the HCS are affected by entanglement, which most of the time occurs during foraging activities at sea, when seabirds are trapped in discarded fishing lines, derelict fishing nets (**Figure 4C**) (Thiel et al., 2011), and single-use plastic bags on beaches (see Supplements 2, 3). We have also observed that lines and rope fragments discarded by aquaculture activities affect coastal

species, such as gulls and cormorants (**Figure 4C**) (MPT and GLJ, own unpublished data). Entanglement in derelict fishing nets is also affecting diving waterbirds, including grebes (*Podilymbus podiceps*, Photo PP01 in Supplement 3 by P. Valencia, and *Podiceps occipitalis*, Portflitt-Toro et al., 2016). During the winter season, grebes are often observed foraging in nearshore waters in the bays of the Coastal System of Coquimbo, where fishermen use gillnets to capture pelagic fishes.

A handful of seabird species are affected by both entanglement and ingestion (*Larus dominicanus* and *Phalacrocorax bougainvilli*), but the negative effects of marine litter are also reaching the nests of several species. The incidence of anthropogenic marine litter for nest construction is not well known for the SE Pacific, but gulls from the Peruvian coast have been reported to use plastic in their nests (Stucchi and Figueroa, 2006). Our revision revealed that 12 species are using litter for nest construction, comprising both continental and oceanic seabirds; at least 10 of those 12 species are also exposed to organism entanglement and plastic ingestion at sea. Species like cormorants (*Phalacrocorax* spp.), frigatebirds (*Fregata minor*), and albatrosses (*Thalassarche* spp.) are actively selecting and transporting marine litter to their nests, while other species inhabiting the oceanic Salas and Gómez Island are affected by plastic litter accumulated by oceanic currents near their foraging grounds. Abundant incorporation of plastic litter in nests (see **Figure 4D**) calls for further research due to (i) the



FIGURE 4 | Examples of species entangled with marine plastic litter. **(A)** Galapagos shark *Carcharhinus galapagensis* from coastal waters of Rapa Nui (Easter Island) entangled with a closure ring for plastic drums; Image Naiti Morales. **(B)** Humpback whale *Megaptera novaeangliae* from the Peruvian coast entangled in large fishing net; Image Aldo Pacheco. **(C)** Inca tern *Larosterna inca* found entangled in remains of fishing net near Valparaíso; Image courtesy of Fernanda Barilari. **(D)** Red-legged cormorant *Phalacrocorax gaimardi* from Taltal in nest; Image courtesy of Ivan Torres.

risk of entanglement of adults and chicks, and (ii) the potential effects of anthropogenic litter on the thermal properties of the nest both during nesting and chick-rearing phases.

Marine Mammals

There is no published information regarding the ingestion of marine debris for marine mammals in the SE Pacific. Overall, few studies examined the stomach contents of marine mammals. In a study on the diet of the South American sea lion *Otaria flavescens*, George-Nascimento et al. (1985) did not report any plastic items in stomach contents. Feces from the South American sea otter *Lontra felina* contained a diverse range of prey remains from fishes, crustaceans, and molluscs, but no plastic items were listed (Medina-Vogel et al., 2004; Córdova et al., 2009). A study of four delphinid species captured along the central coast of Peru reported prey items in stomach contents based on fish otoliths and cephalopod beaks, but no marine debris was documented (García-Godos et al., 2007). In southern Chile, an examination of seven stranded false killer whale carcasses reported only empty stomachs (Haro et al., 2015). Similarly, a study on the diet of long-finned pilot whales from southern Chile (Mansilla et al., 2012) found no plastic particles or marine litter (Carlos Olavarría, personal communication). However, the case of a Risso's dolphin *Grampus griseus* with a plastic bag in its mouth (Photo by M. Bravo) in the Coastal System of Coquimbo, in northern-central Chile, shows that plastic ingestion by cetaceans should not be ruled out.

Reports on the entanglement of marine mammals along the SE Pacific are much more common than reports about plastic ingestion. Throughout the HCS, fisheries are very intense at both artisanal and industrial levels (Thiel et al., 2007; Alfaro-Shigueto et al., 2010), and many of the observed entanglements are likely to have occurred with active fishing gear. An important number of pinnipeds, large baleen whales, and Odontocetes in general (dolphins, porpoises, and toothed whales) have been reported entangled in fishing gear throughout neritic and oceanic waters off Peru and Chile (Table 1). Entanglements may occur when large gillnets are deployed at the bottom or drifting near the sea surface, depending on the fishery (Aguayo-Lobo, 1999; Alfaro-Shigueto et al., 2010). Marine mammals swim or dive through the mesh and become entangled. Small animals, such as sea otters and sea lions, may die shortly after entanglement, as these species may not have the necessary strength to escape from nets and being air-breathers will consequently drown. This is probably also the case for dolphins such as the dusky dolphin (*Lagenorhynchus obscurus*), bottlenose dolphin (*Tursiops truncatus*), long-beaked common dolphin (*Delphinus capensis*), and the Burmeister porpoise (*Phocoena spinipinnis*) in Peru. In addition to the aforementioned species, in Chile the southern right whale dolphin (*Lissodelphis peronii*), Commerson's dolphin (*Cephalorhynchus commersonii*), Chilean dolphin (*Cephalorhynchus eutropia*), and Peale's dolphin (*Lagenorhynchus australis*) also suffer mortality from entanglements (Table 1).

Large baleen whales get into nets but may keep moving, subsequently carrying large pieces of entangled nets on their body. Along the HCS of Peru, the humpback whale *Megaptera novaeangliae* is the most affected large whale species. Campbell et al. (2017) reported that 51% of stranded whales off Peru were humpback whales and all individuals showed evidence of entanglement (**Figure 4B**). Observations made during daily sightings of humpback whales throughout their breeding migration (mid July to late October, Guidino et al., 2014) in northern Peru ($\sim 4^{\circ}\text{S}$) suggest that in the HCS, humpback whales frequently get entangled with drifting gillnets (ASP, unpublished data). As the stranding data suggest (Campbell et al., 2017), the fate of entangled whales is often death, unless the net is quickly removed from the whale.

Along the HCS of Chile, artificial coastal structures such as breakwaters and harbors appear to accumulate more marine debris than the natural rocky intertidal shore (Aguilera et al., 2016). This accumulation could be a problem for the marine otter (*Lontra felina*), a small mustelid endemic along the Pacific coast of South America. This species uses natural rocks or artificial constructions as habitat. At the northern-most location of its distributional range in northern Peru, the marine otter has been observed resting in an artificial cave full of marine debris (see Figure 3 in Alfaro-Shigueto et al., 2011). While this case does not constitute a direct interaction with marine plastic litter, the risk for entanglement or ingestion is evident.

Overview of Plastic Ingestion and Entanglement by Marine Vertebrates From the SE Pacific

This first review of interactions with AMD of marine vertebrates from the SE Pacific reported a total of 97 species (**Table 1**). Seabirds represent nearly 55% of the total, followed by fishes with 21%, marine mammals with 19%, and sea turtles with 5%. Considering the number of species per taxonomic group, the type of interaction (ingestion or entanglement), and environment (continental or oceanic), an overall pattern is emerging. For fishes, more species with plastic ingestion were documented along the continental coast than in the open ocean, and few oceanic species become entangled near oceanic islands (Rapa Nui and Salas and Gómez Island). However, it needs to be taken

into account that the simple species list presented in **Table 1** only shows whether a species had ingested microplastics or not, which does not allow for inferences on the individual risk of ingestion. For example, in the case of the Peruvian anchoveta *Engraulis ringens* from the HCS, of 116 studied individuals only one (<1%) had one microplastic in its stomach (Ory et al., 2018), whereas of 20 amberstrip scads *Decapterus muroadsi* from Rapa Nui 16 individuals (80%) had ingested on average 2.5 microplastics per individual (Ory et al., 2017), underscoring that the risk of microplastic ingestion is much higher for oceanic planktivorous species than for species from the HCS. In contrast to the general pattern documented for fishes, the incidence of microplastic ingestion in seabirds is much higher for oceanic species than for those from the HCS, but the latter are suffering intense entanglement (**Table 2**). Marine mammals are scarce in oceanic waters, so marine mammals are principally affected by entanglement with AMD floating in the productive waters of the HCS (**Table 2**). Regarding sea turtles, none of the species from the SE Pacific are safe from interactions with AMD, ingestion or entanglement, and thus are equally threatened in coastal and oceanic waters. This overall pattern agrees well with the spatial distribution of micro- and macroplastics in the SE Pacific (see **Figures 1, 2**). Future systematic studies in the SE Pacific should provide more information about the actual number of species affected, which will also help authorities to improve efforts for efficient solutions.

Other Interactions

Similar to other oceans (Carson, 2013), in the SE Pacific litter is frequently bitten by large marine organisms, which are thought to be vertebrates (Eriksen et al., 2017), but might also originate from large invertebrates with powerful jaws, in particular squids and/or cuttlefish. On Rapa Nui, up to 10% of stranded AMD can have bitemarks (MT, unpublished data).

DISCUSSION

Ingestion of Plastics

The results from this review indicate that microplastic ingestion is uncommon along the Pacific coast of South America. Neither fishes nor seabirds from the continental coast had

TABLE 2 | Number of species of marine vertebrates for which ingestion and entanglement has been documented.

Group	Entanglement			Ingestion			Entang. and Ingest.			Total
	Continental	Oceanic	Continental and Oceanic	Continental	Oceanic	Continental and oceanic	Continental	Oceanic	Continental and oceanic	
Fishes	0	2	0	13	4	0	0	1	0	20 ^a
Sea turtles	0	1	0	0	0	0	2	1	1	5
Seabirds	14	2	0	3	24	2	3	5	0	53
Marine mammals	18	0	0	0	0	1	0	0	0	19

Total refers to the numbers of species that have been reported for plastic ingestion and entanglement (based on the data presented in **Table 1**).

^aThis value does not consider four fish species that were examined but in which no plastic was found in their stomachs (see **Table 1**).

high frequencies of microplastic ingestion, and information on the diet of marine mammals in the SE Pacific is very limited and thus does not allow inference on the risk of microplastic ingestion. An exception from this pattern seems to be the relatively high incidences of plastic ingestion in sea turtles in the HCS, but most of those plastics are of larger sizes and can be characterized as meso- and macroplastics. Also, intertidal habitats, such as beaches, tidepools, estuarine saltmarshes, and especially the seashores in the fjords of southern Chile require future research attention, because intense microplastic pollution may cause localized impacts in species from shore habitats (see e.g., Mizraji et al., 2017).

The low incidences of microplastic ingestion in most marine vertebrates from the HCS could be resulting from low concentrations of microplastics in coastal waters or due to specific foraging behaviors, or a combination of both. A data comparison from the SPSG and from other parts of the world can shed some light on these questions. For example, some planktivorous fish species from the SPSG had a very high frequency of microplastic ingestion (Ory et al., 2017), and other species had ingested microplastics more frequently than any of the planktivorous species from the HCS (Chagnon et al., unpublished data; Ory et al., 2018). For seabirds, the pattern was similar: microplastic ingestion was much more common in oceanic species than in species from the HCS (Tables 1, 2), regardless of feeding types (planktivorous, invertivorous, and piscivorous). This suggests that the observed pattern might not be due to differences in foraging and feeding behaviors, but rather to differences in microplastic abundances. Nevertheless, plastic ingestion was also documented in a number of species from the HCS, which might be consequence of their biology. For example, incidence of plastics in the digestive system of different seabird species is related to their foraging behavior (e.g., surface feeders, pursuit feeders, among others) and the digestive system morphology (i.e., muscular gizzard in petrels) (Ainley et al., 1990; Spear et al., 1995; Roman et al., 2016). This latter aspect causes indigestible items to become trapped in the bird's gut system (Ainley et al., 1990).

Other factors such as the geographic distribution may impact the amount of plastic ingested, as found by Spear et al. (1995), who reported that seabirds foraging predominantly in the North Pacific had higher incidence of ingestion than species from the South Pacific. However, the paper suggested that this pattern may be biased by the lack of studies from the SE Pacific. This is very similar for marine mammals, in particular dolphins and whales. Since the end of whaling in the region during the early 80's, the scientific examination of body parts (including stomachs) of large baleen and sperm whale carcasses have considerably ceased in the region. Scientific treatment of stranded animals is limited due to the difficult logistics needed to examine cases of cetacean strandings in remote areas (e.g., Haro et al., 2015; Häussermann et al., 2017). In this regard, there is an urgent need for the implementation of effective action plans for the scientific treatment of stranded whales and dolphins, if we aim to understand the impacts of the ingestion of marine litter in megafauna. This is particularly important since researchers are adopting non-invasive methods

(e.g., stable isotopes, DNA analysis) for both live (Haro et al., 2016) and stranded charismatic animals. At present, it is difficult to understand the magnitude of the plastic ingestion problem for marine mammals in the SE Pacific. However, plastic ingestion by diverse cetacean species has been reported in several coastal areas elsewhere (Baulch and Perry, 2014; Lusher et al., 2018), often with lethal consequences (see Jacobsen et al., 2010; de Stephanis et al., 2013; for cases on sperm whales). Microplastics of several polymer types have been documented for the first time in a humpback whale stranded on the coast of the Netherlands (Besseling et al., 2015). In the SE Pacific, the problem is likely being underestimated.

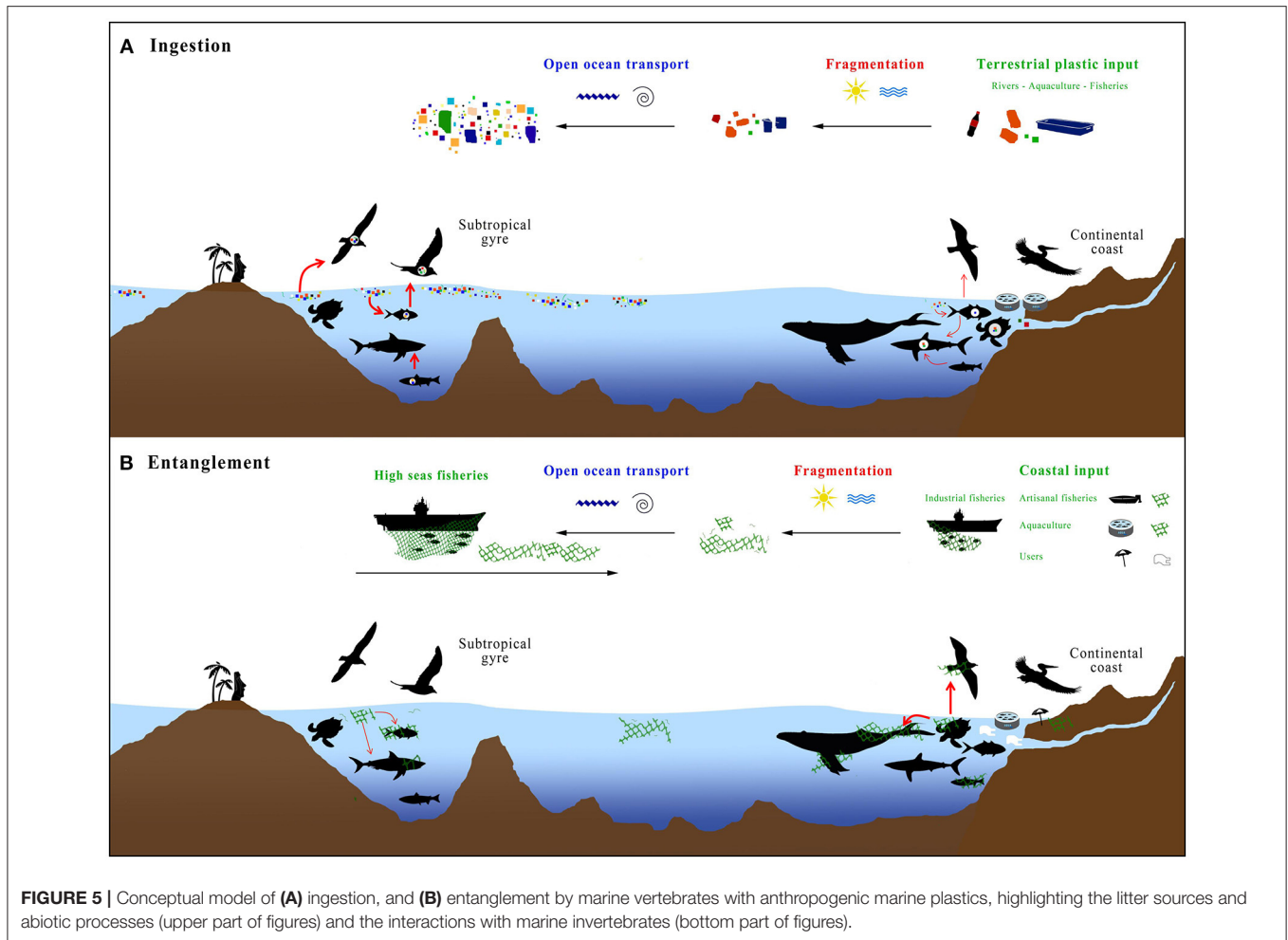
The relatively high frequency of bitemarks in plastics stranded on Rapa Nui shores indicates that some species directly bite into floating plastics. It is currently not well known which species engage in this behavior and why (Carson, 2013), but most of the bitemarks found on plastics from Rapa Nui resemble those of the green turtle *Chelonia mydas* (Eriksen et al., 2017), a species commonly reported to ingest larger plastic pieces (see above). The potential risk of plastic ingestion as a result of biting into floating plastic litter is reason for concern.

Entanglement

Entanglement reports of fishes are very rare, while they are common for seabirds, marine mammals, and sea turtles. The lack of reports from fishes might be due to the fact that mortality at sea would immediately cause sinking, whereas seabird, mammal, and sea turtle carcasses float at the sea surface; not surprisingly many reports of entanglement come from dead animals (see above).

From all the records of top fish predators interacting with plastic debris around the world, carcharhinid sharks seem to be most at risk of entanglement (Laist, 1997; Sazima et al., 2002; Ceccarelli, 2009), probably due the high abundance and species diversity in this group (Compagno, 1984). Cliff et al. (2002) reported an increase over time in entanglement of a carcharhinid species from South Africa, which furthermore underscores that species from this group are at highest risk of negative interactions with floating litter. Oceanic shark species are also likely to be impacted by plastic debris, but the limited number of studies on oceanic sharks underscores that more research is required to determine the full extent of this problem.

Seabird entanglement is common in the world's oceans (Kühn et al., 2015). Herein entanglement was reported mostly for species from the HCS, and observations included fisheries litter (nets, lines) and consumer plastics (mostly plastic bags). While interactions with fisheries items are likely to happen at sea (e.g., Moore et al., 2009), entanglement with consumer plastics may occur on the shore or at waste disposal facilities, as highlighted by the frequent observations of kelp gulls *L. dominicanus* with plastic bag entanglement (Table 1). Our data suggest that entanglement is more common in species from the continental coast than in oceanic species. The fact that Procellariiformes (which are mostly oceanic species) have the lowest frequencies of entanglement (Kühn et al., 2015) seems to support this pattern. However, herein we observed



plastic litter in the nests of several oceanic species (Table 1), which underscores the imminent risk of entanglement for these species.

Although sea turtle entanglement in AMD has been recognized as a cause of mortality globally, there are quantitative knowledge gaps on rates and population implications (Duncan et al., 2017). Recent studies report entanglements across all species, life stages, and ocean basins, with higher vulnerability in pelagic juveniles (Nelms et al., 2016; Duncan et al., 2017). However, reports of entanglement incidents in the scientific literature are scarce and it is likely that many individual cases are never published, and therefore these data may be highly underestimated (Nelms et al., 2016). Duncan et al. (2017) reported that derelict fishing gear contributed globally to the majority of entanglements, while debris from land-based sources contributed to a lesser extent. Entanglements are a greater threat to sea turtles than climate change and direct exploitation, but less of a threat than plastic ingestion and bycatch (active gear) (Duncan et al., 2017).

Incidences of entanglement were reported for many species of marine mammals from the SE Pacific (Table 1), mostly with items of fisheries origin. Similar to other areas of the

southern hemisphere (e.g., Page et al., 2004), sea lions seem to be most at risk of entanglement with derelict fishing gear as indicated by several independent observations recorded herein (Table 1). However, our review also reveals that many whale species from the HCS become entangled in (active?) fishing gear. Some efforts are being conducted to mitigate the entanglement problem. In Peru, the implementation of acoustic alarms (pingers) has proven to have dissuasive effects, thus reducing dolphin entanglements (Mangel et al., 2013). The use of modified long lines in the Patagonian toothfish (*Dissostichus eleginoides*) fishery in southern Chile reduces the interaction of killer and sperm whales with active fishing gear (Moreno et al., 2008). Yet, these efforts are only localized and eventually should be implemented at the whole scale of the respective fisheries.

Differential Risk of Marine Litter Interactions Across the Oceanic Gradient

Several studies highlight that risk of both ingestion and entanglement is highest where main foraging grounds overlap with accumulation areas of floating AMD (Wilcox et al., 2013; Fossi et al., 2017). Our study showed that some species foraging

in the highly productive HCS frequently interact with marine plastics, which at first glance might be surprising given that litter densities are substantially lower than in the open ocean. However, many of these species feed in areas where hydrographic features, e.g., frontal systems or meso-scale gyres, concentrate food and also floating plastics (Pichel et al., 2007). Interestingly, one of the first direct observations of this phenomenon comes from the HCS off the central coast of Chile, where Bourne and Clark (1984) observed planktivorous seabirds feeding in a coastal front that also had concentrated large amounts of floating plastics. The high incidences of entanglement and also plastic ingestion, especially by sea turtles and some seabird species from the HCS, likely occurred in these temporary hotspots. These interactions are common in the productive upwelling systems of the eastern boundary currents (for overview see Scales et al., 2014), and cause high risk for marine vertebrates despite the fact that densities of floating litter are lower than in the subtropical gyres.

In the open ocean, especially in the oligotrophic subtropical gyres, marine productivity is low, and often concentrated above seamounts or near oceanic islands. If these islands are located within the range of the litter accumulation zones of the subtropical gyres, some species are at high risk of negative interactions with floating plastics (Figure 5). Our review showed that planktivorous fish and seabirds living on the oceanic islands in the vicinity of the SPSG have high incidences of microplastic ingestion, possibly due to the extraordinarily high densities of floating microplastics in this region (Figure 5). The limited number of entanglement reports from this area is likely a combination of lower densities of marine vertebrates in the subtropical gyres (see also Titmus and Hyrenbach, 2011) and the limited number of observers, compared to the continental coasts.

CONCLUSIONS AND OUTLOOK

Herein interactions with marine plastic litter were documented for a total of 97 species of marine vertebrates. The risk of microplastic ingestion seems to be high in nearshore waters (including tidepools), decreases above the continental shelf of the eastern boundary currents, but again reaches very high probabilities in oceanic waters associated with the gyre accumulation zones, especially for fishes and seabirds (Figure 5). The current interaction records suggest that marine vertebrate species living in the productive waters of the HCS are at higher risk of facing entanglement than species from the open ocean, albeit several oceanic species have also been observed to be entangled in marine plastics, mostly from high seas fisheries (Figure 5).

Further systematic research on the ingestion and entanglement rates in marine vertebrates and their impacts on populations from the SE Pacific is required. Investigations to determine hotspots of marine plastic pollution will also enable prioritizing resources and to focus and steer conservation measures. Detailed stranding data and a centralized regional

database are recommendable for a better documentation of negative interactions of marine vertebrates with plastic litter. Education, community involvement, together with effective measures to reduce the amounts of plastic litter entering the ocean, are essential to reduce the impact on marine vertebrates, particularly the highly threatened sea turtles.

ETHICS STATEMENT

The paper is based mostly on previously published information and does not include any sampling and laboratory analysis of marine organisms. Therefore, no ethics approval was required.

AUTHOR CONTRIBUTIONS

MT and GL-J designed the review, coordinated the team, and led the writing. RÁ-V, CG, IH, NL, DM-U, NM, NO, ASP, MP-T, and CZ contributed the observations and helped with the writing. IH and MP-T coordinated the quest for entanglement observations from citizen scientists. CG, DM-U, and MP-T prepared the figures.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2018.00238/full#supplementary-material>

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