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FACULTAD DE CIENCIAS DEL MAR
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

MICROPLASTICS IN MARINE BIOTA: A REVIEW

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Curso 2019/2020

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Trabajo Fin de Título para la obtención del título de Máster Universitario en Oceanografía

MICROPLASTICS IN MARINE BIOTA: A REVIEW

Trabajo Fin de Título presentado por Kevin Ugwu Hernández para la obtención del título de Máster Universitario en Oceanografía por la Universidad de Las Palmas de Gran Canaria, la Universidad de Vigo, y la Universidad de Cádiz.

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Las Palmas de Gran Canaria, 14 de diciembre de 2020.

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Abstract

Plastics are the most important component in marine debris. In turn, within plastics, microplastics (<5mm) are those that most affect marine biota. Thus, this review has as its main objective to show the current state of studies of microplastics, as well as to determine the groups of vertebrates most affected by microplastics, and the type and predominant color of microplastics. For this research, we review a total of 142 articles. Our results show that the group more affected is turtles, the predominant type is fibers (67.3%), polymer is polyethylene (27.3%), and color is blue (32.9%). Therefore, we believe that it is necessary to carry out more research and appropriate policies for reduction of plastics in the environment.

Introduction

Marine litter has become a dilemma for the whole of society, affecting all sectors: economic, social, environmental, and even cultural, becoming a multigenerational problem (Hardesty et al., 2015). Within marine litter, plastics, a family of organic polymers, has become one of the main waste products, mainly due to the high demand for its use, which has caused a exponential growth, overcoming the rest of artificial materials (Geyer et al., 2017). This demand in the plastic industry has caused it to increase from 5 million tons in 1960 to 359 million in 2018 (Europe & EPRO, 2019). In addition, it is estimated that 275 million tons were generated in 2010, of which 12.7 million tons ended up in the marine environment (Jambeck et al., 2015). And world plastics production in 2018 was distributed in: 51% Asia, 20% Europe, 18% North America, 7% Africa, 4% South America (Europe & EPRO, 2019). Thus, it is estimated that in 2014 there were 5.25 trillion plastic particles in the oceans, and North Pacific contained 37.9% of these particles, due to the dynamics of the thermohaline current (Eriksen et al., 2014).

Plastic waste produces a massive environmental impact, due to its abundance and persistence in the environment, especially in the marine environment, becoming one of the most serious threats for the oceans and biodiversity (Carbery et al., 2018; Gall & Thompson, 2015). So, plastic pollution is one of the main environmental problems in most of the terrestrial and marine environments, causing damage of communities at both the macro and micro levels, with no known ecosystem which does not fall under the scope of this type of contamination (Taylor et al., 2016).

The origin of plastics that end up in the marine environment is mainly terrestrial, through wind, rivers, effluents, and wastewater, although recreational activities and fishing are also sources of plastics in the marine environment (Anbumani & Kakkar, 2018; Ryan et al., 2009).

Thus, most of the plastics found in the oceans are nets, plastic bags, plastic bottles and cooking tools (Hardesty et al., 2015), all of these materials have been made from fossil fuels, and none of them are biodegradable (Geyer et al., 2017).

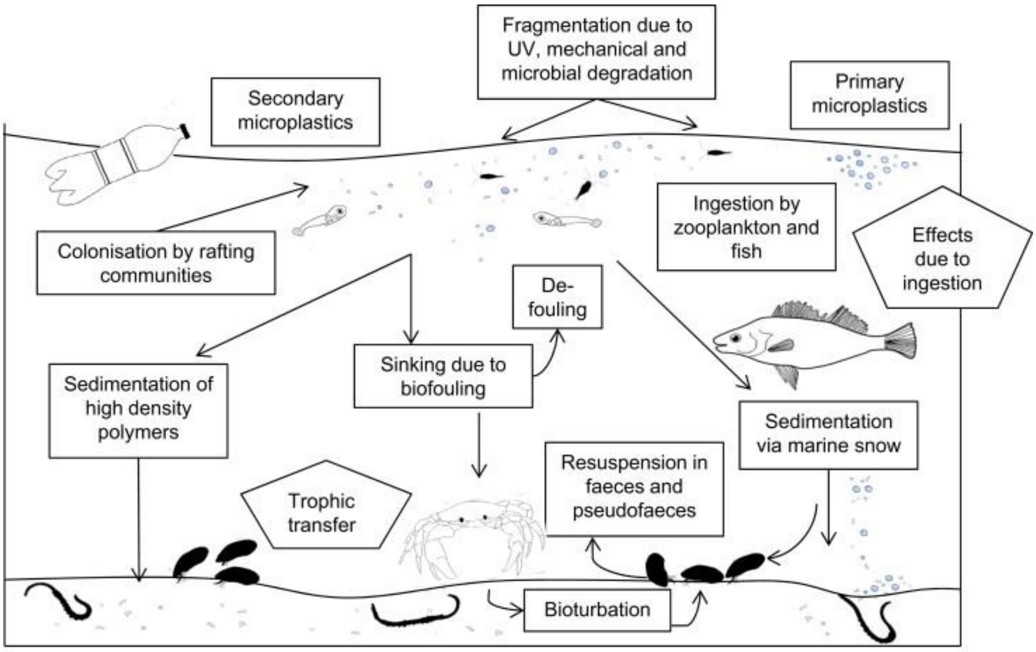


Figure 1. Potential pathways in transport of microplastics and biological interactions (Whright et al., 2013).

Plastics can be classified according to their size, shape, origin, and polymer composition. When grouped by size, they can be divided into macroplastics (> 25mm), mesoplastics (5-25mm), and microplastics (<5mm) (Lee et al., 2013). However, there are difficulties when defining microplastics based on their size, since on many occasions the authors define this concept based on the methodology or instrumentation they use, which is why the following categories have been defined based on the size ranges: nanoplastics: 1 to <1000nm; microplastics: 1 to <1000µm; mesoplastics: 1 to <10mm; and macroplastics: 1 cm and larger (Hartmann et al., 2019). Anyway, the nanoplastics and microplastics are the size that affect a greater number of species (Wesch et al., 2016), because they can be actively ingested by zooplankton, or through passive ingestion, by higher trophic level consumers (Anbumani & Kakkar, 2018). Therefore, microplastics are gaining special attention due to their potential as a threat to marine fauna (Santos et al., 2016).

Microplastics can be divided according to their origin into three different groups: primary microplastics, which are those that are specifically created with a size lower than 5 mm, due to their abrasive qualities (Microbeads); Secondary microplastics are those that originate from the disintegration or fragmentation of macro and mesoplastics due to the action of physical agents and UV rays (Fibers, fragments, films); and tertiary microplastics, which are those used for the preproduction of plastics and reach the environment in the same state in which they were produced, they are called pellets (Carbery et al., 2018).

On the other hand, there are different types of microplastics according to their shape: fibers, fragments, pellets, films, and foams (Anderson et al., 2016). Finally, the worldwide production of microplastics according to their polymer composition is as follows: 36% Polyethylene (PE), 21% polypropylene (PP), 12% polyvinyl chloride (PVC), <10% polyethylene terephthalate (PET) , <10% polyurethane (PUR) and <10% polystyrene (PS) (Geyer et al., 2017).

Currently, all the oceans and seas in the world are contaminated by microplastics (Kühn & van Franeker, 2020; Rochman et al., 2015), accumulating in pelagic zones and sedimentary environments (Thompson et al., 2004). The main concern of plastics is their impact on biota, and it began in the 1960s, when plastic fragments were found in the gastrointestinal system of birds in the marine environment (Ryan et al., 2009). Since then, microplastics have been described in the gastrointestinal system of 690 species (Carbery et al., 2018), with 17% of these species being part of the IUCN Red List (Hardesty et al., 2015), so that it may contribute to the species extinction (Gall & Thompson, 2015).

In addition, the bioavailability of microplastics can increase due to flocculation with marine particles, creating aggregates that enter in food chain. In turn, fecal remains with microplastics can be ingested by detritivorous species (Wright et al., 2013). On the other hand, the ingestion of microplastics by marine zooplankton has been demonstrated (Desforges et al., 2015), as well as the transfer of microplastic particles from mesozooplankton to macrozooplankton, so exist a real risk of microplastics getting on marine food webs (Setälä et al., 2014). Likewise, microplastic transfer has been found in marine invertebrates, such as the species of *Mytilus edulis* (mussel) and *Carcinus maenas* (crab) (Farrell et al., 2013), proving that there are higher trophic levels that ingest microplastics through their prey (Wright et al., 2013). Therefore, the potential of microplastics to be ingested by all levels of biological organization is clearly demonstrated (Gouin, 2020).

Likewise, the factors that have been defined as the main responsible for the ingestion or assimilation of microplastics by marine organisms are the following: size (the smaller are more bioavailable), the density (greater the quantity of microplastics lead to greater the possibility of ingestion and / or adsorption), abundance (greater variety of microplastics involves a greater possibility of organisms being attracted to this material), and color (it has been shown that there are certain colors that tend to attract certain groups of organisms), all these factors cause an increase in the bioavailability of microplastics in organisms with respect to other anthropogenic waste (Wright et al., 2013). On the other hand, microplastics in their degradation process in the marine environment release volatile organic compounds, such as dimethyl sulfide (DMS), a compound present in algae, so that an olfactory mark is generated, causing that some organisms of zooplankton, such as copepods consume microplastics mistaking them for their prey (Procter et al., 2019). Furthermore, this behavior has also been demonstrated in seabirds, showing that the chemical aromatic signal released by the microplastics produces greater ingestion in marine fauna (Savoca et al., 2016).

Also, one has to take into account the difficulty in providing a standardized method of sampling about ingestion of microplastics by marine biota. However, it is possible to establish guidelines about the area, time, number and size of organisms indicating contamination by microplastics (Wesch et al., 2016). In this sense, a quality assessment protocol has been described using several criteria: sampling method and strategy, sample size, sample storage and processing, laboratory preparation, controls, and polymer treatment and identification, providing a standardized protocol for the detection of microplastics in marine biota (Hermsen et al., 2018).

Futhermore, is important highlight that, given the characteristics of microplastics, a set of techniques for their detection in marine biota have been used since their discovery, among which those included in the Table 1.

Technique	Description	Advantages	Disadvantages
Visual identification	Use of very basic instruments such as the human eye and rules to determine the microplastic. Sometimes microscopy is used, which allows to improve the results. This method is necessary to separate the microplastics from other waste	The type, color and shape of the microplastic can be easily distinguished Help distinguish field samples from those originating from laboratory contamination	A dissecting microscope should be used to detect the smallest microplastics Particles of less than 1 mm must have spectroscopic confirmation Does not identify polymers Risk of overlooking particles Need a lot of time and effort
Density separation and C:H:N analysis	Particles are separated by difference in density	C:H:N: analysis allows identification of plastic polymers	Not applicable for high density polymers Need a lot of time and effort
Pyrolysis-GC/MS	Compare the results of pyrograms (polymer-specific combustion products) with the original polymers	Identifies polymers More accurate than density separation and visual identification	Not recommended for processing large quantities of samples
Raman spectroscopy	Sample is irradiated with a monochromatic laser where wavelengths are typically between	Identifies the types of plastic polymers and their abundance	Fluorescent samples can not be measured

	500 and 800 nm, and the results are compared with a library of standard polymer spectra	Identifies the smallest microplastics (<1 mm)	
Fourier Transform Infrared (FTIR) spectrometer	Sample is stimulated by infrared radiation producing different types of molecular vibrations depending on the composition and structure of the substance	Trusted method for polymer identification Low cost and easy to use Plastic polymers with highly specific spectra	Black particles can not be detected with this technique

Table 1. Comparison of current techniques for measuring microplastics in marine biota. Adapted from Rezania et al., 2018.

Finally, the impact of microplastics on marine fauna is mainly due to two issues: on the one hand, after ingestion of microplastics, these can accumulate in the animal's organs, generating mechanical obstruction and preventing them from feeding or breathing, which is a physical impact on the biology of the individual (Anbumani & Kakkar, 2018).

Moreover, there is chemical impact, since it has been shown that microplastics can contain persistent organic pollutants (POPs), such as polychlorinated biphenyl (PCB) (Hermsen et al., 2018). In turn, it has been shown that microplastics from beaches around the world contained organochlorine compounds such as DDT and its derivatives DDE and DDD, HCH, and PCB, all classified as POPs (Ogata et al., 2009).

In addition, the potential of microplastics to transport hydrophobic contaminants such as phenanthrene in sediments has been demonstrated, so this can affect organisms living in these habitats (Teuten et al., 2007). Most of the compounds from which microplastics are made, such as phthalates and BPA, affect reproduction in various organisms, including crustaceans and fish, and produce genetic malformations, altering hormonal systems

(Oehlmann et al., 2009). Likewise, an increase in epithelial cysts in plastic-feeding birds has also been reported (Roman et al., 2019). Different additives and microplastic by-products have been found in seabirds, among which UV stabilizers such as UV-328, UV-236, and UV-237 containing benzotriazole groups and BP-12 containing a benzophenone group, which alter the endocrine system, and flame retardants such as hexabromocyclododecane (HBCDD) and deca-BDE, which are included in the list of persistent organic pollutants (POPs) (Tanaka et al., 2019). It is also important to highlight the occurrence of organic UV filters found in microplastics, such as BP-3, 4-MBC, OC, OMC and OD-PABA (Cadena-Aizaga et al., 2020). Likewise, up to 81 chemical compounds have been found in microplastics in the Canary Islands, in the North Atlantic, among which organochlorine compounds such as PCB, DDT and derivatives, organochlorine pesticides (OCP), polycyclic aromatic hydrocarbons (PAH) and bromodiphenyl esters (BDE) stand out (Camacho et al., 2019).

The latter is of vital importance, since these persistent chemical compounds bioaccumulate and biomagnify in the organisms, and can be ingested by humans through the diet, in commercial organisms contaminated by microplastics (Figure 2).

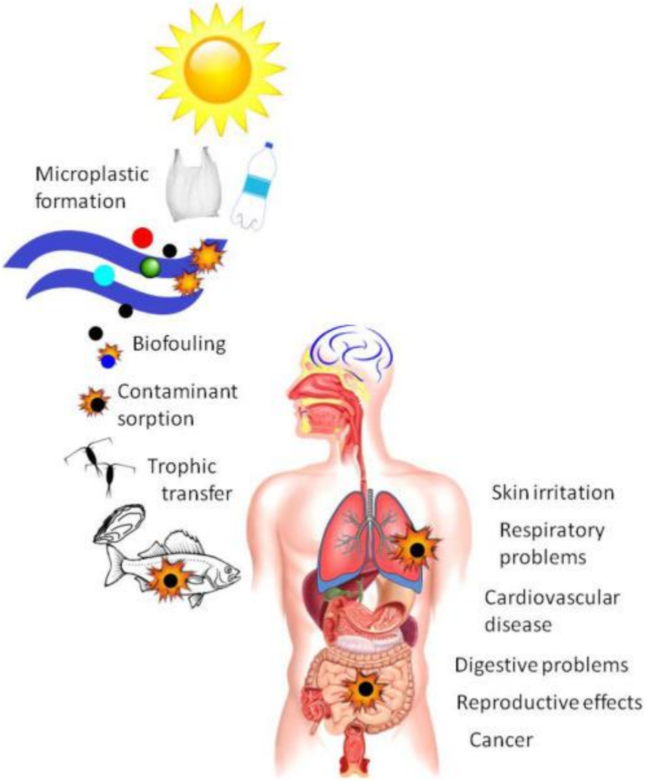


Figure 2. Potential health effects from bioaccumulation and biomagnification of microplastics in the human body (Carbery et al., 2018).

Objectives

The main objectives of this research work were the following:

1. To carry out a review of the existing studies in microplastic (MP) pollution in the marine biota studied in its natural environment, focusing on marine vertebrates (sea birds, fish, marine mammals and turtles).

2. To visualize temporal trend in the number of studies on microplastics, in order to determine their importance based on the growing number of studies.

3. To create a database with a summary of the main results in the studies conducted to date.

4. To establish, based on the studies carried out until now, the main types, polymers and colors of microplastics in marine vertebrates in order to support for decision making in management and future research.

5. To determine the main methods for measuring microplastics in marine biota, evaluating those that should be used in the future in order to harmonize methodologies.

Methodology

To carry out this bibliographic review, a list of references obtained from the Web of Science Database (WOS) was used. The key search word was “microplastics”, obtaining a total of 3,623 references on May 17, 2020. The list obtained was then filtered by the fields “Plant Science”, “Zoology”, “Oceanography”, giving a total of 1,345 references, divided into 143 references for Oceanography, 219 for Plant Science, and 983 for Zoology.

Once this first selection was made, all those references that did not study species in the marine environment were first disregarded, that is, studies carried out in rivers, lakes or reservoirs were disregarded. At the same time, research carried out in the laboratory was also disregarded, since it has been demonstrated that significant differences exist between field studies and experiments on exposure to microplastics in the laboratory (Rezania et al., 2018).

This study showed that of the 1,345 references found, only 213 references were in biota in the natural environment, divided into the following: 20 marine mammals, 15 seabirds, 9 turtles, 97 fish, 69 invertebrates, and 3 plants (Figure 3). Once we had these perfectly defined references, we limited ourselves to studying only vertebrates 142 articles (marine mammals, seabirds, turtles and fish).

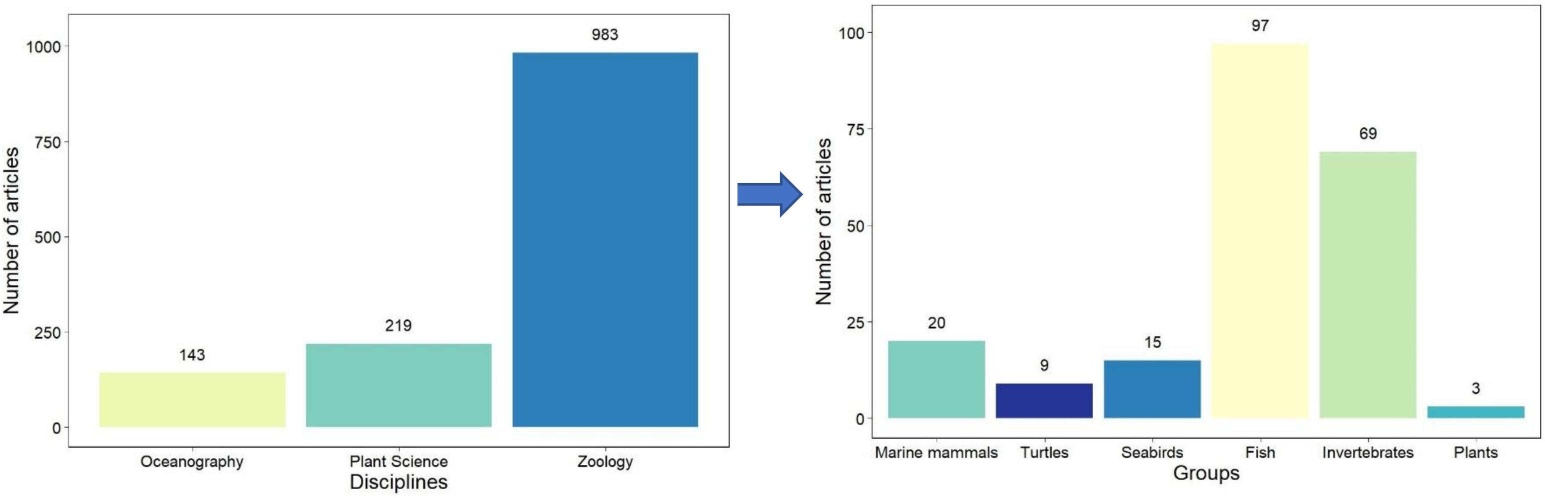


Figure 3. References found by disciplines in Web of Science (Left) and distribution by groups of the references used in this review (right).

Therefore, from the 142 articles, review articles and those which weren't complete were disregarded, making a final list of 132 articles. The following information was obtained from each article: location, sample size (n), group (sea birds, fish, marine mammals and turtles), species, organ of analysis (feces, stomach, gastrointestinal tract, others), % of individuals with microplastics, number of microplastic items per individual, number of total microplastic particles, predominant type of microplastic (fibers, fragments, pellets, films, and foams), predominant type of polymer, predominant color of microplastic, type of visual instrumentation (dissecting microscope, stereo microscope, rulers), and use of advanced instrumentation (Raman spectroscopy/FT-IR spectroscopy), creating the data table shown in the results.

Once obtained this table, created in the Microsoft Excel spreadsheet program version Microsoft 365, the statistical program R studio was used in its version R version 3.6.1 (2019-07-05) with the set of packages tidyverse 1.3.0 (Wickham et al., 2019) and ggplot2 (Wickham et al., 2016) to make the graphs that are shown in the results.

Results

Spatial and temporal distribution and instrumentation

The data obtained from the 213 articles cover all oceans and continents, so that the most studied areas are the Atlantic Ocean (77), the Pacific Ocean (69) and the Mediterranean Sea (35), while the least studied are the Indian Ocean (17), the Arctic Ocean (8), the Baltic Sea (4) and the Antarctic Ocean (3), all of which are shown in figure 4.

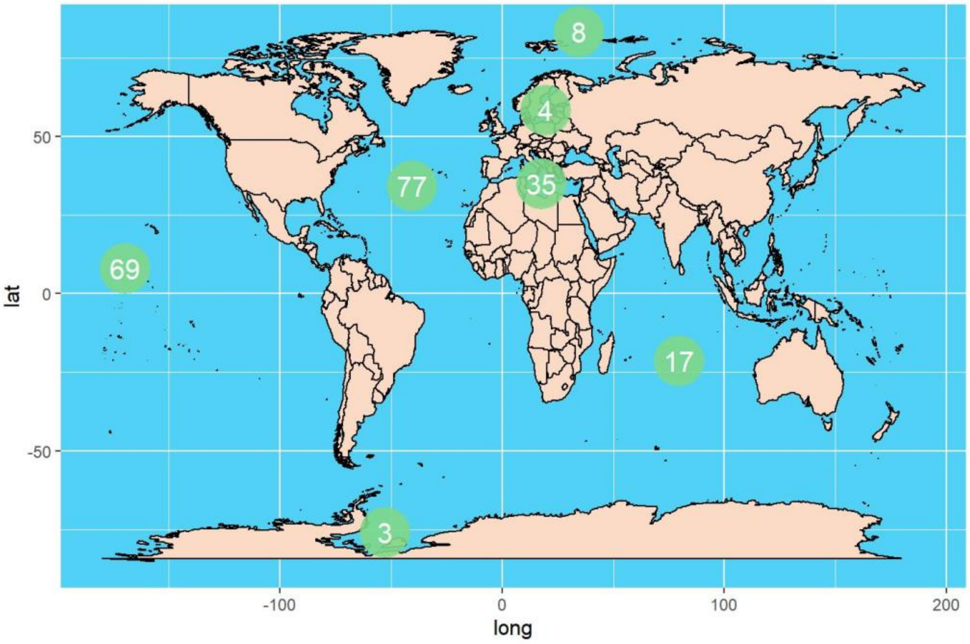


Figure 4. Distribution of studies about microplastics in marine biota in the Atlantic Ocean, Pacific Ocean, Indic Ocean, Artic Ocean, Antartic Ocean, Mediterranean Sea and Baltic Sea.

In turn, if we study scientific production for years, we can see how the discipline of microplastics in marine fauna is very recent. The first article that studies microplastic waste specifically in vertebrates was published in 2010, and the first article about invertebrates in 2014. Since 2010, the number of articles has increased exponentially, going from a single article in that year to 60 articles in 2019 and 42 articles in the first five month of 2020 (Figure 5).

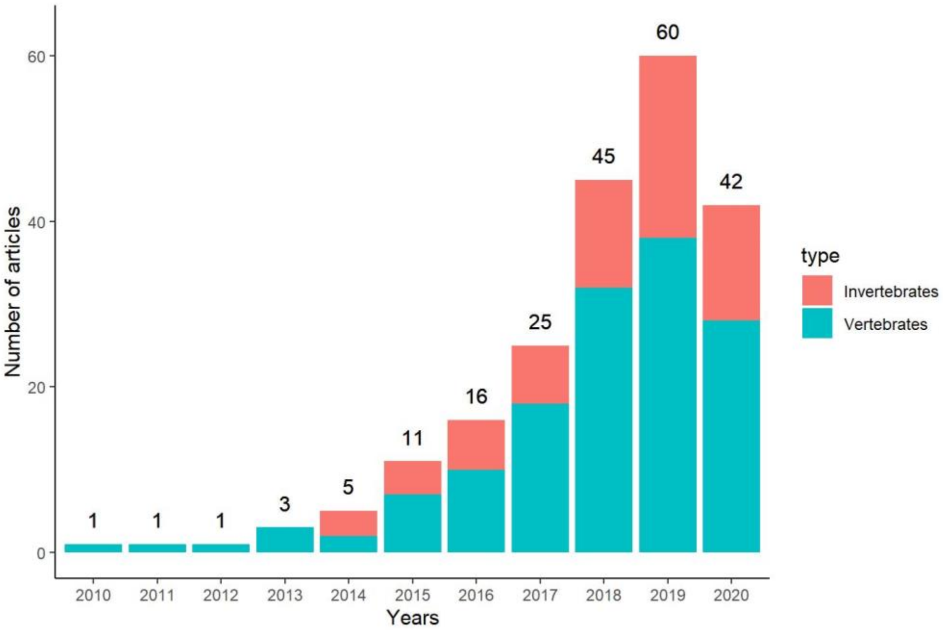


Figure 5. Distribution of studies about microplastics in marine biota in the last 10 years.

Thus, of the 132 studies reviewed in this work, 129 reported microplastics in organs of marine fauna, and only 3 articles (2 articles of marine mammals and 1 article of fish) reported that no microplastics had been found in any individual, that is, 97.73% of the articles found microplastic contamination in the organisms studied. Overall, the articles reviewed have studied a total of 25,907 individuals, finding microplastic particles in 7,375 individuals, therefore, 28.47% of all individuals studied were contaminated with microplastic particles.

The characterization of the microplastic particles depends on each research group, since there are different methods of analysis and none of them is standardized (Gouin, 2020), so it is interesting to determine the organs in which the particles have been found and the analytical instruments used.

Of the 132 articles reviewed in this study, most, 83 articles, perform the analysis of microplastics on the gastrointestinal tract, 34 articles only in the stomach, and 9 in the feces, while only 5 in other organs such as gills, muscles and livers. It is verified that most of the articles are focused on the gastrointestinal tract, which provides more information about the microplastic contamination of the individual than studying only the stomachs.

In turn, of the 132 articles, most of them used advanced techniques for the detection of microplastics (Figure 6), such as the Fourier Transform Infrared (FTIR) spectrometer, reaching 60.4% of the articles reviewed, and to a lesser extent Raman spectroscopy. It is important to highlight that an important percentage of the articles, 32.8%, did not use any advanced analysis technique, so the identification was based on the use of visual techniques such as the microscope.

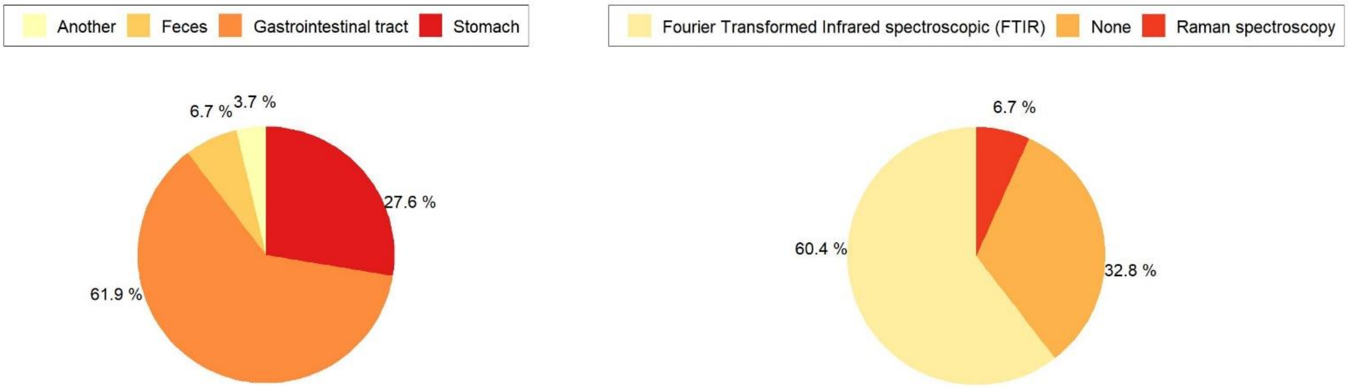


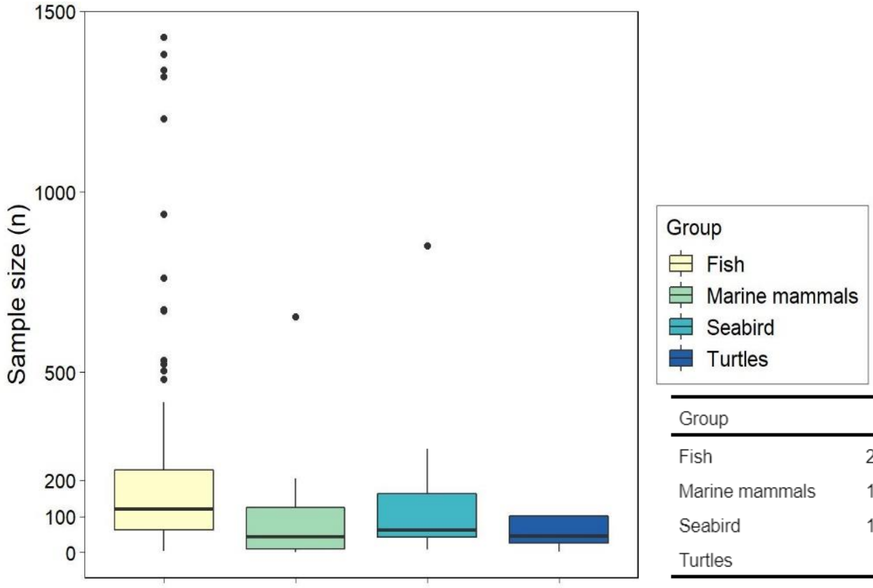
Figure 6. Distribution of microplastic articles according to the organ studied (left) and according to the use of advanced technology instrumentation (FTIR/Raman spectroscopy) (right).

Concentration and sample size of microplastics

It is important to take into account the size of the sample when carrying out studies of contamination by microplastics, since an excessively small size can give us an idea of individual contamination but not group or species contamination. The study of the average number of individuals analyzed by each article was carried out.

In general, all the articles carry out their respective studies with a fairly high number of specimens. The studies carried out on fish are noteworthy, since with an average of 233 specimens, there are outpoint articles that study up to 1429 specimens. The rest of the groups present very similar averages and medians. It is also important to note that in all cases, except for the seabirds, there are studies that fall below 5 individuals.

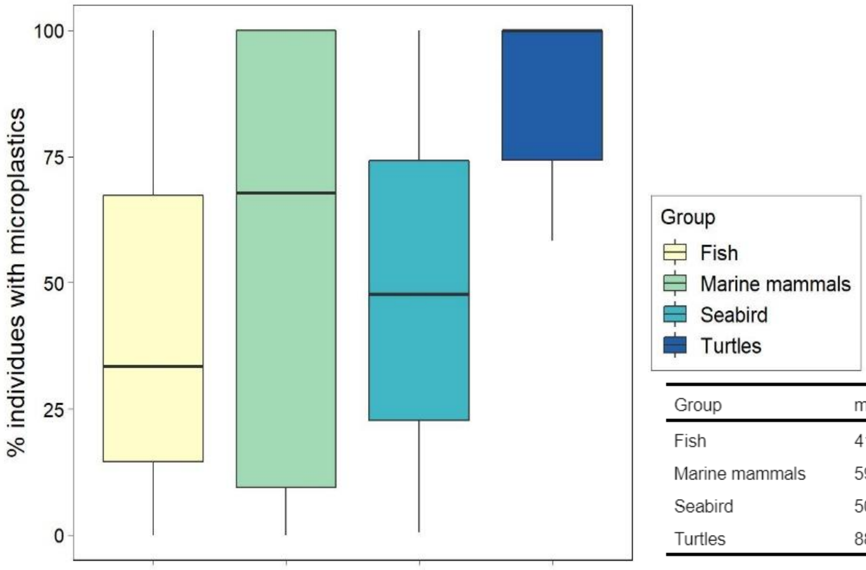
This is related, especially in the case of turtles and marine mammals, with the great difficulty in obtaining samples, because they are obtained from strandings or accidental fishing of these species. This information can serve as a guide for future studies, since using the medians of the studies carried out as a reference, can give us an idea of the sample size that may be adequate for the study of these groups: 121 in fish, 44 in marine mammals, 62 in sea birds, and 47 in turtles (Figure 7). This will avoid underestimating due to lack of data or investing unnecessary effort.



Group	mean	minimum	maximum	median
Fish	233.09	5.00	1,429.00	121.00
Marine mammals	100.73	1.00	654.00	44.00
Seabird	143.27	9.00	850.00	62.00
Turtles	57.00	2.00	102.00	46.50

Figure 7. Sample size by group (fish, marine mammals, seabirds, and turtles) in the studies reviewed.

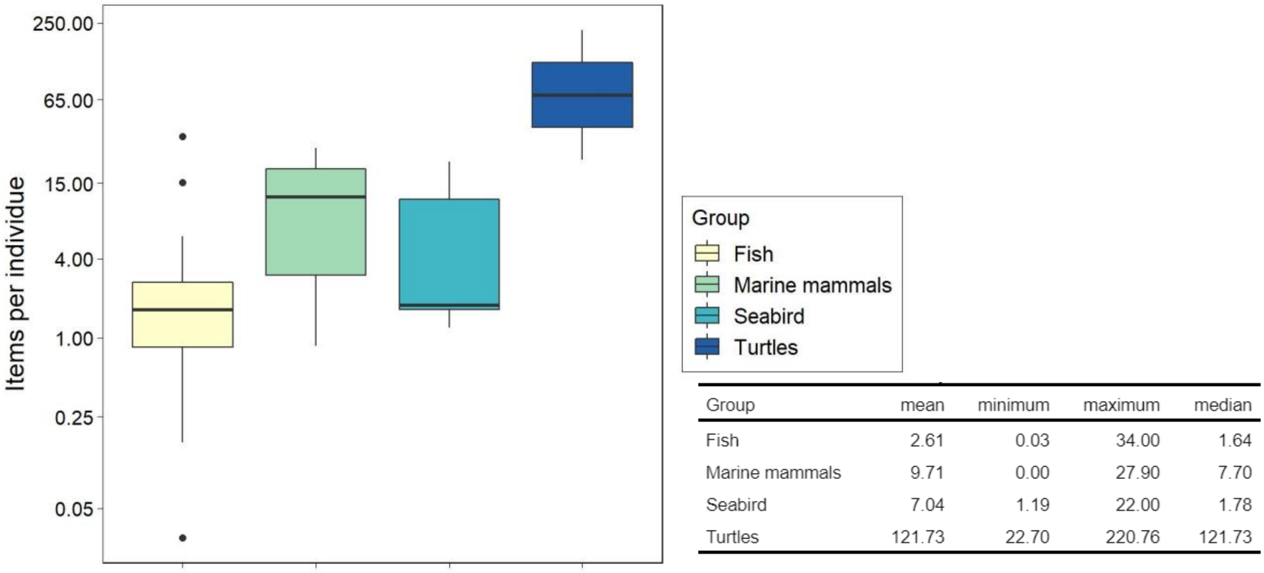
On the other hand, we show the average % of individuals with microplastics by groups, in which we can determine, that the group most affected by these particles are the turtles, 88% of the specimens studied were contaminated by microplastics. The rest of the groups present very similar values: 42% of the fishes affected, 59% of the marine mammals affected, and 50% of the sea birds affected (Figure 8). Something fundamental to take into account is that all the groups consist of articles where all the studied individuals were contaminated by microplastics.



Group	mean	minimum	maximum	median
Fish	41.99	0.00	100.00	33.50
Marine mammals	59.49	0.00	100.00	67.80
Seabird	50.38	0.50	100.00	47.70
Turtles	88.17	58.30	100.00	100.00

Figure 8. Percentage of individuals affected by microplastic contamination by group (fish, marine mammals, seabirds, and turtles).

In turn, it is interesting to determine the average number of microplastic particles found in the individuals of each group. The data are very interesting, since they show us the great potential that many organisms have to accumulate microplastics, the most controversial case is that of the turtles, whose average number of particles differs by two orders of magnitude from the rest of the groups. Thus, the average of microplastic particles found in turtles is 121.7 particles per individual, while in fishes it is 2.6 particles, in marine mammals 9.7 particles and in sea birds 7.0 particles. Likewise, the minimum of particles found in turtles, 22.7 particles, is similar to the maximum of particles found in fishes 34.0 particles, in marine mammals 27.9 particles, and in sea birds 22.0 particles, being the maximum for turtles 220.7 particles (Figure 9). Therefore, the group most affected by micro-plastic pollution is turtles.



Group	mean	minimum	maximum	median
Fish	2.61	0.03	34.00	1.64
Marine mammals	9.71	0.00	27.90	7.70
Seabird	7.04	1.19	22.00	1.78
Turtles	121.73	22.70	220.76	121.73

Figure 9. Concentration of microplastic particles by individuals by group (fish, marine mammals, seabirds, and turtles) in logarithmic scale.

Type and colors of microplastics

As for the type of microplastic, it is interesting to determine the shape of the microplastic, since it is one of the best indicators about its origin. In case the ingestion of pellets prevails, it provides us with information that the area is affected by industrial processes, while if fibers prevail, the source can be residual water with remains of clothes, and when fragments and others prevail, we can estimate that it is a "fast" process of breakage of macro and mesoplastics. So, biomonitoring is a suitable method to determine the sources and speed of microplastics in marine ecosystems (Gouin, 2000).

At an average level of all the organisms studied in the articles reviewed, the predominant type of microplastic in each article has been obtained, the fibers predominant microplastics, which are found as predominant in 67.3% of the articles reviewed. The next important group of fragments, representing 25.7% of the articles reviewed. Pellets and films, represent only 3.5% each (Figure 10).

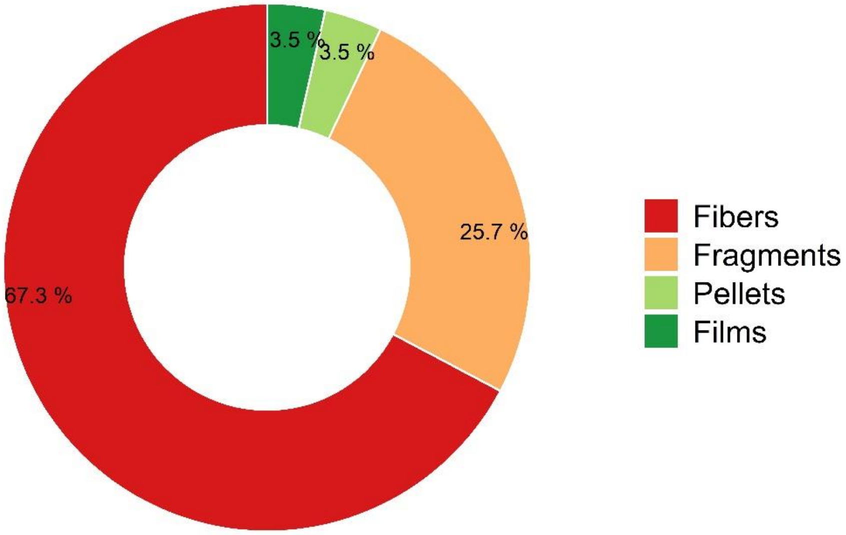


Figure 10. Predominant type of microplastic (fibers, fragments, films, pellets) in vertebrate marine biota

However, if we analyze the predominant type of microplastic according to the different groups, we obtain different trends from those generally expected. In this case, we can observe how the fish group shows a similar trend to the general average (71.1% fibers, 21.7% fragments, 3.6% pellets, 3.6% films), which makes sense given that it is the majority group of articles that have been studied.

In marine mammals, none of the articles show as predominant microplastic pellets or films, being the predominant microplastic fibers in 72.7% of the articles (Figure 11). The group of marine birds is interesting, since it is the only group where the fibers do not represent the majority type of microplastics, since they are found in the same percentage as the fragments (45.5% each), and in addition pellets appear as the predominant microplastic in 9.1% of the articles. This shows us that birds are much more affected by microplastics in granular or fragment form, than by microplastics in fiber form. Finally, the turtle group also has fibers as the predominant microplastic, but to a lesser extent than fish or mammals, as it only represents 50% of the articles. Fragments representing 37.5% and films 12.5% become important in this group.

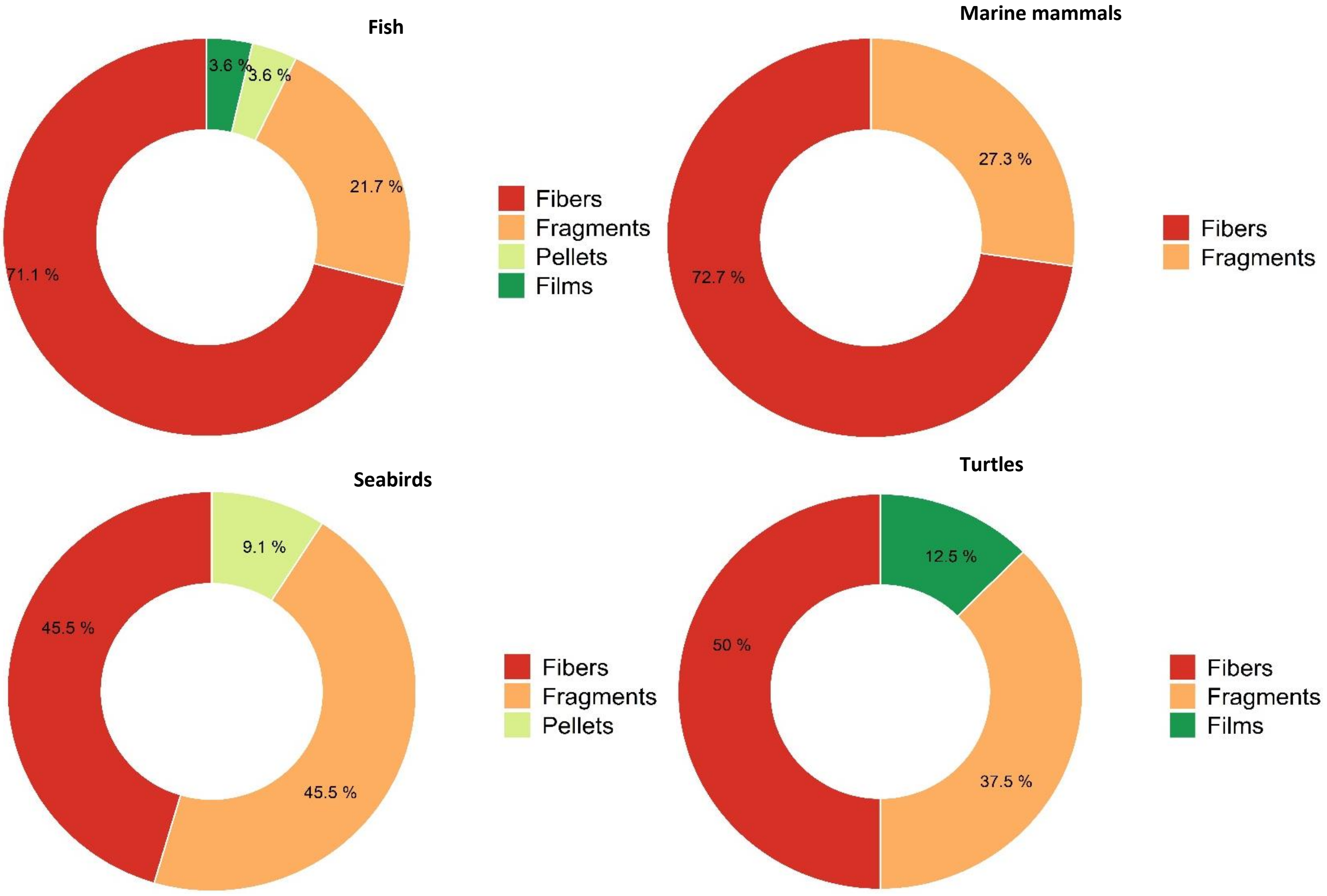


Figure 11. Predominant type of microplastic (fibers, fragments, films, pellets) by group (fish, marine mammals, seabirds, and turtles).

On the other hand, knowing the predominant polymer from which the microplastic particles are formed gives us an idea of the period of time that this microplastic will take to degrade, since each polymer has a certain period of degradation, as well as the possible organic compounds that can be released by the microplastic due exclusively to the polymer. The data show that the predominant polymer found in the studied vertebrates is polyethylene (PE) in 27.3% of the articles, followed by polypropylene (PP) in 14.3% of the articles, rayon in 11.7% of the articles and polyester in 10.4% of the articles (Figure 12).

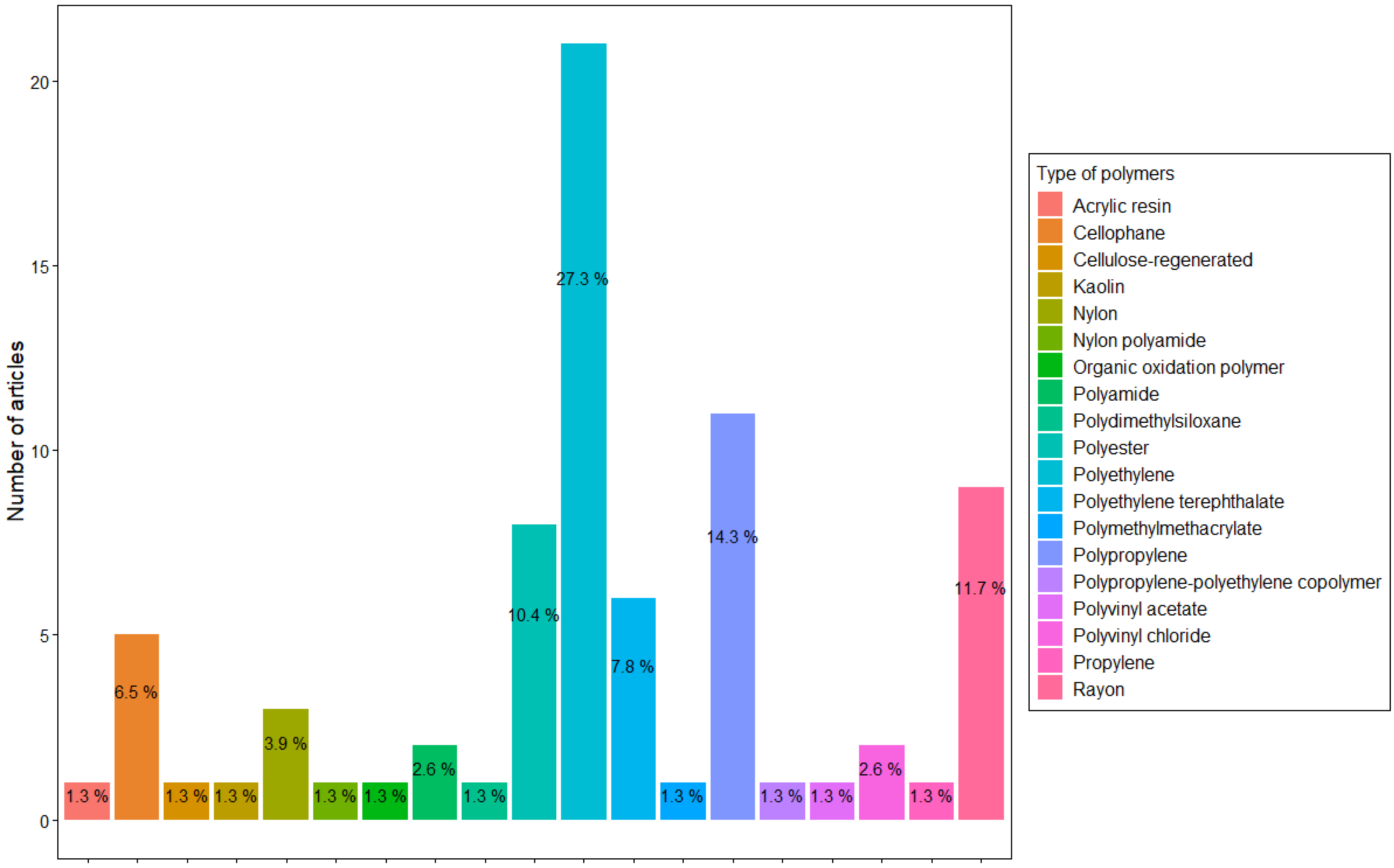


Figure 12. Predominant polymers of microplastic in vertebrate marine biota.

Finally, the predominant color of the microplastics in the fauna studied in each of the articles was reviewed, obtaining the following results: dark colors represented 58.82%, distributed as follows in 32.94% blue, 18.82% black, 3.53% green, 2.35% red, and 1.18% brown, while light colors represented 41.18%, distributed in 24.71% white and 16.47% transparent (Figure 13). Thus, it can be seen that the majority color is blue, in 32.94% of the articles, followed by white, in 24.71% of the articles.

However, studying the groups separately we find very different trends from the previous one. In fish, dark colors represent 59.37% of the articles, with blue (28.12%), black (23.44%), green (4.69%) and red (3.12%). Light colors are 40.63% represented by white (18.75%) and transparent (21.88%). In marine mammals, dark colors represent 62.5%, and only consist of blue (50%) and black (12.5%), and light colors by the transparent (37.5%). Birds are the only group where light colors are the majority, formed only by the transparent (55.56%), with dark colors representing 44.44%, formed by blue (33.33%) and brown (11.11%). Finally, in the group of turtles we only find two colors: blue color that represents 75% of the items and the transparent color that represents the remaining 25% of the items (Figure 14).

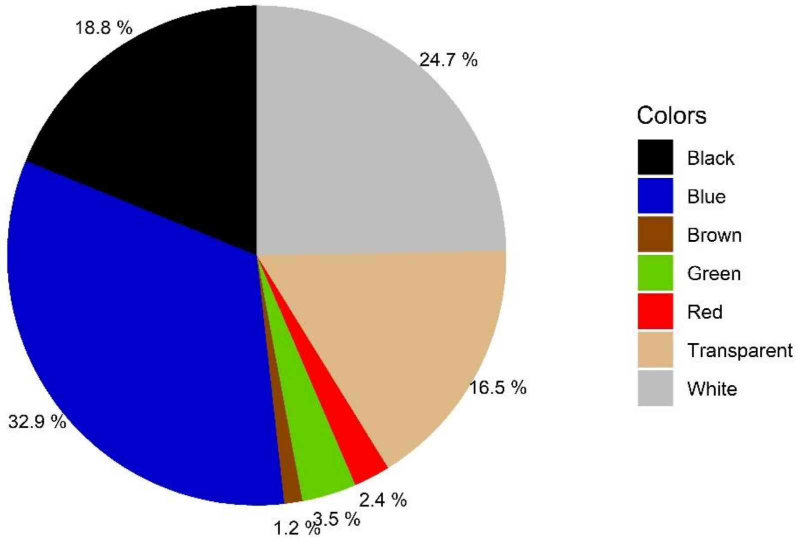


Figure 13. Predominant colour of microplastic in vertebrate marine biota

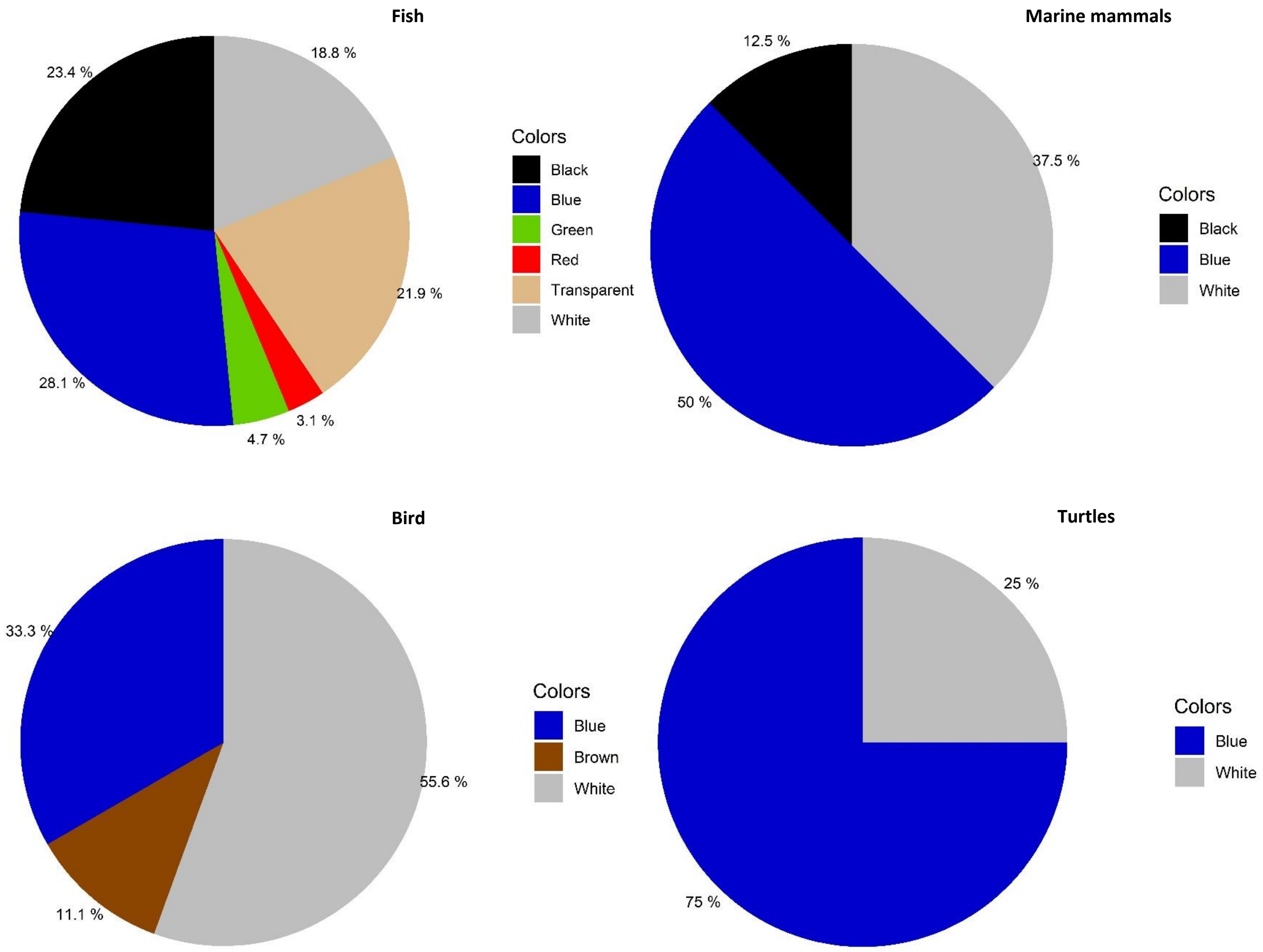


Figure 14. Predominant colour of microplastic by group (fish, marine mammals, seabirds, and turtles).

Discussion

The present review makes an extensive revision of all the information contained of microplastics in marine biota. In this sense, our data show that 132 scientific articles make studies of microplastics in marine vertebrates (turtles, mammals, birds and fish), this number coincides with other reviews of microplastics in vertebrates, which studying only cetaceans, fish and turtles reach 112 articles with a review methodology similar to ours (López-Martínez et al., 2020). On the other hand, our data show that, in the last decade, studies of microplastics in marine biota have increased exponentially, going from the first study specifically of microplastics in 2010 to 60 studies in 2019. This exponential behavior in the number of studies on microplastics ingestion confirms the assumptions that the environmental threat of plastics is significant in marine animals and is acquiring great attention in recent years (Santos et al., 2016), other reviews show the same exponential behavior in the study of microplastics in the last decade (Gouin, 2020).

As for the geographical distribution, it can be seen that most of the articles made (112/213) have been made in the Atlantic and Mediterranean, and in the Pacific (69/213). These data agree to with reports from the Secretariat of the Convention on Biological Diversity, which reports that the largest number of articles describing plastic contamination in the world are from North America (117), Europe (52) and Australia (56) (Dias & Lovejoy, 2012). This behavior can be associated with the greater amount of resources for research by countries in Europe, Asia, and the Americas, and the greater pollution by plastics that occurs in these countries (89% of the world's plastics production comes from Asia, North America, and Europe) (Europe & EPRO, 2019).

Our results also show a clear tendency to study the complete gastrointestinal system of the species, with most studies (83/132) being reasonable considering the difficulty in evaluating all microplastics in incomplete samples, so that the gastrointestinal systems show to be the most effective organs to evaluate microplastics in biota (Hermsen et al., 2018). In turn, 67. 2% of the articles used FTIR and Raman, which has two major benefits: the first is that visual examination by microscopy does not allow the identification of different polymers, a problem that is solved by the use of these advanced techniques, and also allows a distinction between natural and synthetic polymers (Gouin, 2020). On the other hand, visual identification techniques without subsequent verification by FTIR or Raman, are more likely to miss particles that are mixed in the digestive tracts with other materials, and whose extraction is more complicated (Wesch et al., 2016).

As for the number of individuals per group (median is 121 in fish, 44 in marine mammals, 62 in sea birds, and 47 in turtles) it is essential to take into account the ethical bases of the study of microplastics in living organisms. Research directed at marine mammals, turtles, and birds does not use hunting or fishing techniques, therefore they are based on studies of feces or acquire individuals that have died prior to the study. In fish, however, many studies carry out fishing and instead others acquire them in markets and fishmongers where the specimen had already been fished with a different objective than the study of microplastics, which makes it possible to have a greater number of specimens for research. In our opinion, and taking into account the logic of species conservation, in no case should you hunt or fish for individuals, whatever the group they belong to, since this could be a contradiction, carrying out scientific work to "protect" certain species through knowledge of the effect of microplastics on them, but on the other hand minimizing their populations and being able to provoke changes in the ecosystems from which they come depending on the number of individuals used. Therefore, for future studies, we recommend that the analysis of microplastics be carried out on species that have been captured or have died previously, and that therefore the study of microplastics is not one of the reasons for the death of individuals.

Our results also show that turtles are the group most affected by microplastics, as it is the group with the highest percentage of individuals affected by microplastics (88% turtles, 59.5% marine mammals, 50.4% sea birds, 42% fish). However, the high prevalence of microplastics in turtles is shown not only in the proportion of contaminated individuals, but also in the mean number of microplastic particles found in individuals (121.7 items in turtles, 2.6 items in fishes, 9.7 items in marine mammals, 7.0 items in sea birds). We associate this great difference with the rest of the groups mainly to two processes: first, the large spatial distribution of the turtles and their migratory movements, which allows them to be found in areas highly contaminated by microplastics at certain times of their lives, so that microplastic particles may be present due to environmental exposure (Pham et al., 2017), and on the other hand the diet, turtles can feed on pelagic organisms when they are young, so that the shape of the plastic bags can be confused with organisms such as jellyfish, and they can feed on benthic organisms when they are adults, so that they can acquire the microplastics when they are swallowed, since an important part of the microplastics remains in the sediments and sedimentary organisms (Duncan et al., 2019). For the remaining groups, the percentages are relatively similar between them, in all cases exceeding 40% of affected individuals. This provides us with quite clear information on the enormous impact that microplastics have on marine vertebrate biota.

Although the proportion of individuals is similar, the mean number of microplastic particles in birds, mammals and fish differ, being mammals (9.7) and seabirds (7.0) larger than fish (2.6), in mammals this increase of microplastic particles compared to fish is associated with a trophic transfer (Moore et al., 2020), since they consume the entire prey, and can contain this microplastic, obtaining them through the diet (Hernandez-Milian et al., 2019). In birds it is associated with trophic transfer through the consumption of prey with microplastics, but also with the direct ingestion of the microplastics, which can be confused by their shape and color with plankton organisms (Amélineau et al., 2016). It has also been demonstrated that the microplastics can come from pieces of macro and mesoplastics that are broken down into pieces in the gastrointestinal system of birds (Provencher et al., 2018). These arguments could explain the difference between the fish group and the marine mammal and seabird groups, but there is no doubt that more research is needed on the sources and mechanisms of microplastics in marine fauna. In turn, it is necessary to comment that the number of particles in fish fits with other studies, which describe from 1 to 20 particles depending on the fish species (Rezania et al., 2018).

The predominant type of microplastics found in all groups are fibers (71.1% in fish, 72.7% in marine mammals, 45.5% in seabirds, 50.0% in turtles), we associate this with the fact that most microplastic particles identified in the marine environment are fibers (Wright et al., 2013), and also match to with other studies that state that the predominant microplastic in fish was fibers (Rezania et al., 2018; Rochman et al., 2015). This can be explained by the fact that most plastics come from land-based sources, through sewage and solid waste treatment plants, which could explain the prevalence of fiber-type microplastics from laundry. Moreover, the loading of microplastics from fishing nets also contributes to increase the proportion of fibers compared to other types of microplastics (Anbumani & Kakkar, 2018). Birds and turtles show different behaviors from the rest, they present a lower proportion of fibers compared to the proportion of fragments, this can be associated with two different processes: first, part of the studies observe species of coastal birds, and correlations have been shown between the type of microplastic predominant on the coast and that found in the stomach of birds (Kain et al., 2016). So that this decompensation against other groups may be due to the greater amount of fragments against fibers in coastal habitats, secondly, birds select plastic particles that resemble zooplankton prey (Floren & Shugart, 2017), so depending on the similarity of the prey of each species there will be a prevalence towards one type of microplastic or another. This case is also notable in turtles, which have a greater attraction to components similar to gelatinous macro-zooplankton (Vélez-Rubio et al., 2018). Prevalence of pellets in birds with respect to the rest of the groups is due to the fact that the areas where the samples were analyzed are closer to plastic industries that use this type of microplastics in their production processes (Adika et al., 2020), and that they can release them in nearby areas, affecting the local marine fauna.

The predominant polymers in marine biota are directly related to their production and therefore to the quantities that reach the environment. The polyethylene match to being the largest polymer in world production (36%) and that found in marine vertebrate organisms (27.3%). The same happens with the polypropylene, which is the second polymer in world production (21%) and that found in marine vertebrate organisms (14.3%), and the same with polyester that is the third in world production (<10%) and fourth in marine vertebrate organisms (10.4%) (Geyer et al., 2017).

As for the predominant color, we found that in most of the groups studied the dark colors stand out (59.37% fish, 62.5% marine mammals, 75% turtles), being in all cases the majority blue (28.12% fish, 50% marine mammals, 75% turtles), this fits with other studies that highlight the predominant color in marine fauna such as black and blue (Rezania et al., 2018), the main explanation for this is that marine fauna confuse their common prey with microplastic particles due to the color (Kain et al., 2016; Rios-Fuster, Alomar et al., 2019). This has been demonstrated in plankton fish, which showed a preference for blue colored fragments, because their prey in the natural environment are blue copepods (Ory et al., 2017). However, birds are the only group with a preference for light colors (55.56%) with respect to the rest of the groups. These data are consistent with other studies that show a preference for light colors in birds compared to blue colors (Amélineau et al., 2016; Floren & Shugart, 2017; Kain et al., 2016). This can be explained by the probability that visual searchers locate the colors, thus animals that observe plastics from below ingest dark colored fragments, while animals that observe plastics from above ingest light colored plastics (Santos et al., 2016), this fits our data perfectly, and provides a reasonable explanation for the difference in color preference by groups.

Finally, it is essential to emphasize the need to harmonize terms and methodologies of studies of microplastics, since there is a great challenge when making comparisons between different studies (Gouin, 2020), and it is certain that many studies prior to 2010 will have been left out of this review because they do not use the term "microplastic" but any other term similar to it. These types of studies provide a global idea and a brief explanation of the world of microplastics, but the need for further research, focusing on terrestrial and marine sources, is indisputable. More attention needs to be paid to EDAR treatment areas (Carbery et al., 2018; Hardesty et al., 2015; Rezania et al., 2018; Ryan et al., 2009), as well as the extent of microplastic contamination in deep-sea marine biodiversity (Choy et al., 2020; Taylor et al., 2016), the toxic effect of organic contaminants associated with microplastics that can cause serious health problems in wildlife and humans who consume marine animals contaminated by microplastics (Abbasi et al., 2018; Carbery et al., 2018), and to assess and promote changes at the political and social levels that encourage real plastic reduction strategies (Gall & Thompson, 2015; Hardesty et al., 2015; Ryan et al., 2009).

Conclusions

The conclusions of this Final Master Dissertation are the following:

1. There is an urgent need to carry out studies of microplastic contamination in little studied areas such as Antarctica, the Arctic and the Indian Ocean, as well as to determine the degree of microplastic contamination in the species that live in the deep zones of the oceans.

2. It is essential to create a global knowledge network on microplastic contamination, promoting multidisciplinary teams and generating networks at an international level.

3. It is required to create a common methodology for the study of microplastics in marine biota, making quality studies that do not underestimate the impact of contamination due to the methodology. In this sense, we suggest that all studies of microplastics have been constructed using advanced technologies: Fourier Transformed Infrared Spectroscopic, Raman Spectroscopy, or any other not foreseen in this study that identifies microplastics with great effectiveness.

4. There is an urgent need to develop protection and conservation programs for the groups and species most affected by microplastic contamination, such as turtles. As well as for species that are on the Red List or in danger of extinction.

5. The prevalence of fiber-type microplastics gives us a clear idea of the failures in the countries waster water treatments (WWT), which is why further research is needed on the sources of microplastics, but even more necessary is the development of solutions so that these sources stop emitting these contaminants into the natural environment.

6. Adequate information between the scientific community, society and the politicians is now more necessary than ever, and therefore steps need to be taken to encourage connections between these three estates, providing clear and concise information, which will help to have environmental education and education for sustainability programs that will raise awareness and sensitize the whole population to

carry out a change of habits that will minimize the production, use and abandonment of plastics in the natural environment, encouraging the use of alternatives to plastic from the bases of responsible consumption.

7. It is imperative and inexcusable the need for managers, companies and politicians in all countries globally to carry out proper waste management, creating realistic plans and technical supervision of compliance, only by making a collaborative effort between all levels of society we can limit microplastic pollution and minimize its impact on marine biota.

Acknowledgements

This Final Master Dissertation is the result of a great effort and dedication by many people, who either directly or indirectly have allowed this to become a reality. First, I would like to thank my two tutors May and Alicia, who have always been there to support and guide me in the development of this work. On the other hand, I would like to thank the projects IMPLAMAC (MAC2/1.1a/265) Interreg MAC (European Fund to Regional Development, Macaronesian Cooperation) and INDICIT II (European Commission, MSFD- SECOND CYCLE: IMPLEMENTATION OF THE NEW GES DECISION AND PROGRAMMES OF MEASURES), and the SCHOLARSHIP FOR POST COMPULSORY STUDIES OF THE MINISTRY OF EDUCATION OF THE GOVERNMENT OF SPAIN.

On a personal level, I want to thank my grandmother, my mother and my brother Eric, as well as my aunts Susy, Carol and Nancy. I cannot forget my friends Alejandro and Manoli, who have always looked out for my well-being and whose advice has helped me make decisions. I would also like to thank to Enedina for all the help she has given me to carry out this work, and for all the signs of affection and encouragement she has given me during this time. Also, It is necessary for me to thank two people, who surely without their unconditional support would not have been able to reach the university, thank you Andres and Feluca. Finally, I would like to thank all the knowledge and advice that I have been given by some of the fantastic professionals that I have had the pleasure to meet at the University of Las Palmas de Gran Canaria.

Therefore, I hope that this work can be useful to realize the great impact that plastics have in our world, and the importance that society regenerates the spaces of coexistence with nature.

Annex: Table of data on microplastics in vertebrate marine biota

Location	Sample size (n)	Group	Species	Analysis	Individues with MPs (%)	MPs/individue	MPs (particles)	Predominant type (%)	Predominant polymer (%)	Predominant color (%)	Instrumentation	FTIR	Reference
Spain, North Atlantic	41	Bird	*Phalacrocorax aristotelis*	Feces	63.4	1.68 ± 0.42	69	63% Fibers	80% Nylon	N/A	Stereomicroscope	Yes	Álvarez et al., 2018
Greenland, North Atlantic	44	Bird	*Alle alle*	Gular pouch	47.7	9.99	166	97% Fibers	60% Polyvinyl Chloride	N/A	Binocular Microscope	Yes	Amelineau et al., 2016
Portugal, North Atlantic	288	Bird	17 species	Stomach	12.2	1.77	N/A	N/A	N/A	100% White	N/A	No	Basto et al., 2019
Antartic	80	Bird	*Pygoscelis papua*	Feces	20.0	1.19 ± 0.54	19	58% Fibers	60% Polyester	Blue	Microscope	Yes	Bessa et al., 2019
Canada, North Pacific	9	Bird	*Phalaropus fulicarius*	Stomach	100.0	N/A	111	61% Fragments	N/A	61% White	Binocular Microscope	No	Drever et al., 2018
EEUU, North Pacific	171	Bird	*Ptychoramphus aleuticus*	Gastrointestinal tract	41.5	N/A	404	28% Pellets	N/A	75% Brown	Binocular Microscope	No	Floren et al., 2017
Canada, North Pacific	850	Bird	*Ptychoramphus aleuticus*	Food loads	0.5	N/A	N/A	N/A	N/A	N/A	Microscope	No	Hipfner et al., 2017
North Pacific Gyre	25	Bird	*Phoebastria nigripes*	Stomach	100.0	N/A	42	N/A	N/A	54% White	Handheld ruler	No	Hyrenbach et al., 2017

North Pacific Gyre	62	Bird	2 species	Gizzard	53.2	1.795	136	87% Fragments	N/A	77% White	Vernier calipers	No	Kain et al., 2016
South Atlantic Gyre	47	Bird	*Aptenodytes patagonicus*	Feces	76.6	N/A	29	100% Fibers	55% Rayon	N/A	N/A	Yes	Le Guen et al., 2020
Portugal, North Atlantic	160	Bird	8 species	Stomach	22.50%	N/A	135	Fragments	Polydimethylsiloxane	White	Stereomicroscope	Yes	Nicastro et al., 2018
Labrador Sea, North Atlantic	60	Bird	*Fulmarus glacialis*	Feces/stomach	71.7	22 ± 34.4	N/A	49% Fragments	N/A	Blue	Stereomicroscope	No	Provencher et al., 2018
EEUU, North Pacific	168	Bird	2 species	Gastrointestinal tract	85.7	16.4	3111	N/A	N/A	N/A	Binocular Microscope	No	Terepocki et al., 2017
Australia, South Pacific	135	Bird	*Ardenna pacifica*	Stomach	13.3	1.5	N/A	56% Fragments	61% Polyethylene	N/A	Vernier calipers	Yes	Verlis et al., 2018
China Sea, North Pacific	9	Bird	3 species	Gastrointestinal tract	44.44%	N/A	52	89% Thread	84% Polypropylene-polyethylene copolymer	91% Blue	Binocular Microscope	Yes	Zhu et al., 2019
Australia, South Pacific	2	Reptiles	*Chelonia mydas*	Gastrointestinal tract	100%	N/A	7	71% Fibers	N/A	N/A	N/A	Yes	Caron et al., 2018
Greek, Mediterranean	36	Reptiles	*Caretta caretta*	Gastrointestinal tract	72%	N/A	46	76% Fragments	56% Polypropylene	48% White	N/A	Yes	Digka et al., 2020
Mediterranean	102	Reptiles	7 species	Stomach	100%	N/A	811	77% Fibers	63% Rayon	36% Blue	Stereomicroscope	Yes	Ducan et al., 2018

EEUU, North Atlantic													
Australia, South Pacific													
Hawaii, Central Pacific	50	Reptiles	3 species	Gastrointestinal tract	100%	N/A	828	Fragments	66% Polyethylene	N/A	N/A	Yes	Jung et al., 2018
Brasil, South Atlantic	43	Reptiles	*Chelonia mydas*	Stomach	81.40%	22.70 ± 5.87	N/A	N/A	N/A	N/A	Microscope	No	Machovsky-Capuska et al., 2020
Azores, North Atlantic	24	Reptiles	*Caretta caretta*	Gastrointestinal tract	58.30%	N/A	95	87% Fragments	60% Polyethylene	N/A	LCD microscope	Yes	Pham et al., 2017
Uruguay, South Atlantic	96	Reptiles	*Chelonia mydas*	Gastrointestinal tract	70%	220.76 ± 320.82	12454	Laminar	N/A	N/A	Stereomicroscope	No	Vélez-Rubio et al., 2018
EEUU, North Atlantic	13	Reptiles	3 species	Gastrointestinal tract	100%	N/A	13369	N/A	21% Polypropylene	N/A	Raman microscope	No	White et al., 2018
Artic	142	Mammals	3 species	Stomach	0.0	0	0	N/A	N/A	N/A	Steromicroscope	No	Bourdages et al., 2020
North Sea, North Atlantic	107	Mammals	*Phoca vitulina*	Stomach	12.15%	N/A	28	54% Fibers	N/A	N/A	Steromicroscope	No	Bravo et al., 2013
Bering Sea,	44	Mammals	*Callorhinus ursinus*	Feces	54.55%	20.38	584	68% Fragments	N/A	100% White	Microscope	Yes	Donohue et al., 2019

North Pacific													
Spain, North Atlantic	35	Mammals	*Delphinus delphis*	Stomach	100%	12 ± 8	411	97% Fibers	N/A	45% Blue	Steromicroscope	No	Hernández-González et al., 2018
Ireland, North Atlantic	13	Mammals	*Halichoerus grypus*	Gastrointestinal tract	100%	27.9 ± 14.7	363	85% Fibers	N/A	N/A	Microscope	No	Hernández-Milian et al., 2019
EEUU, North Atlantic	161	Mammals	2 species	Feces	2.48%	N/A	4	N/A	50% Cellophane	50% White	Steromicroscope	Yes	Hudak et al., 2019
Ireland, North Atlantic	1	Mammals	*Mesoplodon mirus*	Gastrointestinal tract	100%	N/A	88	58% Fibers	53% Rayon	N/A	Microscope	Yes	Lusher et al., 2015
Artic	7	Mammals	*Delphinapterus leucas*	Stomach	100%	11.6 ± 6.6	81	51% Fragments	44% Polyester	N/A	Microscope	Yes	Moore et al., 2020
England, North Atlantic	31	Mammals	*Halichoerus grypus*	Feces	48.39%	0.87 ± 1.09	26	69% Fragments	27% Polypropylene	27% Black	Microscope	Yes	Nelms et al., 2018
England, North Atlantic	50	Mammals	10 species	Gastrointestinal tract	100%	3.8 ± 2.5	261	84% Fibers	61% Nylon	43% Blue	Binocular Microscope	Yes	Nelms et al., 2019
Chile, South Pacific	51	Mammals	*Arctocephalus australis*	Feces	0	0	0	N/A	N/A	N/A	Microscope	No	Perez-Venegas et al., 2018

Chile, South Pacific	205	Mammals	4 species	Feces	67.80%	N/A	62	64% Fibers	N/A	Blue	Microscope	Yes	Perez-Venegas et al., 2020
North Sea, North Atlantic	654	Mammals	*Phocoena phocoena*	Stomach	6.73%	1.5 ± 0.2	71	N/A	46% Polyethylene	N/A	Binocular	No	Van Franeker et al., 2018
Yellow Sea, North Pacific	7	Mammals	*Neophocaena asiaeorientalis sunameri*	Gastrointestinal tract	100%	19.1 ± 7.2	134	70% Fibers	N/A	Blue	Raman microscope	No	Xiong et al., 2018
China, North Pacific	3	Mammals	*Sousa chinensis*	Gastrointestinal tract	100%	N/A	52	70% Fibers	N/A	White	Steromicroscope	Yes	Zhu et al., 2019
Persian Gulf, Indic	44	Fish	4 species	Gastrointestinal tract, gills, skin, muscle, livers	100%	15.3	734	Fibers	N/A	71% Black	Fluorescence microscopy	No	Abbasi et al., 2018
Ghana, North Atlantic	155	Fish	3 species	Gastrointestinal tract	100%	34.0 ± 2.1	N/A	31% Pellets	N/A	N/A	Steromicroscope	No	Adika et al., 2020
Persian Gulf, Indic	71	Fish	4 species	Muscle	100%	N/A	N/A	Fibers	N/A	N/A	Electron microscope	No	Akhbarizadeh et al., 2018
Spain, Mediterranean	125	Fish	*Galeus melastomus*	Stomach	16.80%	0.34 ± 0.07	N/A	86% Fibers	33% Cellophane	42% Transparent	Steromicroscope	Yes	Alomar et Deudero ., 2017

Spain, Mediterranean	417	Fish	*Mullus surmuletus*	Stomach	27.30 %	0.42 ± 0.04	N/A	97% Fibers	34.6% Polyethylene terephthalate	30% Blue	Steromicroscope	Yes	Alomar et al., 2017
Persian Gulf, Indic	20	Fish	8 species	Gastrointestinal tract	N/A	N/A	3	100% Fragments	Polyethylene	N/A	Steromicroscope	Yes	Al-Salem et al., 2020
Thailand, North Pacific	165	Fish	24 species	Stomach	66.70 %	1.75	204	Fibers	N/A	41% Transparent	Steromicroscope	No	Azad et al., 2018
Red Sea, Indic	178	Fish	26 species	Stomach	15.17 %	1.57	N/A	98% Fibers	42% Polypropilene	42% Black	Binocular microscope	Yes	Baalkhuyur et al., 2018
Portugal, North Atlantic	150	Fish	3 species	Gastrointestinal tract	49%	1.3 ± 2.5	175	54% Fibers	80% Polyethylene	67% Blue	Steromicroscope	Yes	Barboza et al., 2020
Spain, Mediterranean	128	Fish	*Mullus barbatus*	Stomach	18.75 %	1.9 ± 1.29	N/A	71% Fibers	N/A	51% Black	Steromicroscope	No	Bellas et al., 2016
Spain, North Atlantic	84	Fish	2 species		15.48 %	1.20 ± 0.45							
Ligurian Sea, Mediterranean	139	Fish	*Prionace glauca*	Stomach	31.40 %	N/A	28	72.4% Sheetlike	75% Polyethylene	47% Transparent	Microscope	Yes	Bernardini et al., 2018
Norwey, North Atlantic	302	Fish	*Gadus morhua*	Stomach	2.98%	N/A	3	N/A	Polyester	N/A	Steromicroscope	Yes	Brate et al., 2016
Central Gyre, North Pacific	670	Fish	6 species	Gastrointestinal tract	35%	2.1	1375	94% Fragments	N/A	58% White	Microscope	No	Boerger et al., 2010

Tyrrenian Sea, Mediterranean	67	Fish	2 species	Gastrointestinal tract	64.2%	3.45	N/A	99% Fibers	N/A	96% Black	Ion microscope	No	Bottari et al., 2019
North Sea, North Atlantic	57	Fish	3 species	Gastrointestinal tract	29.82%	1.8	N/A	45% Fibers	54% Polyethylene	37% Blue	Steromicroscope	Yes	Bour et al., 2018
Phillipines, North Pacific	120	Fish	*Siganus fuscescens*	Gastrointestinal tract	46.70%	0.6	N/A	N/A	Polypropylene	N/A	Steromicroscope	Yes	Bucol et al., 2020
Baltic Sea, North Atlantic	673	Fish	3 species	Gastrointestinal tract	0.43%	N/A	N/A	N/A	N/A	N/A	Steromicroscope	No	Budimir et al., 2018
Australia, Southern Ocean	342	Fish	21 species	Gastrointestinal tract	0.30%	N/A	2	100% Fragments	100% Acrylic resin	100% Green	Steromicroscope	Yes	Cannon et al., 2016
Tyrrenian Sea, Mediterranean	125	Fish	5 species	Gastrointestinal tract	14.40%	0.78	31	97% Fibers	31% Polypropylene	Black	Steromicroscope	Yes	Capillo et al., 2020
Brasil, South Atlantic	122	Fish	*Priacanthus arenatus*	Stomach	49.10%	N/A	210	55% Fragments	N/A	N/A	Steromicroscope	No	Cardozo et al., 2018
Chile, South Pacific	93	Fish	2 species	Gastrointestinal tract	8.60%	1.75	16	55% Flakes	55% Polyvinyl acetate	50% Blue	Microscope	No	Chagnon et al., 2016
China, North Pacific	60	Fish	*Mugil cephalus*	Gastrointestinal tract	60%	2.25	129	60% Fibers	42% Polypropylene	44% Green	Steromicroscope	Yes	Cheung et al., 2018

France, Mediterranean	14	Fish	3 species	Livers	79%	N/A	N/A	N/A	Polyethylene	N/A	Steromicroscope	No	Collard et al., 2017
North Atlantic	9	Fish	3 species	Stomach	100%	N/A	11	N/A	Polyethylene	N/A	Steromicroscope	No *	Collard et al., 2015
North Atlantic	60	Fish	3 species	Stomach	45%	N/A	43	Fibers	37% Polyethylene	N/A	Electron microscope	No *	Collard et al., 2017
Canada, North Pacific	74	Fish	*Oncorhynchus tshawytscha*	Gastrointestinal tract	59%	1.15 ± 1.41	N/A	95% Fibers	N/A	41% Transparent	Microscope	No	Collicutt et al., 2019
Spain, Mediterranean	210	Fish	2 species	Gastrointestinal tract	14.80%	0.21 ± 0.23	41	83% Fibers	30% Polyethylene terephthalate	N/A	Stereomicroscope	Yes	Compa et al., 2018
Brasil, South Atlantic	92	Fish	*Genidens genidens*	Stomach	13%	0.46	N/A	Fragments	Nylon polyamide	N/A	Steromicroscope	No	Dantas et al., 2019
Brasil, South Atlantic	214	Fish	7 species	Stomach	55%	N/A	306	68% Fibers	69% Polyester	32% Blue	Steromicroscope	No *	Dantas et al., 2020
Iceland, North Atlantic	85	Fish	2 species	Gastrointestinal tract	53%	0.28	22	59% Fibers	N/A	38% Blue	Microscope	Yes	De Vries et al., 2020
China Sea, North Pacific	31	Fish	29 species	Gastrointestinal tract	83.90%	3.5 ± 3.1	95	67% Fibers	31% Rayon	Blue	Steromicroscope	Yes	Ding et al., 2019
Yellow Sea, North Pacific	124	Fish	6 species	Gastrointestinal tract, gills, skin	100%	N/A	2060	98% Fibers	33% Cellophane	49% Black	Steromicroscope	Yes	Feng et al., 2019

Fiji, South Pacific	120	Fish	5 species	Gastrointestinal tract	67.50 %	N/A	N/A	60% Fibers	27% Polyethylene	N/A	Microscope	Yes	Ferreira et al., 2020
North Sea, North Atlantic	1203	Fish	7 species	Gastrointestinal tract	2.60%	N/A	42	N/A	25% Polyethylene	N/A	Steromicroscope	Yes	Foekema et al., 2013
Portugal, North Atlantic	27	Fish	*Alepisaurus ferox*	Stomach	74%	4.7 ± 4.8	126	86% Fibers	N/A	39% Black	Steromicroscope	Yes	Gago et al., 2020
Spain, Mediterranean	102	Fish	*Boops boops*	Gastrointestinal tract	46.08 %	1.68 ± 0.31	92	60% Fragments	56% Polypropylene	Blue	Steromicroscope	Yes	García-Garin et al., 2019
French Polynesia, South Pacific	133	Fish	4 species	Gastrointestinal tract	21.05 %	1.25 ± 0.13	35	69% Fragments	N/A	N/A	Microscope	No	Garnier et al., 2019
Tyrrenian Sea, Mediterranean	229	Fish	2 species	Gastrointestinal tract	22.71 %	1.38	65	81% Fibers	N/A	49% Blue	Steromicroscope	Yes	Giani et al., 2019
Turkey, Mediterranean	1337	Fish	26 species	Gastrointestinal tract	34.18 %	1.6	1822	70% Fibers	N/A	50% Blue	N/A	Yes	Güven et al., 2017
North Sea, North Atlantic	400	Fish	4 species	Gastrointestinal tract	0.25%	N/A	2	N/A	100% Polymethylmethacrylate	100% Transparent	Microscope	Yes	Hermsen et al., 2017
Canary Islands, North Atlantic	120	Fish	*Scomber colias*	Gastrointestinal tract	78.33 %	2.77±1.91	260	74% Fibers	N/A	55% Blue	Steromicroscope	Yes	Herrera et al., 2019

Canada, North Pacific	939	Fish	2 species	Gastrointestinal tract	1.60%	N/A	106	100% Fibers	Polyester	25% White	Microscope	Yes	Hipfner et al., 2018
India, Indic	75	Fish	3 species	Gastrointestinal tract	100%	5.91 ± 1.54	443	55% Fibers	Polyamide	White	Microscope	Yes	Hossain et al., 2019
China, North Pacific	120	Fish	32 species	Gastrointestinal tract	47%	2.83 ± 1.84	342	70% Fibers	35% Polyethylene	N/A	Steromicroscope	Yes	Huang et al., 2020
China Sea, North Pacific	N/A	Fish	21 species	Gastrointestinal tract	N/A	4.05	N/A	56% Fibers	49% Cellophane	N/A	Steromicroscope	Yes	Jabeen et al., 2017
Australia, South Pacific	60	Fish	*Pomacentrus moluccensis*	Gastrointestinal tract	95.00%	N/A	208	100% Fibers	43% Rayon	33% White	Steromicroscope	Yes	Jensen et al., 2019
India, Indic	190	Fish	13 species	Gastrointestinal tract	8.95%	N/A	17	Films	Polyethylene	71% Transparent	Steromicroscope	Yes	Karuppasamy et al., 2020
China Sea, North Pacific	481	Fish	24 species	Gastrointestinal tract	49.10%	0.228 ± 0.080	N/A	96% Fibers	44% Polyester	83% Transparent	Steromicroscope	Yes	Koongolla et al., 2020
Australia, South Pacific	20	Fish	*Plectropomus ssp.*	Gastrointestinal tract	100%	N/A	115	97% Fibers	24% Cellulose-regenerated	25% White	Steromicroscope	Yes	Kroon et al., 2018
Artic	72	Fish	*Boreogadus saida*	Stomach	2.78%	N/A	2	100% Fragments	100% Kaolin	N/A	Steromicroscope	Yes	Kuhn et al., 2018
India, Indic	40	Fish	2 species	Gastrointestinal tract	30.00%	N/A	N/A	80% Fibers	N/A	20% Transparent	Steromicroscope	Yes	Kumar et al., 2018

France, Mediterranean	169	Fish	2 species	Gastrointestinal tract	12%	0.16	26	99% Fibers	80% Polyethylene terephthalate	52% White	Steromicroscope	Yes	Lefebvre et al., 2019
Labrador Sea, North Atlantic	205	Fish	*Gadus morhua*	Gastrointestinal tract	2.44%	N/A	7	43% Fragments	N/A	71% White	Microscope	Yes	Liboiron et al., 2016
Labrador Sea, North Atlantic	1429	Fish	3 species	Gastrointestinal tract	1.68%	1.12	19	53% Fibers	N/A	47% White	Microscope	No*	Liboiron et al., 2019
English Channel, North Atlantic	504	Fish	10 species	Gastrointestinal tract	36.50%	1.90 ± 0.10	351	68% Fibers	58% Rayon	45% Black	Microscope	Yes	Lusher et al., 2013
North Sea, North Atlantic	761	Fish	10 species	Gastrointestinal tract	11%	1.2 ± 0.54	101	93% Fibers	N/A	42% Black	Steromicroscope	No	Lusher et al., 2014
Morocco, North Atlantic	251	Fish	3 species	Stomach	26.00%	N/A	N/A	N/A	Polyamide	N/A	N/A	Yes	Maaghloud et al., 2020
Tyrrenian Sea, Mediterranean	50	Fish	*Scyliorhinus canicula*	Gastrointestinal tract	80%	0.7	138	83% Fibers	Polyethylene terephthalate	64% Black	Steromicroscope	No*	Mancia et al., 2020
Brasil, South Atlantic	32	Fish	11 species	Stomach	21.88%	N/A	N/A	100% Pellets	N/A	N/A	Microscope	No	Miranda et al., 2016
Brasil, South Atlantic	14	Fish	2 species	Stomach	50%	N/A	N/A	100% Pellets	N/A	N/A	Binocular microscope	No	Miranda et de Carvalho-

													Souza., 2016
Chile, South Pacific	62	Fish	5 species	Gastrointestinal tract	N/A	N/A	N/A	99% Fibers	N/A	Transparent	Microscope	No	Mizraji et al., 2017
Artic	156	Fish	2 species	Gastrointestinal tract	25%	1.1 ± 0.3	N/A	88% Fibers	34% Polyester	49% Blue	Steromicroscope	Yes	Morgana et al., 2018
Spain, Mediterranean	337	Fish	*Boops boops*	Gastrointestinal tract	67.7%	3.75 ± 0.25	731	N/A	N/A	N/A	Steromicroscope	No	Nadal et al., 2016
South Africa, Indic	70	Fish	*Mugil cephalus*	Gastrointestinal tract	72.80%	3.8	260	51% Fibers	N/A	42% White	Microscope	No	Naidoo et al., 2016
England, North Atlantic	31	Fish	*Scomber scombrus*	Gastrointestinal tract	32.26%	0.58 ± 1.05	18	72% Fibers	28% Propylene	28% Red	Microscope	Yes	Nelms et al., 2018
Portugal, North Atlantic	263	Fish	17 species	Stomach	20.53%	0.27 ± 0.63	73	66% Fibers	Polypropylene	N/A	Steromicroscope	Yes	Neves et al., 2015
China Sea, North Pacific	35	Fish	16 species	Gastrointestinal tract	60.00%	3.1	N/A	Fibers	N/A	Transparent	Steromicroscope	No*	Nie et al., 2019
Easter Island, South Pacific	20	Fish	*Decapterus muroadsi*	Gastrointestinal tract	100%	2.5 ± 0.4	48	92% Fragments	81% Polyethylene	40% Blue	Microscope	Yes	Ory et al., 2017
South America, South Pacific	292	Fish	7 species	Gastrointestinal tract	2.10%	N/A	6	60% Fragments	60% Polyethylene	40% Green	Microscope	Yes	Ory et al., 2018

Adriatic Sea, Mediterranean	533	Fish	*Solea solea*	Gastrointestinal tract	95%	1.73 ± 0.05	4566	72% Fragments	21% Polypropylene	N/A	Microscope	Yes	Pellini et al., 2018
EEUU, North Atlantic	1381	Fish	6 species	Stomach	42%	1.93	1141	86% Fibers	N/A	36% Blue	Microscope	No	Peters et al., 2017
EEUU, North Atlantic	116	Fish	8 species	Gastrointestinal tract	10.40%	N/A	N/A	37% Fibers	N/A	N/A	N/A	Yes	Phillips et Bonner, 2015
Chile, South Pacific	60	Fish	6 species	Gastrointestinal tract	33.33%	N/A	N/A	100% Fibers	75% Polyethylene terephthalate	80% Red	Microscope	Yes	Pozo et al., 2019
Adriatic Sea, Mediterranean	160	Fish	2 species	Stomach	93.50%	2.94	N/A	57% Fibers	61% Polyvinyl Chloride	Black	Steromicroscope	No	Renzi et al., 2019
Spain, Mediterranean	197	Fish	4 species	Gastrointestinal tract	28.35%	1.13 ± 1.99	127	93% Fibers	N/A	58% Blue	Steromicroscope	No	Rios-Fuster et al., 2019
India, Indic	70	Fish	23 species	Gastrointestinal tract	21.40%	N/A	22	77% Fibers	38% Polyethylene	68% White	Steromicroscope	Yes	Robin et al., 2020
Indonesia, Indic	76	Fish	11 species	Gastrointestinal tract	28%	N/A	105	60% Fragments	N/A	N/A	Microscope	No	Rochman et al., 2015
EEUU, North Pacific	64	Fish	12 species		25%		30	80% Fibers					
Tyrrenian Sea,	121	Fish	3 species	Stomach	18.18%	N/A	29	100% Fragments	N/A	Transparent	Steromicroscope	No	Romeo et al., 2015

Mediterranean													
Italy, Mediterranean	522	Fish	4 species	Stomach	2.68%	N/A	14	100% Fragments	N/A	36% Transparent	Steromicroscope	No	Romeo et al., 2016
Baltic Sea, North Atlantic	290	Fish	5 species	Gastrointestinal tract	5.52%	0.03 ± 0.18	17	56% Fragments	40% Polyethylene	43% White	Steromicroscope	Yes	Rummel et al., 2016
India, Indic	100	Fish	6 species	Gastrointestinal tract	N/A	1.49 ± 1.43	174	70% Fibers	54% Polyethylene	55% Blue	Microscope	Yes	Sathish et al., 2020
Tyrrenian Sea, Mediterranean	39	Fish	2 species	Gastrointestinal tract	10.26%	N/A	N/A	100% Fibers	100% Nylon	100% Black	Steromicroscope	Yes	Savoca et al., 2019
Tyrrenian Sea, Mediterranean	30	Fish	*Boops boops*	Gastrointestinal tract	63.30%	2.7	80	100% Fibers	N/A	85% Black	Steromicroscope	No*	Savoca et al., 2019
English Channel, North Atlantic	347	Fish	23 species	Gastrointestinal tract	2.90%	N/A	12	83% Fibers	Rayon	83% Blue	Microscope	Yes	Steer et al., 2017
Yellow Sea, North Pacific	1320	Fish	19 species	Gastrointestinal tract	34%	1.2	546	67% Fibers	40% Organic oxidation polymer	N/A	Steromicroscope	Yes	Sun et al., 2019
Japan, North Pacific	64	Fish	*Engraulis japonicus*	Gastrointestinal tract	77%	2.3 ± 2.5	150	86% Fragments	52% Polyethylene	40% White	Microscope	Yes	Tanaka et Takada., 2016

Tyrrenian Sea, Mediterranean	96	Fish	3 species	Gastrointestinal tract	68.80%	N/A	258	86% Fibers	40% Polypropylene	69% Black	Microscope	Yes	Valente et al., 2019
Baltic Sea, North Atlantic	139	Fish	*Zoarces viviparus*	Gastrointestinal tract	7.91%	N/A	11	93% Fibers	35% Polyester	N/A	Microscope	Yes	Verlaan et al., 2019
Yellow Sea, North Pacific	5	Fish	3 species	Gastrointestinal tract	100%	N/A	814	N/A	N/A	N/A	Electron microscope	Yes	Wang et al., 2019
German, North Atlantic	150	Fish	*Zoarces viviparus*	Gastrointestinal tract	0%	N/A	N/A	N/A	N/A	N/A	Steromicroscope	Yes	Wesch et al., 2016
China Sea, North Pacific	193	Fish	11 species	Gastrointestinal tract	57.50%	0.77 ± 1.25	250	60% Fibers	44.9% Polyethylene terephthalate	Blue	Steromicroscope	Yes	Zhang et al., 2019
China Sea, North Pacific	35	Fish	13 species	Gastrointestinal tract	97%	1.96 ± 1.12	N/A	52% Films	57% Cellophane	62% Transparent	Microscope	Yes	Zhu et al., 2019

***Use Raman Spectroscopy**

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