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Plásticos en peces marinos del Pacífico Oriental: una revisión

Plastics in Marine Fish from the Eastern Pacific: a Review

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RESUMEN

El objetivo del estudio es dar un panorama general acerca de los plásticos de diversos tamaños en elasmobranquios y teleósteos del Océano Pacíficio Oriental y discutir acerca del uso de los bioplásticos como alternativa potencial al uso de los plásticos derivados del petróleo. Se incluyeron estudios realizados en las costas del occidente de América (Áreas de pesca definidas por la FAO: Pacífico noreste-PNE, Pacífico oriental central-PEC, y Pacífico sureste-PSE). El número de elasmobranquios con plásticos en todo el Pacífico Oriental fue de 361 (165 en el PEC y 196 en el PSE); el tamaño de las partículas fluctuó de 0.008 mm a 25.5 cm. El número de teleósteos con contenido de plásticos en todo el Pacífico Oriental fue de 5,943 (2,946 en el PNE, 2,615 en el PEC y 382 en el PSE); el tamaño de las partículas varió desde 10 µm hasta 19.86 mm. Los bioplásticos pueden ser una opción benéfica con respecto a los petroplásticos debido a su menor huella de carbón, menor requerimiento energético durante su manufactura, no utilización de petróleo crudo, reducción de los desechos y tiempo de degradación menor.

Palabras clave: bioplásticos; efectos; Pacífico Oriental; elasmobranquios; teleósteos

ABSTRACT

This study aims to give a general view of the plastics of varying sizes in elasmobranchs and teleosts from the Eastern Pacific Ocean and discuss the use of bioplastics as a potential alternative to the use of plastics derived from petroleum. We included studies in fish from the western coasts of America (FAO fishing areas: Pacific northeast-PNE, Pacific Eastern Central-PEC, and Pacific southeast-PSE). The number of elasmobranch specimens with plastics in studies from the Eastern Pacific was 361 (165 in the PEC and 196 in the PSE) with particle sizes from 0.008 mm to 25.5 cm. The number of teleosts with plastic content in the Eastern Pacific was 5,943 (2,946 in the PNE, 2,615 in PEC, and 382 in the PSE) with sizes from 10 µm to 19.86 mm. Bioplastics may be a beneficial choice over petroplastics due to their lower carbon footprint, lower energy requirement for their manufacturing, no use of crude oil, reduction of litter, and faster degradation time.

Keywords: bioplastics; effects; America; Eastern Pacific; elasmobranchs; teleosts

INTRODUCTION

Plastics may reach the ocean directly or indirectly. Land sources contribute to approximately 80% of the plastic in marine litter (Andrady 2011); especially from littering and solid waste disposal (Derraik 2002). Plastics in untreated sewage and in not properly disposed litter can be directly discharged into the marine environment or transported by rivers (Hammer et al. 2021). Plastics from other land activities are also transported through rivers (Cole et al. 2011). In industrialized regions or densely populated areas, the main inputs of plastic litter are composed of packaging materials (Gregory 1991). Considering the long-lasting nature of plastics, it is important to bear in mind their accumulation in the marine environment. Information related to the cumulative production of plastics is scarce, especially on a regional and global scale. A global analysis of all mass-produced plastics ever manufactured was made using data on their production, use, and fate; it was estimated that 8300 million metric tons (Mt) of virgin plastics have been produced to date (Geyer et al. 2017). By 2015, around 6,300 Mt had been produced, 79% had been accumulated in landfills, 12% was incinerated and only nine % was recycled (Geyer et al. 2017). Though plastics are resistant to decomposition and stay for long periods in the marine environment (Peng et al. 2020), the breakdown of big pieces may result in meso-plastics [size of 5-40 mm] (Thompson et al. 2004), microplastics [size 1-5,000 μm] (Thompson 2015), and nanoplastics [size ≤ 1 μm] (Gigault et al. 2018). Microplastics that are manufactured for specific applications in the industry or household use are termed primary microplastics (Auta et al. 2017), larger plastics that eventually divide into smaller pieces are known as secondary microplastics since they eventually become microplastics (Norwegian Environment Agency 2015). With the trends of plastic production and waste management, it has been estimated that by 2,050 around 12,000 Mt of plastic waste will be located in landfills and the natural environment (Geyer et al. 2017). Microplastics in the marine environment have increased their concentrations in the last twenty years (Claessens et al. 2011); however, other authors have indicated minimum changes in microplastic contamination between the 1980s and the 1990s (Thompson et al. 2004). Consequently, studies concerning the occurrence, fate, and trends of plastic accumulation in the marine environment are needed. Such studies are challenging due to the enormous variability of plastic abundance in the ocean (Ryan et al. 2009). In this study, we aimed to give a general view of the presence of plastics of varying sizes in ichthyofauna from the Eastern Pacific Ocean and comment about bioplastics as a potential alternative to the use of plastics derived from petroleum.

2. Plastics in the ocean

Once that plastic debris are in the ocean, their fate is variable but surface currents lead them to different destinations. On a global scale, oceanographic modeling has helped to track plastic movement and accumulation (van Seville et al. 2015). Such movements have resulted in the accumulation of plastic patches; in fact, plastic debris that are floating have been accumulating in subtropical gyres (Lebreton 2022). Patches in the ocean include plastic and other type of garbage that accumulate in large areas (Filho et al. 2021). Such patches are formed as a consequence of ocean gyres. There are six gyres, the North Pacific Gyre, the South Pacific Gyre, the East Pacific Gyre, the North Atlantic Gyre, the South Atlantic Gyre, and the Indian Ocean Gyre (NOAA 2021). The Great Pacific Patch is located in the North Pacific Gyre and is the largest garbage patch in the world with an estimated area of 1.6 million km^2 (Lebreton et al. 2018). The major fishing areas in the world cover all oceanic regions, in this review, we include information on plastic occurrence in fish from FAO fishing areas (FAO 2015), we included studies in fish from the waters in contact with the western coasts of America (Fig. 1), from Alaska to Chile (FAO fishing areas: Pacific northeast, Pacific Eastern Central and Pacific southeast). Though some estimations of floating plastics in the ocean exist (Geyer et al. 2017; Jambeck et al., 2015), they account for approximately 1 % (Egger et al. 2020); i.e. the fate of the remaining amount of plastic is unknown. According to a model prediction, an elevated percentage (66 %) of plastics released from land since the decade 1950 has settled in different coastal areas in the world and eventually resurfaced (Lebreton et al. 2019). This issue has relevant implications for the accumulation of plastics of varying sizes in benthic and pelagic fish.

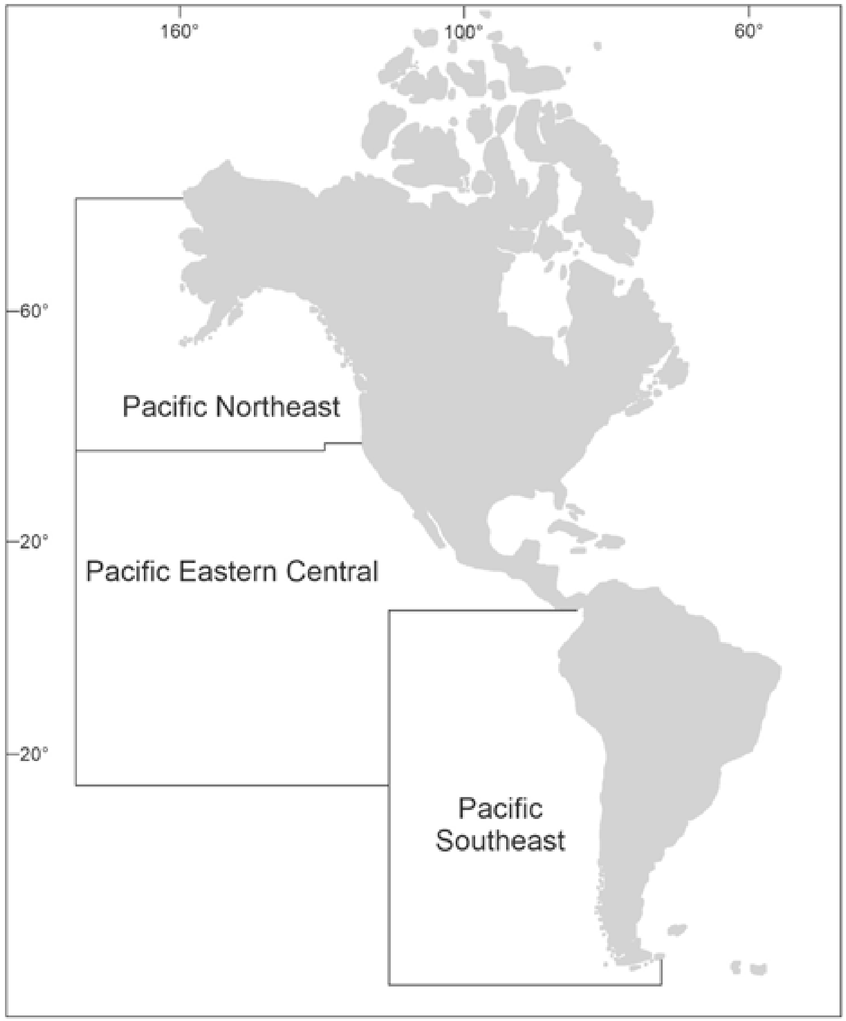

Fig. 1. Location of FAO Major Fishing Areas in the Eastern Pacific. Pacific Northeast (PNE), Pacific Eastern Central (PEC) and Pacific Southeast (PSE).

MATERIALS AND METHODS

Information related to the occurrence of plastics in teleost and elasmobranchs from the Eastern Pacific was obtained after searching published information through search tools (i.e. Google Scholar, and Scopus). Three regions were considered according to FAO Major Fishing Areas (Fig. 1): the Pacific Northeast (PNE), the Pacific Eastern Central (PEC), and the Pacific Southeast (PSE). For every published study, the following information was included: species and family of teleost/elasmobranch, the polymer type, the tissue analyzed, and the average number and size of plastic particles. To determine variations in the number of studies related to plastic content in teleost /elasmobranchs from the Eastern Pacific, studies were arranged according to the publication year. Plastic counts in teleost /elasmobranchs from the different FAO Fishing Areas were statistically compared. Differences in the mean concentration of plastics in the digestive tract of bony fish and elasmobranchs and different FAO zones were analyzed using a one-way ANOVA (Glantz 2012), with the plastic abundance as the dependent variable, and the FAO zone as the categorical factor. Homocedasticity of variances was checked with a Cochran´s C test (Underwood 1997), and a Tukey's HSD test (Glantz 2012) was used for pairwise mean comparison in case of significant results. Spatial ingested plastic variations between FAO zones and elasmobranch and teleosts were assessed through multivariate analyses (PERMANOVA and PCoA) according to the factors zone and type of fish (elasmobranch or teleost). A similarity matrix of plastic abundance between factors was constructed using the Bray-Curtis similarity. A permutational multivariate analysis of variance (PERMANOVA; Anderson 2017) was performed on the similarity matrix to test the H_0: the microplastic abundance between zones and species is not different, with a significance of $p < 0.05$. To reduce type I error, a Bonferroni test was applied by dividing α (0.05) by the number of comparisons. To visualize how the species and FAO areas clustered according to the plastic content, in case of statistical differences, a Principal Coordinate Analysis (PCoA; Clark et al. 2020) was performed. This analysis allowed us to determine which features best-explained cluster separation through a two-dimensional scatterplot. The importance of a given species on any FAO zone was indicated by the trajectory of the vector, so both axes have a scale from -n to n, with a centroid of value 0,0 where all the points should be if the null hypothesis was true.

4. Plastics in marine fish from the Eastern Pacific

The total number of elasmobranch families in the Eastern Pacific was four (Table 1 see the end of this text). Elasmobranch families Urotrygonidae and Alopiidae were represented by two species;

Carcharhinidae and Sphyrnidae had reports of only one species. Fibers were the most commonly found plastic type. The plastics were determined in the digestive system.

The number of elasmobranch specimens with plastic particles in studies from the Eastern Pacific was 361 (165 in the PEC and 196 in the PSE). In PEC, plastic particles were reported in two species; in PSE reports corresponded to five species. Average plastic particles per specimen were in the same magnitude order following the sequence PEC (5.17 particles) and PSE (2.34 particles). In these reports, particle size was highly variable, from 0.008 mm to 25.5 cm. As apex predators, sharks are susceptible to accumulating plastics with prey ingestion (Bernardini et al. 2018) but also through water during horizontal and vertical migrations. Reports of plastic occurrence in elasmobranchs from the Eastern Pacific are scarce though published studies show that these species are susceptible to environmental pollution (Pinho et al. 2022; Malthaner et al. 2024). The issue of plastic presence in the marine environment is a relevant topic because such particles contain additives that are eventually released and may produce deleterious effects; additionally, plastic particles may carry diverse pollutants such as polychlorinated biphenyls (PCBs), dioxins, and metals (Alfaro Núñez et al. 2021). Moreover, predator species may contain plastics from secondary ingestion; i.e. plastic particles that are inside prey, and this issue has been scarcely studied (Markic et al. 2018). The total number of teleost families was 50 (Table 1). Families with more species reporting plastic particles in the Eastern Pacific were Carangidae (eight species), Clupeidae (six species), Engraulidae and Scombridae (five species). Fibers were the most commonly reported type of plastic. All reported plastics were found in the digestive system. The total number of individuals with plastic content in the Eastern Pacific was 5,943 (2,946 in the PNE, 2,615 in PEC, and 382 in the PSE). In the studied FAO Major Fishing areas, the PEC had more species reporting plastic residues (78 species), followed by PSE (22 species) and PNE (six species). The average number of plastics per individual for the studied regions was PNE (4.13 particles), PEC (4.1 particles), and PSE (4.84 particles). The plastic size reported in published studies ranged from 10-19.86 mm.

According to ANOVA, no differences were found between the mean abundance of plastics between elasmobranchs and teleosts ($F_{(1,117)}$=0.29174, p<0.05) (Fig. 2), nor between the mean plastic abundance in different FAO zones for the case of the teleost fish ($F_{(2,116)}$=0.239426, p<0.05) (Fig. 3). PERMANOVA also indicated that differences do not exist in the microplastic abundance between species and FAO zones (Table 2). The PCO (Fig. 4) shows no clear-cut groups formed according to any of the apriori-defined factors.

Published studies on plastic occurrence in the digestive tract of teleosts and elasmobranchs from the Eastern Pacific are scarce. In elasmobranchs the reports are from 2018 to 2022; in teleosts, more studies have been published and ranged from 2010 to 2023 (Fig. 5a). Considering all fish species with published studies from the Eastern Pacific, plastic particles per individual were highly variable (Fig. 5b).

Fig. 2. Mean concentrations of plastic particles in the digestive tract of bony fish and elasmobranchs from the Eastern Pacific.

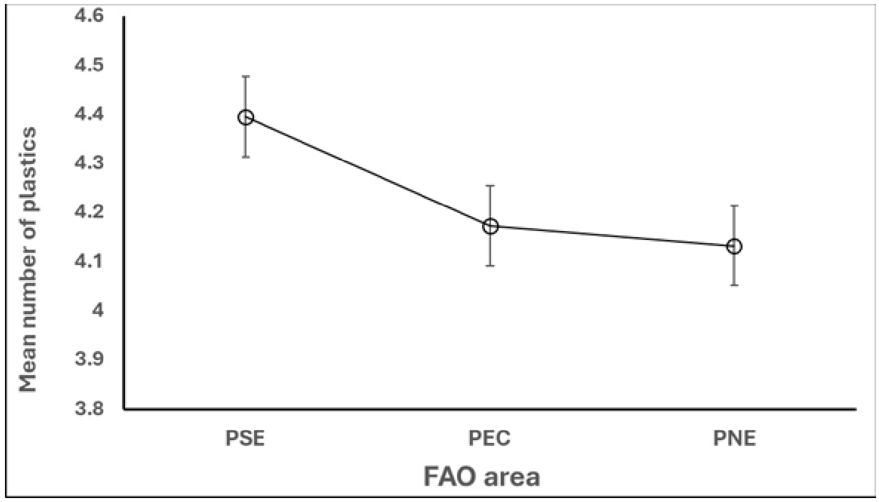

Fig. 3. Mean concentrations of plastic particles in the digestive tract of bony fish and elasmobranchs from the FAO zones in the Eastern Pacific (PNE, Pacific Northeast; PEC, Pacific Eastern Central; PSE, Pacific Southeast).

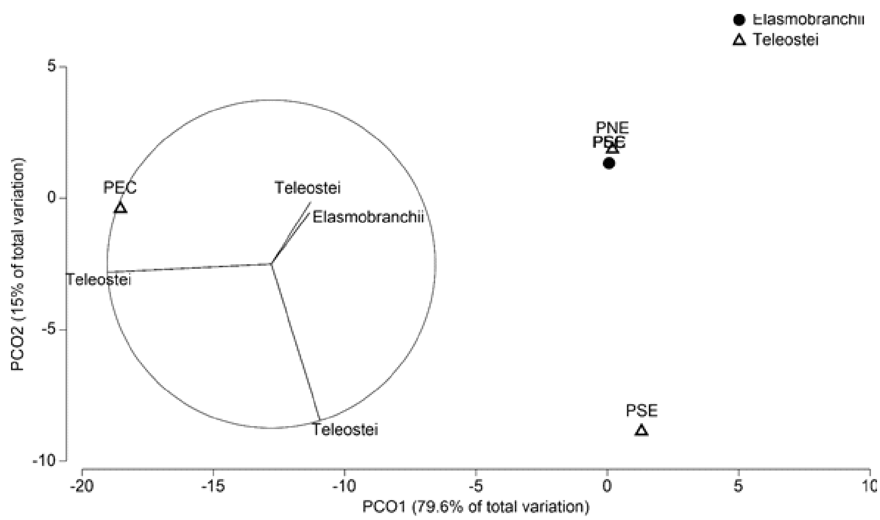

Fig. 4. Principal Coordinate Analysis (PCoA) of clusters of FAO zones and fish species according to plastic content.

Source	df	SS	MS	Pseudo-F	P-value
FAO	2	284.23	142.12	0.86905	0.598
Species	1	163.53	163.53	0.478	0.6582
Res	1	163.53	163.53		
Total	4	541.57			

Table 2. Results of permutational multivariate analysis of variance (PERMANOVA) to test the null hypothesis (H0) that the microplastic abundance between zones and species is not different (significance of $p < 0.05$).

Average plastic particles followed the sequence all elasmobranchs<all teleosts. In elasmobranchs, the statistical comparison of mean plastic particles per specimen from PEC and PSE (Fig. 6a) resulted in no significant differences (p>0.05). In teleosts, differences in mean plastic particles in specimens from PNE, PEC, and PSE (Fig. 6b) were not significant (p>0.05). After the massive manufacturing of plastics in the decade of 1940, their production has had a fast increase (Cole et al. 2011); accordingly, studies related to plastic particles in marine fish have increased over the last decade due to their environmental consequences. In the case of fish, diverse studies have highlighted the need to standardize the sampling and processing protocols (Savoca et al. 2021) to make more accurate intercomparisons. FAO Major Fishing Areas comprise 19 marine areas (in the Atlantic, Indian, Pacific, and Southern oceans with their adjacent seas) and seven major inland areas that cover inland waters of the continents; such areas and related information allow customers of fishing resources to know the origin of the products, especially in fish markets in Europe (Garibaldi 2012). In the Eastern Pacific, there are three FAO Major Fishing Areas (PNE, PEC, and PSE) with variable species diversity, oceanographic conditions, and sources of plastics. Another issue of concern about the presence of plastics in the marine environment is that some fish feed selectively and sometimes they prey on white spherules instead of prey (Carpenter et al. 1972).

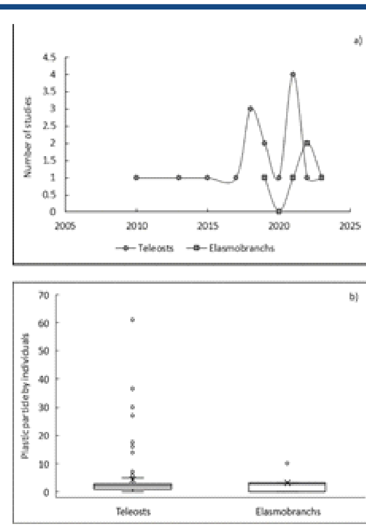

Fig. 5. (a) Studies related to plastic occurrence in teleosts and elasmobranchs from the Eastern Pacific from 2010 to 2023, and (b) average number of plastic particles in all teleosts and elasmobranchs from the Eastern Pacific.

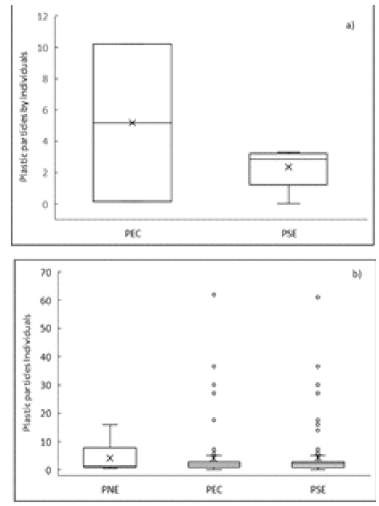

Fig. 6. (a) Comparison of the amount of plastic particles in elasmobranchs from the Pacific Eastern Central (PEC) and from the Pacific Southeast (PSE), and (b) among teleosts from the Pacific Northeast (PNE), the Pacific Eastern Central (PEC) and the Pacific Southeast (PSE).

5. Hot Spots in the Eastern Pacific

Though plastics of varying sizes, types, and chemical composition exist in the marine environment, some areas may be recognized as hotspots of marine debris of plastics that turn into problems of entanglement (Hoiberg et al. 2022) and ingestion (Eriksen et al. 2017) by marine biota. While more plastics are accumulating in certain areas associated with ocean gyres, other plastic particles start to sink and eventually reach the ocean floor that is not exactly below the surface patches. Plastics below the sea surface are driven by thermohaline currents (Kane et al. 2020) that eventually end in a deep-sea distribution that produces hotspots on the ocean floor. On the surface of the ocean, garbage patches are regions of the oceans where many types of garbage and debris accumulate; such patches are associated with ocean gyres (Leal Filho et al. 2021). Considering the FAO Major Fishing Areas in the Eastern Pacific, the biggest plastic patch in the world (the North Pacific Garbage Patch, NPGP) is located in the PEC zone. Now there is evidence that vertical transfer of plastics from the surface to the underlying deep sea is occurring and is mostly composed of polyethylene and polypropylene that fall from the surface waters (Egger et al. 2020). For the Eastern Pacific, it may be said that areas of concern are associated with the North

Pacific Patch and the South Pacific Patch (Filho et al. 2021). Risks to marine fauna from entanglement (Thiel et al. 2018) and ingestion (Boerger et al. 2010; Davison and Asch 2011; Savoca et al. 2021) of plastics in North and South Pacific gyres in the Eastern Pacific have been reported. In the case of entanglement, reports indicate that most interactions occur along the continental coast. There are some exceptions like the entanglement of the Pacific chub *Kyphosus sandwicensis*, the surgeon fish *Acanthurus leucopareius,* and the Galapagos shark *Carcharhinus galapagensis* in the oceanic waters of the southern Pacific (Thiel et al. 2018). Concerning ingestion, more studies have reported the occurrence of plastics in diverse regions of the Eastern Pacific; for example, in the North Pacific Central Gyre around one-third of planktivorous fishes had ingested plastic (Boerger et al. 2010). In another research on plastic ingestion by mesopelagic fishes from the North Pacific Subtropical Gyre, it was estimated ingestion that ranges from 12,000-24,000 t per year; the authors concluded that mesopelagic fishes from other subtropical gyres have similar rates (Davison and Asch 2011). In an extensive review of plastic ingestion by marine fish, it was found that predatory species are the most likely to ingest plastics; in the case of pelagic fishes, most of them consume plastics below the mixed seawater layer while most demersal fish species ingest plastic particle in shallow waters (Savoca et al. 2021).

6. Effects of plastics on fish and mitigation measures

There is a wide range of health issues in fish related to the presence of plastics in the aquatic environment. It has been mentioned that entanglements and ingestion of macroplastics generate severe problems for marine biota including fish. In the case of microplastics, they may damage tissues and cause oxidative stress, and changes in gene expression; as a consequence, fish may present growth retardation, neurotoxicity, and behavioral abnormalities (Bhuyan 2022). Considering the severity of deleterious effects of plastics on aquatic biota and humans, and since most plastic litter (around 80%) with land sources goes to the marine environment (Andrady 2011), mitigation strategies should start in the continent, but studies related to management measures are scarce

(Bond et al. 2014). It is worth mentioning that on a global scale, management practices have focused mainly on macroplastics (Ogunola et al. 2018) but management plans directed to mitigate the presence of microplastics in some regions are non-existent (Seltenrich 2015). The strategies to reduce plastic pollution may be voluntary or mandatory and they include preventive (eco-labeling, recycling, bans and imposed fees, regulatory agreements) and corrective measures (removing/cleaning-up strategy, behavioral change) (Ogunola et al. 2018).

7. Bioplastics: a potential alternative

Bioplastics are made from polymers derived from biological sources such as potato starch, sugar cane, and cellulose from trees and cotton (Shamsuddin et al. 2017) and gelatine (Prasteen et al. 2018); they include a family of materials with diverse properties and applications. From a sustainable perspective, bioplastics show several advantages over petroplastics; bioplastics have a lower carbon footprint, they require lower energy costs for manufacturing, they do not use crude oil, less generation of litter (Pilla 2011), and they undergo faster degradation since bioplastics require from three to six months for complete biodegradation while petroplastics need several centuries to disintegrate (Nanda et al. 2022). In diverse industries bioplastics have the potential to replace conventional plastics made from oil sources (Nanda et al. 2022); given their biocompatibility and biodegradability, they are strong candidates for packaging and biomedical applications (Prasanth et al. 2021).

8. Concluding remarks

For the whole Eastern Pacific, studies related to the plastic presence in elasmobranch (four families) and teleost families (50 families) are scarce. The fiber was the most common plastic type with bigger sizes in elasmobranchs (25.5 cm) than in bony fishes (19.85 mm). The sequence of average number of plastics was elasmobranchs < teleosts. The biggest plastic patch in the world is located in the PEC zone but there are other areas of concern in the South Pacific Patch. Entanglement of fish with plastics occurs mostly along the continental coast. In the case of plastic ingestion, more studies have reported the presence of plastics in planktivorous fish from the North Pacific Central Gyre and mesopelagic fish from the North Pacific Subtropical Gyre. Entanglement and ingestion of plastics by fish cause diverse problems; in the specific case of microplastics, some consequences are tissue damage, oxidative stress, changes in gene expression, growth retardation, neurotoxicity, and behavioral abnormalities. The choice of bioplastics is beneficial over petroplastics due to their lower carbon footprint, lower energy requirement for their manufacturing, no use of crude oil, reduction of litter, and faster degradation time. Compatibility and degradability of bioplastics make them candidates for biomedical and packaging applications.

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Table 1. Plastic residues in elasmobranchs and teleosts from diverse FAO fishing areas in the Eastern Pacific

Family	Species	Plastic type	Tissue/organ	N	FAO fishing area	Concentration range	Plastic size	Reference
Elasmobranchs								
Carcharhinidae	*Prionace glauca*	Fibers	Pylorus	23	PEC	0.15 ± 0.38	45.87–3220.22 µm	Huang et al (2022)
Urotrygonidae	*Urobatis halleri*	Fibers	Gastrointestinal tract	142	PEC	10.2 (±7.4)	0.00821 mm to 0.953 mm	Pinho et al (2022)
Alopiidae	*Alopias pelagicus*	NA	Digestive tract	15	PSE	3.31	>200 µm	Alfaro-Núñez et al (2021)
Alopiidae	*Alopias superciliosus*	NA	Digestive tract	15	PSE	3.08	>200 µm	Cáceres-Farias et al (2023)
Carcharhinidae	*Prionace glauca*	Plastic bag	Stomach content	136	PSE	0.02 ± 0.01	17.5 – 25.5 cm	Fernández-Ojeda and Anastasopoulou (2019)
Sphyrnidae	*Sphyrna lewini*	NA	Digestive tract	15	PSE	2.85	>200 µm	Cáceres-Farias et al (2023)
Urotrygonidae	*Urotrygon chilensis*	NA	Digestive tract	15	PSE	2.42	>200 µm	Alfaro-Núñez et al (2021)
Average of elasmobranchs from PEC						3.95±5.45 (10.2-0.15)		
Average of elasmobranchs from PSE						2.34±1.34 (3.31-0.02)		
Average of elasmobranchs						2.94±3.20		
Teleosts								
Alepisauridae	*Alepisaurus ferox*	Fibers	Gastrointestinal tract	1563	PNE	1	<500 µm	Savoca et al (2022)
Ammodytidae	*Ammodytes personatus*	Fibers	Stomach	734	PNE	1 - 9	<500 µm	Hipfner et al (2018)
Clupeidae	*Clupea pallasii*	Fibers	Stomach	205	PNE	5 - 27	<500 µm	Hipfner et al (2018)
Coryphaenidae	*Coryphaena hippurus*	Fibers	Gastrointestinal tract	50	PNE	1	<500 µm	Savoca et al (2022)
Engraulidae	*Engraulis spp.*[b]	Fibers	Gastrointestinal tract	354	PNE	0.6	<500 µm	Savoca et al (2022)
Salmonidae	*Oncorhynchus tshawytscha*	Fibers	Gut	40	PNE	1.2 (± 1.4)	<500 µm	Collicutt et al (2019)
Average of teleosts from PNE						4.13±6.04 (16-0.6)		
Acanthuridae	*Acanthurus lineatus*	Fragments, films, fibers	Gut	24	PEC	1.5	100-500 µm	Markic et al (2018)
Acanthuridae	*Ctenochaetus striatus*	Fragments, fibers, films	Gut	27	PEC	1.6	100-500 µm	Markic et al (2018)

Acanthuridae	*Naso lituratus*	Fragments, films, fibers	Gut	28	PEC	1.8	100-500 µm	Markic et al (2018)
Acanthuridae	*Naso unicornis*	Fragments, films, fibers	Gut	30	PEC	1.4	100-500 µm	Markic et al (2018)
Alepisauridae	*Alepisaurus ferox*	Monofilament line	Stomach	24	PEC	2.7 ± 2.0	17.7 ± 21.5 mm	Choy and Drazen (2013)
Ariidae	*Arius guatemalensis*	Fibers	Gut	7	PEC	1.5	10-100 µm	Mazariegos-Ortíz et al (2021)
Atherinopsidae	*Atherinopsis californiensis*	fibers	Gastrointestinal tract	7	PEC	0.6 (±0.9) 0 - 2	>500 µm	Rochman et al (2015)
Balistidae	*Balistes polylepis*	NA	Gastrointestinal tract	15	PEC	2	100 µm	Jonathan et al (2021)
Carangidae	*Caranx caninus*	Threads	Gastrointestinal tract	562	PEC	2.7	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Carangidae	*Caranx papuensis*	Fragments, fibers, films	Gut	32	PEC	2.4	100-500 µm	Markic et al (2018)
Carangidae	*Decapterus macrosoma*	Fragments, fibers, films	Gut	25	PEC	1.1	100-500 µm	Markic et al (2018)
Carangidae	*Decapterus muroadsi*	Fragments, fibers, films	Gut	25	PEC	2.4	100-500 µm	Markic et al (2018)
Carangidae	*Seriola lalandi*	Fibers, fragments, films	Gut	15	PEC	1.0	100-500 µm	Markic et al (2018)
Carangidae	*Trachurus novaezelandiae*	Fibers, fragments, films	Gut	31	PEC	1.0	100-500 µm	Markic et al (2018)
Carangidae	*Trachinotus paitensis*	Threads	Gastrointestinal tract	4	PEC	3	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Clupeidae	*Lile stolifera*	Threads	Gastrointestinal tract	6	PEC	2	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Centrolophidae	*Schedophilus velaini*	Fragments, fibers, films	Gut	14	PEC	2.5	100-500 µm	Markic et al (2018)
Centropomidae	*Centropomus armatus*	Fibers	Gut	7	PEC	2.67	10-100 µm	Mazariegos-Ortíz et al (2021)
Centropomidae	*Centropomus nigrescens*	Fibers, fragments	Gut	10	PEC	1.83	10-100 µm	Mazariegos-Ortíz et al (2021)
Centropomidae	*Centropomus robalito*	Fibers, fragments	Gut	33	PEC	2.13	10-100 µm	Mazariegos-Ortíz et al (2021)

Centropomidae	*Centropomus viridis*	Fibers, films	Gut	10	PEC	1.5	10-100 µm	Mazariegos-Ortíz et al (2021)
Characidae	*Astyanax aeneus*	Fibers, fragments, films	Gut	26	PEC	2.92	10-100 µm	Mazariegos-Ortíz et al (2021)
Cheilodactylidae	*Nemadactylus macropterus*	Fibers, fragments, films	Gut	23	PEC	3.5	100-500 µm	Markic et al (2018)
Cichlidae	*Oreochromis niloticus*	Fibers	Gut	5	PEC	1	10-100 µm	Mazariegos-Ortíz et al (2021)
Clupeidae	*Lile gracilis*	Fibers	Gut	12	PEC	2.4	10-100 µm	Mazariegos-Ortíz et al (2021)
Clupeidae	*Opisthonema sp.*	Fibers	Intestinal tract	30	PEC	36.7(±0.86)	<500 µm	Bermúdez-Guzmán et al (2020)
Coryphaenidae	*Coryphaena hippurus*	Fragments, fibers, films	Gut	10	PEC	2.0	100-500 µm	Markic et al (2018)
Coryphaenidae	*Coryphaena hippurus*	Fragments, fibers, films	Gut	51	PEC	17.6	NA	Castillo-Rosas et al (2023)
Coryphaenidae	*Coryphaena hippurus*	Fibers	Stomach	32	PEC	62	0.25-5.0 mm	Alejo-Plata et al (2019)
Cyclopsettidae	*Citharichthys sordidus*	fiber, film	Gastrointestinal tract	5	PEC	1 (±1.2) 0 - 3	>500 µm	Rochman et al (2015)
Eleotridae	*Dormitator latifrons*	Fibers, fragments, films	Gut	248	PEC	1.59	10-100 µm	Mazariegos-Ortíz et al (2021)
Engraulidae	*Engraulis mordax*	Fiber, film, monofilament	Gastrointestinal tract	10	PEC	0.3 (±0.5) 0 - 1	>500 µm	Rochman et al (2015)
Exocoetidae	*Cheilopogon pitcairnensis*	Fragments, fibers, films	Gut	21	PEC	1.0	100-500 µm	Markic et al (2018)
Gempylidae	*Thyrsites atun*	Fragments, fibers, films	Gut	28	PEC	1.9	100-500 µm	Markic et al (2018)
Gerreidae	*Diapterus peruvianus*	Fibers, films, fragments	Gut	13	PEC	1.8	10-100 µm	Mazariegos-Ortíz et al (2021)
Gerreidae	*Eucinostomus dowii*	NA	Gastrointestinal tract	21	PEC	30	100 µm	Jonathan et al (2021)
Gerreidae	*Gerres cinereus*	Threads	Gastrointestinal tract	2	PEC	4.5	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Gerreidae	*Polydactylus approximans*	Threads	Gastrointestinal tract	34	PEC	1	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)

Gobiidae	*Gobiomorus maculatus*	Fibers, fragments, films	Gut	27	PEC	2.31	10-100 µm	Mazariegos-Ortíz et al (2021)
Gobiidae	*Gobionellus microdon*	Fibers, fragments, films	Gut	39	PEC	2.41	10-100 µm	Mazariegos-Ortíz et al (2021)
Hexagrammidae	*Ophiodon elongatus*	Film	Gastrointestinal tract	11	PEC	0.1 (±0.3) 0 - 1	>500 µm	Rochman et al (2015)
Kyphosidae	*Girella tricuspidata*	Fragments, fibers, films	Gut	20	PEC	5.9	100-500 µm	Markic et al (2018)
Kyphosidae	*Kyphosus sandwicensis*	Fragments, fibers, films	Gut	39	PEC	4.0	100-500 µm	Markic et al (2018)
Lampridae	*Lampris sp* (big eye)	Colored plastic	Stomach	29	PEC	2.3	10.6 ± 10.3 mm	Choy and Drazen (2013)
Lampridae	*Lampris sp (small eye)*	Colred plastic, white plastic	Stomach	5	PEC	5.8	27.9 ± 21.0 mm	Choy and Drazen (2013)
Lethrinidae	*Gnathodentex aureolineatus*	Fragments, fibers, films	Gut	29	PEC	1.0	100-500 µm	Markic et al (2018)
Lethrinidae	*Lethrinus amboinensis*	Fragments, films, fibers	Gut	26	PEC	1.7	100-500 µm	Markic et al (2018)
Lethrinidae	*Lethrinus obsoletus*	Fragments, films, fibers	Gut	30	PEC	1.3	100-500 µm	Markic et al (2018)
Loricariidae	*Pterygoplichthys sp.*	Fibers, fragments	Gut	1	PEC	4	10-100 µm	Mazariegos-Ortíz et al (2021)
Lutjanidae	*Eucinostomus entomelas*	Threads	Gastrointestinal tract	254	PEC	2.4	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Lutjanidae	*Lutjanus colorado*	Threads	Gastrointestinal tract	2	PEC	1	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Lutjanidae	*Lutjanus gibbus*	Fragments, films, fibers	Gut	29	PEC	1.7	100-500 µm	Markic et al (2018)
Monacanthidae	*Meuschenia scaber*	Fibers, fragments, films	Gut	19	PEC	2.0	100-500 µm	Markic et al (2018)
Moronidae	*Morone saxatilis*	Fiber, film, foam	Gastrointestinal tract	7	PEC	0.9 (±1.2) 0 - 3	>500 µm	Rochman et al (2015)
Mugilidae	*Ellochelon vaigiensis*	Fragments, fibers, films	Gut	33	PEC	4.3	100-500 µm	Markic et al (2018)
Mugilidae	*Mugil cephalus*	Fibers, fragments, films	Gut	22	PEC	2.0	100-500 µm	Markic et al (2018)

Mugilidae	*Mugil curema*	Fibers, fragments, films	Gut	171	PEC	2.62	10-100 µm	Mazariegos-Ortíz et al (2021)
Mugilidae	*Mugil curema*	Threads	Gastrointestinal tract	6	PEC	6	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Myctophidae	*Hygophum reinhardtii*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	1.3 (±0.71)	1-2.79 mm	Boerger et al (2010)
Myctophidae	*Loweina interrupta*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	1.0	1-2.79 mm	Boerger et al (2010)
Myctophidae	*Myctophum aurolanternatum*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	6.0 (±8.99)	1-2.79 mm	Boerger et al (2010)
Myctophidae	*Symbolophorus californiensis*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	7.2 (±8.39)	1-2.79 mm	Boerger et al (2010)
Poeciliidae	*Poecilia butleri*	Fibers, films	Gut	14	PEC	1.5	10-100 µm	Mazariegos-Ortíz et al (2021)
Polynemidae	*Menticirrhus elongatus*	Threads	Gastrointestinal tract	4	PEC	1	2.71 ± 2.95 (0.23 – 19.86) mm	Salazar-Pérez et al (2021)
Priacanthidae	*Heteropriacanthus cruentatus*	Fragments, fibers, films	Gut	10	PEC	1.0	100-500 µm	Markic et al (2018)
Salmonidae	*Oncorhynchus tshawytscha*	fiber	Gastrointestinal tract	4	PEC	0.25 (±0.5) 0 - 1	>500 µm	Rochman et al (2015)
Scaridae	*Scarus niger*	Fragments, films, fibers	Gut	30	PEC	1.1	100-500 µm	Markic et al (2018)
Scaridae	*Scarus oviceps*	Fragments, films, fibers	Gut	45	PEC	2.8	100-500 µm	Markic et al (2018)
Scaridae	*Scarus psittacus*	Fragments, fibers, films	Gut	30	PEC	1.0	100-500 µm	Markic et al (2018)

Scomberesocidae	*Cololabis saira*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	3.2 (±3.05)	1-2.79 mm	Boerger et al (2010)
Scombridae	*Katsuwonus pelamis*	Fragments, films, fibers	Gut	26	PEC	1.5	100-500 µm	Markic et al (2018)
Scombridae	*Thunnus albacares*	Fragments, fibers, films	Gut	10	PEC	3.1	100-500 µm	Markic et al (2018)
Sebastidae	*Sebastes flavidus*	Fiber	Gastrointestinal tract	3	PEC	0.3 (±0.6) 0 - 1	>500 µm	Rochman et al (2015)
Sebastidae	*Sebastes mystinus*	fibers	Gastrointestinal tract	10	PEC	0.2 (±0.4) 0 - 1	>500 µm	Rochman et al (2015)
Serranidae	*Paralabrax maculatofasciatus*	NA	Gastrointestinal tract	17	PEC	27	100 µm	Jonathan et al (2021)
Siganidae	*Siganus punctatus*	Fragments, films, fibers	Gut	29	PEC	1.8	100-500 µm	Markic et al (2018)
Sparidae	*Pagrus auratus*	Fibers, fragments, films	Gut	22	PEC	1.0	100-500 µm	Markic et al (2018)
Sparidae	*Calamus brachysomus*	NA	Gastrointestinal tract	16	PEC	5	100 µm	Jonathan et al (2021)
Sphyraenidae	*Sphyraena forsteri*	Fragments, films, fibers	Gut	12	PEC	1.5	100-500 µm	Markic et al (2018)
Stomiidae	*Astronesthes indopacifica*	Fragments, film, fishing line, styrofoam, filaments	Gut	NA	PEC	1.0	1-2.79 mm	Boerger et al (2010)
Triglidae	*Chelidonichthys kumu*	Fibers, fragments, films	Gut	27	PEC	2.0	100-500 µm	Markic et al (2018)
Average of teleosts from PEC						4.2±8.89 (62-0.1)		
Anthiadidae	*Hemanthias peruanus*	NA	Digestive tract	15	PSE	2.11	>200 µm	Alfaro-Núñez et al (2021)
Atherinopsidae	*Odontesthes regia*	Fragments	Gut	9	PSE	0.1 (±0.1)	<500 µm	Ory et al (2018)
Blenniidae	*Scarthychthys viridis*	Microfibers	Gastrointestinal tract	19	PSE	14 (max 36)	<1 mm	Mizraji et al (2017)
Carangidae	*Chloroscombrus orqueta*	NA	Digestive tract	15	PSE	2.44	>200 µm	Alfaro-Núñez et al (2021)
Carangidae	*Decapterus muroadsi*	NA	Gut	20	PSE	2.5	0.2 - 5 mm	Ory et al (2017)
Carangidae	*Selene peruviana*	NA	Digestive tract	15	PSE	1.82	>200 µm	Alfaro-Núñez et al (2021)

Centropomidae	*Centropomus robalito*	NA	Digestive tract	15	PSE	2.11	>200 µm	Alfaro-Núñez et al (2021)
Clupeidae	*Opisthonema libertate*	Threads	Gut	20	PSE	0.05(±0.04)	<500 µm	Ory et al (2018)
Coryphaenidae	*Coryphaena hippurus*	NA	Digestive tract	15	PSE	2.69	>200 µm	Alfaro-Núñez et al (2021)
Eleotridae	*Dormitator latifrons*	NA	Digestive tract	15	PSE	2.00	>200 µm	Cáceres-Farias et al (2023)
Engraulidae	*Cetengraulis mysticetus*	Fragments	Gut	30	PSE	0.03(±0.03)	<500 µm	Ory et al (2018)
Engraulidae	*Cetengraulis mysticetus*	NA	Digestive tract	15	PSE	2.08	>200 µm	Cáceres-Farias et al (2023)
Engraulidae	*Engraulis ringens*	Fragments	Gut	13	PSE	0.1(±0.1)	<500 µm	Ory et al (2018)
Gerreidae	*Diapterus brevirostris*	NA	Digestive tract	15	PSE	1.67	>200 µm	Alfaro-Núñez et al (2021)
Kyphosidae	*Girella laevifrons*	Microfibers	Gastrointestinal tract	16	PSE	61 (max 238)	<1 mm	Mizraji et al (2017)
Lutjanidae	*Lutjanus argentiventris*	NA	Digestive tract	15	PSE	2.58	>200 µm	Cáceres-Farias et al (2023)
Mugilidae	*Mugil cephalus*	NA	Digestive tract	15	PSE	2.56	>200 µm	Alfaro-Núñez et al (2021)
Sciaenidae	*Cynoscion analis*	NA	Digestive tract	15	PSE	3.00	>200 µm	Alfaro-Núñez et al (2021)
Sciaenidae	*Cynoscion stolzmanni*	NA	Digestive tract	15	PSE	2.55	>200 µm	Alfaro-Núñez et al (2021)
Sciaenidae	*Larimus argenteus*	NA	Digestive tract	15	PSE	2.17	>200 µm	Alfaro-Núñez et al (2021)
Scombridae	*Scomber japonicus*	Fragments	Gut	30	PSE	0.03(±0.03)	<500 µm	Ory et al (2018)
Serranidae	*Diplectrum maximum*	NA	Digestive tract	15	PSE	1.80	>200 µm	Alfaro-Núñez et al (2021)
Stromateidae	*Peprilus medius*	NA	Digestive tract	15	PSE	2.00	>200 µm	Alfaro-Núñez et al (2021)
Average of teleosts from PSE						4.84±12.54 (61-0.03)		
Average of all teleosts						4.32±9.61 (62-0.03)		

NA, not available; PEC, Pacific, Eastern Central; PNE, Pacific, Northeast; PSE, Pacific Southeast; [b] *Engraulis japonicus* and *E. mordax*