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CAPCIT REPORT

Microplastics in the environment

(particularly in the Mediterranean)

Written by:

Institut d'Estudis Catalans

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Introduction

Thor Heyerdahl explained, in his account of the Ra expedition, that the crew of this raft found plastics and other materials of anthropic origin floating in the sea, many hundreds of miles from the mainland. The famous expedition took place [50] years ago. No reminder is needed on how the transportation of oil by sea has increased and how the production and widespread use of plastic materials have developed since then. Therefore, it is unsurprising that the accumulation of plastics is a problem of the first magnitude – first on our beaches and then in the open sea – and not just an aesthetic issue.

Joandomènec Ros (2014)

Plastic pollution is one of the main environmental challenges posed by the unsustainable use and disposal of products made with plastic materials by human societies. It is currently recognised as a global, multidimensional, and multisectoral problem, with an impact on the environment, economy, public health, food security, and even culture (Bergmann et al., 2015; GESAMP, 2015). The last part of the Anthropocene – the geological epoch characterised by the presence and, above all, the activity of the human species – has even been named Plasticene (Haram et al., 2020). In recent years, researchers in different areas have been identifying sources, quantities, and impacts of plastic pollution, although knowledge is still limited (Figure 1).

Figure 1. Microplastic pollution is common. (Original by Joan-Albert Ros, based on various sources.)

The presence of large plastics (macroplastics) in the ocean has serious consequences for marine life and human health. Marine animals often become entangled in plastic items (e.g. turtles, fish), while others ingest them (e.g. whales, dolphins, turtles, birds), which reduces their digestive capacity until they die of starvation. Many plastic polymers have a lower density than water, so they float to the surface, making it difficult to exchange oxygen and transmit light through the water column (Harrison et al., 2011).

Commercial plastics are never pure. They contain many additives to improve their durability and other properties necessary for their purpose. These additives include a wide range of different chemicals and materials such as plasticisers, colorants, stabilisers, flame retardants and antioxidants, among others. They are found in different proportions in the formulation of plastic materials. Additives found in plastics or polymer oligomers can migrate to aquatic environments, altering the chemistry of water and affecting marine organisms (e.g., Romera-Castillo et al., 2018). The magnitude of the leaching of these substances depends on the types of plastic, the chemical properties of the additives, the stage of degradation of the plastic, etc.

It has been estimated that up to 23,600 t of dissolved organic carbon (DOC) can be released from the plastic that reaches the ocean each year (Romera-Castillo et al., 2018). The washing or leaching of plastics is enhanced by photodegradation, caused by ultraviolet radiation, and most of the released compounds have a molecular weight of less than 350 daltons (Da) (Lee et al., 2020). About 7% of the weight of plastic can be lost in the form of DOC under ultraviolet radiation (Zhu et al., 2020). It has been proved that leached compounds alter the marine food web by stimulating the growth of marine bacteria (Romera-Castillo et al., 2018; Zhu et al., 2020). On the other hand, however, they can negatively affect the ability to photosynthesise and the growth of photosynthetic organisms (such as cyanobacteria of the genus Prochlorococcus; Tetu et al., 2019), which leads to a reduction in the production of organic matter and oxygen.

Another consequence of the presence of plastics in aquatic environments is the introduction of invasive species. As soon as plastic reaches the aquatic environment, it begins to be covered by a biofilm, composed of different colonising microorganisms such as bacteria, microalgae, fungi and various invertebrates. Plastic fragments act as vectors of micro- and macroorganisms, which thus travel aboard the plastic to other habitats and alter the receiving ecosystem (Rech et al., 2016). Invasive alien species transported by plastic waste pose a threat to biodiversity and ecosystem services.

It is known that the presence of plastics in the environment and especially in the ocean is increasing. Among them, microplastics (MP) and nanoplastics (NP) are of special interest because of their small size (less than 5 mm), but also because they can be another source of pollutants through the release of additives and plasticisers (Llorca et al., 2020).

In addition, microplastics can accumulate organic and inorganic pollutants, as well as environmental pathogens (air, water or particles), making them an important vector for the transport of these pollutants to aquatic organisms (Cole et al., 2011; Llorca et al., 2014; Rios et al., 2007; Pittura et al., 2018; Ashton et al., 2010). Due to their small size – similar to plankton, benthic protozoa and bacteria –, microplastics and nanoplastics can enter the marine food web via ingestion by aquatic organisms (Llorca et al., 2014; Pittura et al., 2018; Wright and Thompson, 2013; Cole et al., 2014).

There is, therefore, a scientific, economic, social and environmental interest in microplastics, and there are many studies on the topic that have been and are being carried out. Synthesis works, which offer a general overview at every moment in time, are not uncommon either. This report has made use of these (Bowmer and Kershaw, 2010; GESAMP, 2015; Cózar et al., 2015; Lusher et al., 2017; Costa, 2017; SAPEA, 2019; Barceló and Picó, 2019; ECHA, 2020; Llorca et al., 2020), as well as various specific works, especially by Catalan researchers and researchers from around the Mediterranean basin. The full list of these works can be found in the final bibliography.

2
Physical and chemical characterisation

Microplastics are plastic fragments smaller than 5 mm, from 0.1 or 1 µm. Plastics measuring less than 0.1 µm are called nanoplastics (SAPEA, 2019; Llorca et al., 2020). For the purposes of this report, we will normally refer to microplastics, including nanoplastics. If distinguishing between them is necessary, we will specify it.

Microplastics are solid particles composed of mixtures of polymers – the main component of plastics – and functional additives that improve the properties of these polymers, such as flexibility and durability – i.e. flame retardants, impact modifiers, and antioxidants, among others (ECHA, 2020; “Polymer Properties Database”, 2019). In addition, they may also contain impurities due to the manufacturing process. These tiny plastics can be formed indirectly by wearing of larger plastic fragments (miscellaneous items, synthetic textiles, etc.), or they can be manufactured directly as additives to various products, such as exfoliating beads in facial or body exfoliators (ECHA , 2020).

Microplastics include a wide range of microparticle types (pellets, fragments, fibres, films, foam, etc.), and also have a wide range of sizes, from 5 mm (microplastics) to 1 nm (nanoplastics; Corradini et al., 2019; Caldwell et al., 2019), as well as a wide variety of polymer types. Among the most widely used in industry and in everyday use are polyethylene (PE, high and low density – HDPE and LDPE, respectively), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS – including the expanded, EPS), polyurethane (PUR), polyethylene terephthalate (PET), and polyamides (PA; Caldwell et al., 2019; GESAMP, 2015; Sánchez-Vidal et al., 2018).

3
Origin and means of dispersion

Microplastics are classified into primary and secondary, depending on whether the particles are originally manufactured in this size (primary) or whether they are the result of the fragmentation and decomposition of larger articles (secondary; GESAMP, 2015). For example, granules or pellets of primary virgin resin are used in plastic manufacturing, as well as in the transport of raw resin materials for the prior production of plastic products. Other primary microplastics are used as industrial scrubbers, plastic powder for moulding and in cosmetic formulations such as microbeads, among others (GESAMP, 2015). Secondary microplastics are the result of the fragmentation and weathering of larger plastic articles during the manufacturing process of different products – or within the environment, subjected to different meteors and radiation (GESAMP, 2015).

Microplastics reach the environment from different sources (Figure 1). In the case of primary microplastics, they are released from factories and wastewater, or are lost in a small proportion when transported as virgin pellets (GESAMP, 2015). Their dispersion and transport due to the wind have also been verified. In contrast, the main sources of distribution of secondary microplastics are difficult to identify, as they depend on the distribution of macroplastics and the degradation processes once they reach the environment. In addition, depending on the size of the waste, the effects of the weather influence it to varying degrees (GESAMP, 2015).

In the case of river systems – including water, and river sediments –, the presence of microplastics is due to anthropogenic mechanisms, through the discharge of these products from direct source industries as well as wastewater treatment plants – although water purification effectively removes 80% to 90% of microplastics as they become trapped in sewage sludge (Corradini et al., 2019; Li, X. et al., 2018).

Microplastics that pass through river systems reach the seas and oceans through river discharge. This is one of the main sources of microplastics in marine environments, along with the direct disposal of larger plastics, among other minor sources. Once there, low-density polymers are expected to remain on the surface of the water, while high-density polymers are expected to sink to the sediment as a final drain (Woodall et al., 2014; Sanchez-Vidal et al., 2018). However, low-density polymers can also reach sediments, as their physical and chemical characteristics can change due to the effects of weather, or they can even be modulated by an eco-crown of aquatic organisms that settle on their surface area and increase their density (De Haan et al., 2019).

The main factors influencing the transport of microplastics to sediments are: a) gravity transport in sediment-laden streams; b) deposition – or transport by biological processes – of material that previously floated on the surface or was suspended in the water column; c) transport by thermohaline currents, either during deposition or through the reorganisation of deposited microplastics (Kane and Clare, 2019; Kane et al., 2020).

As for terrestrial sediments, microplastics reach them through various physical, biological, and anthropogenic mechanisms (Rillig et al., 2017). These microplastics are detected in sediments, including agricultural soils. In the latter, their presence is explained by the reuse of sludge from sewage treatment plants as fertilisers (compost) and by irrigation with wastewater, by the weathering and disintegration of plasticulture in crop fields, by the fragmentation of plastic waste and plastic articles, and by sedimentation of soil from flooded areas (Nizzetto et al., 2016a; Rochman, 2018; Bläsing and Amelung, 2018; Scheurer and Bigalke, 2018).

Finally, microplastics that are widespread in the environment can accumulate in animals by ingestion due to their small size and, ultimately, can be consumed by humans (ECHA, 2020; Scheurer and Bigalke, 2018; Lusher et al., 2017; EFSA, 2016).

4
Microplastics in the environment

The field of microplastics research has grown considerably in the last two decades, starting with the marine system and the fundamental work of Thompson et al. (2004). Interest in terrestrial systems is fairly new (Rillig, 2012) and very few studies focus on the presence, destination, or impact of microplastics in soils (Duis and Coors, 2016; Lambert and Wagner, 2016; Rillig, 2012). Recent attempts to conceptualise the “plastics cycle”, not only from the perspective of transport from terrestrial to oceanic environments, but also including atmospheric sciences and biogeochemistry, trophic transfer, and health and human exposure (Bank and Hansson, 2019), have shown that microplastics can move between different compartments on a large scale, including air, terrestrial habitats, rivers and other inland water environments to eventually reach the ocean (Bank and Hansson, 2019).

4.1. Inland waters

There are microplastics in different types of inland waters, in concentrations similar to those found in the sea. They are found on the surface, in the water column, and in the sediments of lakes, rivers, and estuaries (Eerkes-Medrano et al., 2015; Li et al., 2018). Concentrations of microplastics in inland waters vary geographically, from a few items to thousands of items per cubic meter (item/m^3; Horton et al., 2017; Rezania et al., 2018). Concentrations of microplastics in inland water sediments are also highly variable and can reach several thousand items per kilogram (it./kg) of sediment (Hurley et al., 2018; Rezania et al., 2018). In addition, there is a spatial correlation between microplastics in inland waters and human activities (Eerkes-Medrano et al., 2015; Li et al., 2018; Rezania et al., 2018).

A study carried out in 157 sampling points in streams and rivers throughout Spain (León-Muez et al., 2020) found microplastics in the surface waters of 70% of the samples. These microplastics are fibres, fragments, and films of 33 different polymers.

Microplastics, especially fibres, have been found in the Ebro Delta. They accumulate in river sediments, and the salt wedge dynamics of estuaries can facilitate the sinking of microplastics provided by rivers (Simón-Sánchez et al., 2019). Styrene oligomers, which are indicators of polystyrene pollution, are transported from land to sea by surface runoff (Tokyo Bay; Amamiya et al., 2019).

4.2. Seas and oceans

The emergence of plastics and, specifically, microplastics in seas and oceans has been evidenced in many studies (Ros, 2001, 2011, 2012; Sanchez-Vidal et al., 2018; Antunes et al., 2018; León et al., 2018, 2019; Lebreton et al., 2012; Constant et al., 2019; Kaandorp et al., 2020). According to Koelmans et al. (2016), the average concentration of plastic “in the ocean as a whole” could be approximately equal to 2 ng/L, but the largest accumulation is found on the Atlantic beaches near industrial areas, in urban areas and in cargo or port facilities (Antunes et al., 2018). In the specific case of the Mediterranean Sea, the presence of these pollutants along the entire coast and, above all, on the beaches has been proved. The Mediterranean Sea could accumulate between 1,000 t and 3,000 t of floating plastic waste (Cózar et al., 2015), and is one of the marine environments most affected by marine litter (Lebreton et al., 2012).

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A recent study (Kaandorp et al., 2020) indicates that of all the plastics that have entered the Mediterranean Sea since 2006, between 170 t and 420 t float in surface water, of which between 49% and 63% are found near the coast, and between 37% and 51% have sunk. Due to the pollution load, the Mediterranean can be considered as a large region of accumulation of plastic waste due to its characteristic morphology of almost closed basin, with an accumulation comparable to some areas described for the five subtropical ocean gyres (Cózar et al., 2015; Cincinelli et al., 2019).

The main plastic pollution of the surface waters of the Mediterranean is dominated by millimetre-sized fragments (Güven et al., 2017; Suaria et al., 2016; Van der Hal et al., 2017; Schirinzi et al., 2019; Schmidt et al., 2018; Baini et al., 2018; Simón-Sánchez et al., 2019), but with a high proportion of macro- and mesoplastics (Cózar et al., 2015; Gündoğdu and Çevik, 2019). However, the lack of quantitative analytical methods prevents the evaluation of microplastics and nanoplastics, for which only estimated data is available (Llorca et al., 2020).

The microplastics detected in aquatic systems depend, as we have said before, on their physical and chemical properties – such as density and shape, among others –, as well as on the polymer composition, the additives used and the characteristics of aging. In general, the polymers reported in marine environments, including surface and deep water and sediment, are PE, PP, PS, PET, PVC and PA (Llorca et al., 2020; Sánchez-Vidal et al., 2018; De Haan et al., 2019). In addition, environmental characteristics influence the interaction they have with other marine particles, organic matter, and organisms that affect how microplastics float or sink (Sánchez-Vidal et al., 2018; Wright et al., 2013). In recent years, several studies have evaluated the abundance, distribution, and composition of floating macroplastics and microplastics in oceans and seas around the world (Llorca et al., 2020).

In general, the largest amounts of microplastics have been detected near industrialised areas. For example, it has been reported that the Atlantic Ocean is one of the most polluted areas (Koelmans et al., 2016; De Carvalho and Neto, 2016; Law et al., 2010; Lusher et al., 2014; GESAMP, 2015; Bowmer and Kershaw, 2010), with levels below 1,000 it./km² and up to 1,300,000,000 it./km² (in the Guanabara Bay area, Brazil; De Carvalho and Neto, 2016) – although the coast of Portugal reaches up to 362,000,000 items/km² (Antunes et al., 2013) –, and some of its marginal seas, such as the Baltic Sea (Andrady, 2011; Lönnstedt and Eklöv, 2016) and the North Sea (Dubaish and Liebezeit, 2013), have an average of approximately 179,256 items/km² and 14,632,398 items/km², respectively.

From the coast, microplastics are exported to the high seas, as evidenced by samples taken with nets connected to surfboards, which increase the possibility of obtaining coastal samples (Camins et al., 2020; Uviedo et al., 2020).

If we focus on the open ocean, the amounts reported in the eastern Pacific Ocean range from 100,000 it./km² to 1,000,000 it./km² (Bradney et al., 2019; Lebreton et al., 2018; Desforges et al., 2014). It has also been found that the Great Pacific Garbage Patch accumulates plastic rapidly (Lebreton et al., 2018), while microplastic levels in the western seas of the Pacific Ocean – including, among others, the Sea of Japan, the Yellow Sea, the Seto Inland Sea and the East China Sea – are much higher (from below 1,000 it./km² to 46,334,000,000 it./km²; Da Costa et al., 2017; Kim et al., 2015; Isobe et al., 2014; Eriksen et al., 2018). Microplastic pollution has also reached the waters and even the sea ice of the Arctic Ocean, but with much lower values (between <1,000 and 100,000 it./km²; Lusher et al., 2015; Obbard et al., 2014).

In the specific case of the Mediterranean Sea, the floating plastic remains of the entire Mediterranean region have been estimated at a total value of 1,455 t of dry weight (DW; Ruiz-Orejón et al., 2016; see Table 1 for the Catalan coast, and Figure 2). In this characteristic sea, the largest number of microplastics has been recorded in the easternmost part, the Levantine Sea. Some authors have reported values in this area between 100,000 items/km² and 37,600,000,000 items/km² (Van der Hal et al., 2017; Shahul-Hamid et al., 2018; Gündoğdu and Çevik, 2017; Waller et al., 2017; Kazour et al., 2019), while much lower levels have been detected in the Aegean Sea area (Topçu and Öztürk, 2010; Politikos et al., 2017), the Ligurian Sea (Baini et al., 2018; Fossi et al., 2012, 2016; Pedrotti et al., 2014, 2016), the Sardinian Sea (Fossi et al., 2012; Panti et al., 2015; De Lucia et al., 2014), the Adriatic Sea (Blašković et al., 2017; Gajšt et al., 2016; Munari et al., 2017; Palatinus et al., 2019; Vianello et al., 2018; Zeri et al., 2018), the Gulf of Lion

(Constant et al., 2019; Schmidt et al., 2018) and the westernmost and central parts of the Mediterranean Sea, including the Catalan coast, where the amounts of plastics were generally below 500,000 items/km² (Constant et al., 2019; Cózar et al., 2015; Cincinelli et al., 2019; Ruiz-Orejón et al., 2016; Romeo et al., 2015; Filgueiras et al., 2019).

	Latitude	Longitude	Floating plastics (items/km²)	
Cap de Creus South	42º10.8' N	3º14.4' E	157,000.00	de Haan et al., 2018
Cap de Creus North	42º22.0' N	3º17.6' E	257,000.00	de Haan et al., 2018
Off Ter	42º01.2' N	3º14.2' E	10,000.00	de Haan et al., 2018
Off Sant Feliu de Guíxols	41º45.2' N	3º03.8' E	88,000.00	de Haan et al., 2018
Off Tordera	41º37.0' N	2º46.8' E	514,000.00	de Haan et al., 2018
Off Besòs	41º24.3' N	2º16.1' E	70,000.00	de Haan et al., 2018
Catalan coast average			**182,666.67**	
Somorrostro beach	41°22.23'N	2°11.41'E	27,200.00	Camins et al., 2020
Somorrostro beach	41°23.10' N	2°11.83'E	114,000.00	Camins et al., 2020
Somorrostro beach	41°23.07' N	2°11.84'E	36,000.00	Camins et al., 2020
Somorrostro beach	41°22.91' N	2°11.72'E	398,000.00	Camins et al., 2020
El Prat beach	41°17.09'N	2°06.06'E	40,200.00	Camins et al., 2020
El Prat beach	41°17.09'N	2°06.06'E	57,500.00	Camins et al., 2020
Barcelona beaches average			**112,000.00**	
Balearic Islands average			900,324.00	Ruiz-Orejón et al., 2018
Balearic Islands beaches average			858,029.00	Compa et al., 2020
Adriatic Sea - Western Mediterranean average			400,000.00	Suaria et al., 2016
Ligurian Sea average			103,000.00	Pedrotti et al., 2016
North Atlantic			2,500.00	Law et al., 2010
North Pacific			105,100.00	Eriksen et al., 2014
Pacific Subtropical Gyre			678,000.00	Lebreton et al., 2018

Table 1. Abundance of floating plastics (items/km²) at different points off the Catalan coast. Data of microplastics (<5mm) and mesoplastics (5-25mm) is included. Some data from nearby and global areas is shown for comparative purposes.

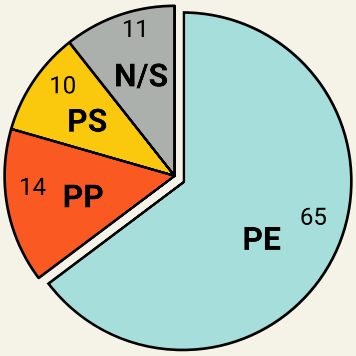

Figure 2. Composition of microplastics floating on the Catalan coast. CEL, cellulose (natural or regenerated); PET, polyethylene terephthalate; PE, polyethylene; PP, polypropylene; AC, acrylic; PA, polyamide. (Adapted from de Haan et al., 2019.)

It is to be expected that plastic materials with a density higher than seawater (1.02 g/cm³) will sink and accumulate in the sediments of the seabed, while low-density materials will initially tend to float on the surface or remain suspended in the water column (Chubarenko et al., 2018). In addition, the association of particles with organic material and organisms (known as biofouling, i.e. the set of organisms that adhere to solid substrates, from particles to boat hulls) produces a change in density that facilitates the sinking of plastic and microplastic waste. In the case of microplastics, they have exceptional mobility once they are in a marine environment, due to the combination of the particles' properties (e.g. density, chemical composition, shape) with external hydrodynamics, marine sedimentology and physical oceanographic conditions.

For example, recent studies have shown that particle shape and bio-inlay are the main contributors to the sedimentation or suspension behaviour of microplastics. The main hypothesis is that floating fibres and threads ("one-dimensional" particles, 1-D) are the first to begin to sink, followed by 2-D films and flakes, and then 3-D fragments (Chubarenko et al., 2018). This hypothesis has been confirmed by various researchers. For example, Sánchez-Vidal et al. (2018) detected large amounts of microfibres in sediments from the deep waters of the Cantabrian Sea, the Black Sea, and the Mediterranean Sea (including the Alboran Sea, the Levant Sea, and the Cretan Sea). In another study, Woodall et al. (2014) showed that the amount of microfibres was higher in deep-water sediments (up to four orders of magnitude) than on the surface of the sea in polluted areas of the Atlantic Ocean, Indian Ocean and Mediterranean Sea. Regarding the type of polymer, the main polymers that have been detected in coastal sediments and high sediments include natural and regenerated cellulose (Sánchez-Vidal et al., 2018), as well as synthetic plastics such as PS, PE, PP (Sánchez-Vidal et al., 2018; Vianello et al., 2013; Abidli et al., 2018), acrylic and polyamide (including nylon; Sánchez-Vidal et al., 2018), and ethylene-vinyl alcohol copolymers (Mistri et al., 2017). See Figure 3 for data from Catalonia.

In the specific case of the Mediterranean Sea, the main amounts of microplastics detected along the marine sediments range between 4 it./kg DW (dry weight) of sediment (Romeo et al., 2015) and more than 2,000 it./kg DW (Vianello et al., 2013). Focusing on the sediments of the Spanish Mediterranean coast, Filgueiras et al. (2019) researched surface sediments from Algeciras to Barcelona, including samples from Málaga, Castell de Ferro, Almería, Cartagena, Benidorm, Benicarló, Vallcarca and Palma de Mallorca. The number of microplastics varied from 45.9 ± 23.9 it./kg DW in Palma de Mallorca to 280.3 ± 164.9 it./kg DW in Málaga. In addition, the authors found that microplastic concentrations are not particularly associated with local sources of pollution (Table 2 and Figure 3). This finding coincides with previous work done in the western region by comparing the load of microplastics in sediments of Cabrera, a marine protected area in the Balearic Islands, with a tourist and heavily populated area of Mallorca, where the authors detected a higher number of microplastics in the protected area (up to 900 it./kg DW) than in the tourist area (Alomar et al., 2016).

Plastics in sediments (items/g)		
Catalan margin		
Continental platform	0.9	Sanchez-Vidal et al., 2018
Underwater canyons	0.5-1.5	Sanchez-Vidal et al., 2018
Deep basin	0.4	Sanchez-Vidal et al., 2018
Balearic Islands	0.9	Alomar et al., 2016
Eastern Mediterranean	0.2-1.2	Sanchez-Vidal et al., 2018
Cantabrian Sea	0.8-1.4	Sanchez-Vidal et al., 2018
Alboran Sea	0.5-1.2	Sanchez-Vidal et al., 2018
North Atlantic	0.1-0.3	Woodall et al., 2014
Indian Ocean	<0.1	Woodall et al., 2014

Table 2. Abundance of plastics (including cellulose textile microfibres) in sediments (items/gr) at different depths and underwater environments off the Catalan coast. Some figures from nearby and global areas are shown for comparative purposes.

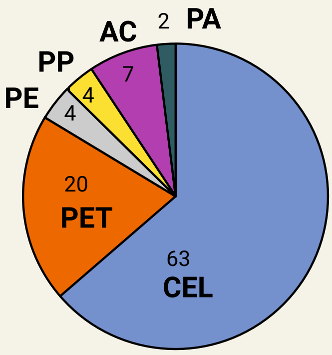

Figure 3. Composition of microfibres in sediments of the Catalan coast. CEL, cellulose (natural or regenerated): PET, polyethylene terephthalate; PE, polyethylene; PP, polypropylene; AC, acrylic; PA, polyamide. (Adapted from Sanchez-Vidal et al., 2018.)

Similar results were also obtained in the Aeolian archipelago, in the Tyrrhenian Sea (Italy), where the values recorded in this marine protected area were similar to those recorded in port sites (between 151 it./kg DW and 679 it./kg DW; Fastelli et al., 2016), or the results of the Telašćica Bay Nature Park (Adriatic Sea), with a number of microplastics ranging from 32 it./kg DW to 378 it./kg DW (Blašković et al., 2017), values that are much higher than those recorded in Malta's Grand Harbour (<12 it./kg DW; Romeo et al., 2015). One of the most polluted areas of the Mediterranean Sea is the Venetian Lagoon (Italy), where microplastics <1 mm were detected in almost all samples, with quantities ranging from 672 it./kg DW to 2,175 it ./kg DW (Vianello et al., 2013), followed by the Maremma regional park in the Tyrrhenian Sea, with values recorded between 45 it./kg DW and 1,069 it./kg DW (Guerranti et al., 2017). In the latter case, the amount of microplastics in this regional park is strongly influenced by the river's runoff (inflow of the Ombrone River) and the impact of materials derived from agricultural activities in coastal areas (Guerranti et al., 2017).

With regard to beach sediments, values up to 422 it./kg DW have been recorded on the beaches of the Ebro Delta (Catalan coastal area), where fibres are also the most abundant type of microplastic. This matches what has been demonstrated for deep-water sediments (Simón-Sánchez et al., 2019), or on beaches in the area of the Mar Menor lagoon (Bayo et al., 2019, 2020). These results were similar to those observed, for example, in the Tunisian coastal zone, with microplastics ranging from 141 it./kg DW to 461 it./kg DW, and fibres as the most abundant form of plastics (Abidli et al., 2018).

A graphic summary of the distribution of different types of microplastics in the global ocean can be seen in Figure 4 (D'Erni-Cassola et al., 2019).

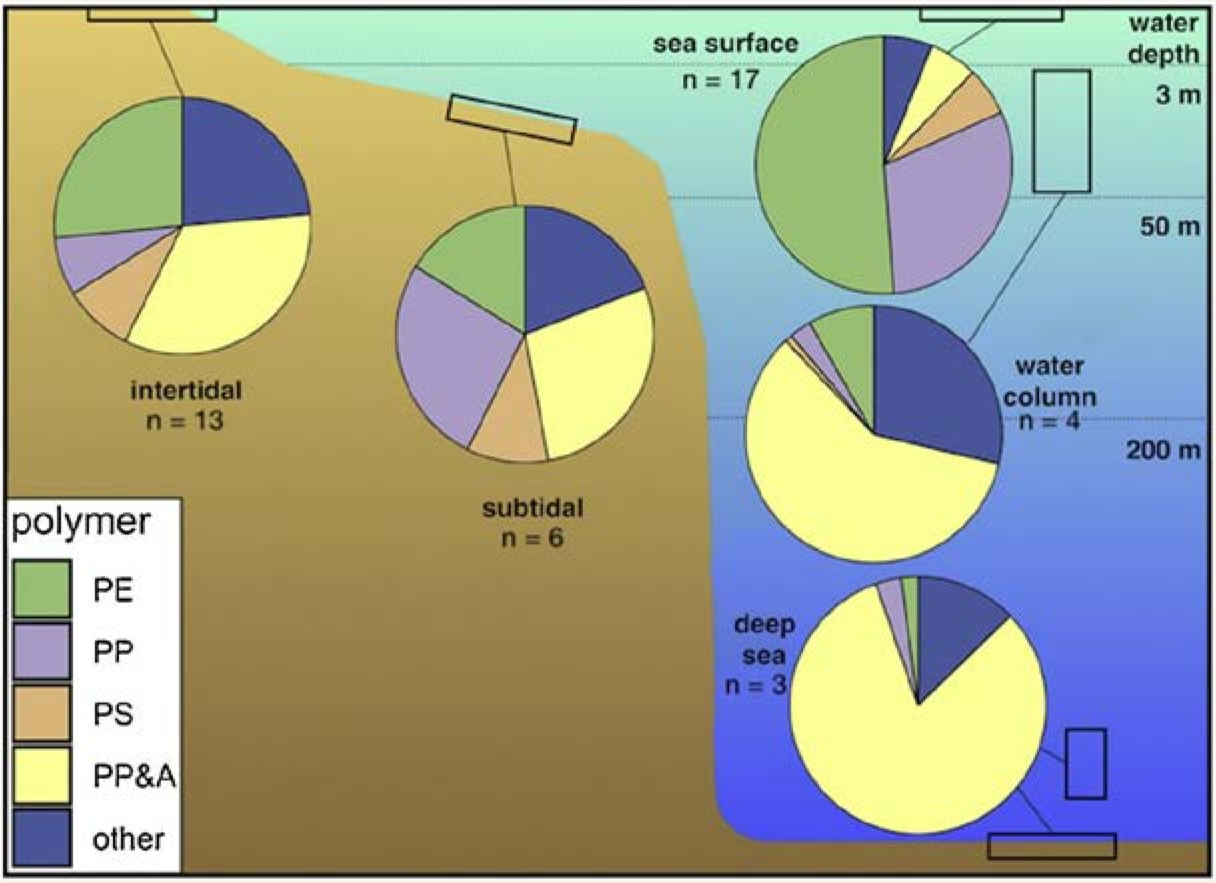

Figure 4. Relative abundance of common polymer types in different marine areas. The pie charts represent abundance data for PE: polyethylene; PP: polypropylene; PP&A: polyester, polyamide and acrylic; PS: polystyrene; n: number of studies in each area. (D'Erni-Cassola et al., 2019).

4.3. Soils

According to Bläsing and Amelung (2018), the sources of microplastics in soil can be divided into three main categories: the contributions of agricultural practices, the influence of surface runoff and deposition, and the fragmentation of larger plastic waste. Agricultural practices include the use of compost and sewage sludge as fertiliser, and plastic covering, a widespread technique to improve crop quality, as well as irrigation and flooding.

Compost is widely used in agriculture as a fertiliser. In 2008, 18,000,000 t of compost were produced in the European Union (Bläsing and Amelung, 2018). With a recommended annual application rate of between 30 t/ha and 35 t/ha and a range of 2.38-180 mg of microplastics per kilogram of compost, this could represent an annual contribution to cultivated soils of between 0.016 kg/ha and 6.3 kg/ha of microplastics per year on a European scale. In this range, small microplastics (<1 mm) and nanoplastics (<1 mm) are not included.

The use of sewage sludge (i.e. the pollutant residue left in the treatment of river water) as a fertiliser is a very common practice in agriculture (it is also dumped into the sea, to get rid of it, with significant negative effects; Ros and Cardell, 1991; Ros, 2001). In Europe, approximately 50% of all sewage sludge produced is used in agriculture. This proportion can reach 79% in Spain (Eurostat, 2020). The concentration of microplastics in sewage sludge varies between 1,500 particles per kilogram (part./kg) and 24,000 part./kg (see Bläsing and Amelung, 2018 and references there). This could represent an annual load of between 63,000 t and 430,000 t of microplastics in the case of the European Union (Nizzetto et al., 2016b).

We have extrapolated the mass of microplastics distributed in the agricultural field in Spain from the use of sewage sludge to an amount of between 21,000 and 150,000 t. This value can be compared to the plastic pollution estimated to be floating in the surface waters of the global ocean – between 93,000 t and 236,000 t (Van Sebille et al., 2015). A recent study in south-east Spain showed that the concentrations in soils without the addition of sewage sludge were 2,030 it./kg of microplastics and 5,190 it./kg with the addition of sewage sludge (Van den Berg et al., 2020). Moreover, plastic loads in soils increase in 710 it./kg of microplastics with each consecutive application of sewage sludge, which results in a high microplastic accumulation in agricultural soils.

Plastic covering is used to remove weeds and conserve water in crop production and landscaping: plants grow through cracks or holes in thin sheets of plastic. With around 120,000 ha of covered agricultural area – cover only, which does not include greenhouses or direct roofs –, Spain is the first European country in plastic covering usage, as it represents approximately 28% of the total covered agricultural area in Europe (extrapolated by Scarascia-Mugnozza et al., 2012). Although it is difficult to estimate the amount of microplastics released into the soil by this practice, it is already known that plastic covers contain from 50 mg/kg to 120 mg/kg of phthalates (a harmful additive), which leads to a concentration of phthalates 74% to 208% higher in plastic-covered soils compared to uncovered soils (Kong et al., 2012).

Regarding flood irrigation, little is known about its impact on the spread of microplastics in soils (Bläsing and Amelung, 2018). However, projections show that in the near future, due to climate change, the direct use of partially treated or untreated wastewater may become the only source of water for agriculture in many places around the world (WHO, 2006). Concentrations of microplastics in wastewater range from 1,000 part./m^3 to 627,000 part./m^3, of which approximately 75% are fibres (see references in Table 2 of Bläsing and Amelung, 2018). Depending on the type of crop and whether we consider developing countries or developed countries, the annual number of microplastics reaching the soil per hectare of crop could range from 2.2 × 106 part./ha to 3.1 × 109 part./ha for the former, and from no particles to 625 × 106 part./ha for the latter. In Spain, with a crop area of 12.4 Mha, the annual load of microplastics related to irrigation could represent 7.75 × 1015 particles.

Along roads and urban areas, plastic debris that is not captured by sewer systems can pollute the surrounding soil. There are virtually no studies evaluating the amount of plastic introduced into the soil by litter or illegal dumping, although an estimate ranging from 0.85 kg/ha to 6.6 kg/ha of litter swept along from highways by water during storms can be considered (Kim et al., 2006, 2004). The fine particles caused by the abrasion of vehicle tires on the roads and which could be introduced to the environment around them by wind or water should be added to this. Estimates range from 10,000 t of microparticles in Sweden (Norén and Naustvoll, 2010) to 100,000 t of microparticles in Germany (Essel et al., 2015). There are no available estimates for Spain.

Finally, microplastics present in soils can result from the fragmentation of larger plastic debris, from different types of dumped plastic waste that degrade into microplastics and even nanoplastics.

4.4. Wastewater

Municipal wastewater is polluted with microplastics, with concentrations ranging from 10 part./m³ to 107 part./m³ (Koelmans et al., 2019). Microplastics enter sewer systems from domestic sources in the form of synthetic textile fibres, cosmetic microbeads, and disintegrated parts of larger consumer products that are flushed down the toilet (Mourgkogiannis et al., 2018; Murphy et al., 2016). Wastewater treatment plants (WWTPs) are an important entry point into the aquatic environment for microplastics.

Plastics and other particulate matter are removed from liquid waste by sedimentation and end up in sewage sludge. Because sewage sludge is used as a fertiliser in many EU member states (Kacprzak et al., 2017), microplastics are introduced into agricultural land (see 4.3 and 5.2), from where they affect terrestrial ecosystems and – at least in theory – end consumers (livestock and humans; see 5.3).

4.5. Air

There are microplastics both in the indoor air of homes (Dris et al., 2017) and in the outdoor air (Cai et al., 2017; Dris et al., 2016). Atmospheric deposition is two orders of magnitude higher in indoor closed environments: 11,000 microplastics/m² daily (Dris et al., 2017). A study carried out on the rooftops of Paris found microplastic fibres in sizes ranging from 7-15 μm to 100-500 μm. Atmospheric precipitation was estimated to range from 2 part./m² to 355 part./m² per day, with higher rates in urban areas compared to suburban areas. The amount of precipitation was estimated at 3 t/year and 10 t/year for an area the size of Paris (2,500 km²; Dris et al., 2016).

The highest values of microplastics in air are found in road areas, due to the wear of vehicle tires, as well as that of the road itself. According to studies conducted in Japan, Europe and the United States, they represent from 0.05 mg/m³ to 0.70 mg/m³ of the fraction of particles of 10 μm or less (Panko et al., 2013). The evaluation of the air inside factories indicates high concentrations of microfibres of polyvinyl chloride (PVC): 7 mg/m³ (Burkhart et al., 1999). Brahney et al. (2020) show that even in natural areas far from industrial and urban areas (protected areas, national natural monuments, etc.), rain and wind introduce microplastics – more than 1,000 t/year in protected areas of the western US.

There may be other sources of microplastics in the atmosphere – the formation of sea salt aerosols, plastic particles from dry sewage sludge from agricultural soils, urban dust, etc. In any case, inhalation of these microparticles must be an important route of entry into the respiratory system of animals and humans (see 5.3).

5
Impact of microplastics

Microplastics can adsorb organic pollutants on their surface, transport them, and disperse them (Cole et al., 2011; Llorca et al., 2014; Ríos et al., 2007). In aquatic environments, plastic materials can concentrate hydrophobic pollutants up to ten million times the concentrations in the surrounding water (Koelmans et al., 2016). These chemicals could eventually be released in other areas when environmental conditions change or after passing through the body of aquatic animals.

5.1. Aquatic ecosystems

Microplastics and nanoplastics can be ingested by aquatic organisms and therefore can be introduced into the marine food web (Wright et al., 2013; Cole et al., 2014). Some species ingest them unconsciously or passively (e.g., suspension and filtering feeders) and others, such as different species of fish (like adult anchovies), selectively. This can also mean a risk to human health, due to the potential accumulation in commercial species that reach consumers, such as mussels (Pittura et al., 2018). A study on Gambusia holbrooki of two coastal lagoons recovered from the Girona coast (Rodríguez et al., 2020) finds abundant microplastics in the digestive tract of this exotic fish. The authors point out that this presence may be indicative of the degree of microplastic pollution on the coast.

Fish and bivalves cannot digest microplastics because they do not have enzymatic pathways available to break down synthetic polymers (Andrady, 2011). However, these particles can be retained in some organs, and nanoparticles, due to their small size, can be translocated into living tissues with adverse effects. This can also endanger human health, due to the potential accumulation in commercial species.

There are significant biases in studies of the effects of microplastic intake on marine organisms: fish and small crustaceans are overrepresented in laboratory and field studies, and in laboratories the concentrations of microplastics tested are very high compared to natural ones. (De Sá et al., 2018).

Plastics can reach concentration factors of one million or more inside organisms (Wardrop et al. 2016). For example, a recent study shows that 60% of sardines and anchovies caught in the northeastern Mediterranean Sea had plastic in their digestive tract (Pennino et al., 2020). Individuals with higher amounts of plastic also had a large number of parasites. The authors suggest that this may be due to the presence of parasites in the plastic biofilm or the increased abundance of parasites in areas where the concentration of plastic was higher, although the debilitating effect of microplastics on fish is not ruled out. Fractions of fish containing microplastics in the gastrointestinal tract are highly variable depending on the study – in ascending order, 0.0025% in fish from the North Sea, 17.5% in fish from the Spanish Atlantic and Mediterranean coasts, 19.8% in fish from the Portuguese coast, 58% in fish from Turkish territorial waters and 100% in South China Sea fish (Zeytin et al., 2020). These differences may depend on the species, the concentration of plastic present in the water, the size of plastics and the methodology used.

Studies in a planktonic copepod (Calanus helgolandicus) show that the intake of microplastics (polystyrene) reduces the rate of microalgae intake, fertility and perhaps the survival of the species (Cole et al., 2015). Setala et al. (2013) study the transfer of microplastics along marine plankton food chains, from mesozooplankton species (such as the copepod Eurytemora affinis) to macrozooplankton species (such as the mysid Neomysis integer).

Other works focus on benthic organisms: there is transfer of microplastics along the food chains (from mussels to crabs), but in a very small concentration, which disappears after about 20 days (Farrell and Nelson, 2013). The effect of this ingestion is a decrease in the energy available to animals (Watts et al., 2015, in the crab Carcinus maenas). The effects of ingestion of microplastics (polystyrene) and PCBs in Arenicola marina show accumulation and reduction in the food activity of this polychaete worm (Besseling et al., 2013).

De Oliveira et al. (2020) review the various studies carried out to date on the effects of microplastics on corals, and highlight a reduction in growth, a marked reduction in detoxifying and immune enzymes, an increase in the activity of antioxidant enzymes, a high production of mucus, reduced biological efficacy, and adverse effects on the relationship between corals and their symbiont microalgae.

As for the incorporation in grey seals (Halychoerus grypus) and the fish they eat (herring, Clupea harengus), there is transfer, but in very small amounts (Nelms et al., 2018). Laboratory studies in zebrafish (Danio rerio; Brandts et al., 2020) indicate that microplastics accumulate in the liver cells of adult animals, and that larvae accumulate them in the digestive tract and pancreas, but that does not affect their survival.

Not much is known about the translocation of plastic or its additives into the tissues, organs or blood of organisms. Translocation to the liver and gills of different species has been reported, but the presence of microplastics in the edible part of the fish (fillet) that is consumed by humans is not well known. For mussels, the translocation of microplastics into the circulatory system and their persistence over 48 days has been observed (Browne et al., 2008). However, a recent study in sea bass (Dicentrarchus labrax) found that even if microplastics from 1 μm to 5 μm were able to transfer to fillets commonly eaten by humans, they did so at relatively low levels, taking into account the high levels of intake. Only one microplastic reached the fillet for a total of 1.87 × 107 ingested microplastics (Zeytin et al., 2020).

However, the main risk to wildlife and human health associated with the presence of plastic in seafood is probably the leaching of the additives they carry. These chemicals can be released inside the body and be easily translocated, which can affect body growth and physiological functions.

5.2. Soils

To date, very few studies have investigated the impact of microplastics on soil organisms (Chae and An, 2018, and references there). Once in the soil, microplastics can be ingested and transferred to the organisms that live there. For example, earthworms (*Eisenia foetida*) exposed to polybrominated diphenyl ether (PBDE), a derivative of polyurethane foam, accumulate it in the body and transfer it to the soil (Gaylor et al., 2013). Another experiment shows that, when exposed to low density polyethylene (LDPE), earthworms (*Lumbricus terrestris*) are affected by high concentrations of microplastics, retain and transfer microplastics to other organisms in the soil ecosystem through the food chain, and also retain and transfer microplastics to the deeper layers of the soil and possibly to groundwater (Huerta-Lwanga et al., 2016). In addition, according to Hodson et al. (2017), microplastics can serve as a pathway for bioavailable metals, including zinc (Zn), in soil ecosystems, although no significant detrimental effects on survival or body weight were measured on the tested earthworms. Interestingly, microplastics ingested by earthworms can be transferred to humans through the food chain. In fact, groundworm-fed poultry shows higher concentrations of microplastics in faeces, but also in the gizzard, which is used for human consumption (Huerta-Lwanga et al., 2017).

Microplastics may be responsible for histopathological damage and immune system response in *Eisenia andrei* earthworms (Rodriguez-Seijo et al., 2017). Other experiments have been performed on other organisms, such as arthropods – collembolans (Maaß et al., 2017) or isopods (Jemec Kokalj et al., 2018) –, but no significant effect has been evaluated.

Jointly with the impacts on soil organisms and ecosystems, some other effects are beginning to be investigated. For example, microplastics are mostly composed of carbon, among other elements. Therefore, their presence in soil ecosystems should represent a carbon source unrelated to photosynthesis and net primary production (Rillig and Lehmann, 2020). This carbon has a slow renewal rate, as the material is mostly inert. However, the behaviour and residence time of microplastics in soil – as well as the rate of entry into ecosystems – are currently unknown, because to date research has mostly focused on quantifying the types and number of particles, rather than on the very carbon derived from microplastics. Originally, most of this carbon is of fossil origin, rather than having been recently fixed from the atmosphere. Due to the resistance to decomposition of microplastics, it is expected to accumulate in soils. This should be taken into account in assessments of soil carbon storage (Rillig, 2018), which is a key function of the ecosystem.

From a biophysical point of view, microplastics can affect the total density, water retention capacity, and functional relationship between microbial activity and stable water aggregates in soils. The effects are underestimated if one does not pay attention to the specific characteristics of particle types and their concentrations, suggesting that purely qualitative environmental data of microplastics could be of limited value for the assessment of their effects on soil. If extended to other types of soils and plastics, it has been suggested that microplastics are relevant long-term anthropogenic stressors as well as drivers of global change in terrestrial ecosystems (De Souza Machado et al., 2018).

Finally, by reducing the total soil density, microplastics (fibres) can lead to greater plant growth, probably because the roots experience less resistance to growth (De Souza Machado et al., 2019). However, negative effects on plants are also possible, probably related to plastic additives (Kleunen et al., 2020).

5.3. Human beings

As we have seen, nano- and microplastics are present in both marine (Yang et al., 2015) and inland waters (Ossmann et al., 2018; Wagner and Lambert, 2018), as well as in the indoor air in dwellings (Dris et al., 2017) and in outside air (Cai et al., 2017; Dris et al., 2016), and in dietary sources. Exposure by ingestion of atmospheric deposition also represents a substantial route (68,415 microplastics/person/year; Catarino et al., 2018). Exposure by inhalation depends on the aerodynamic diameter (deposition <10 μm in aerodynamic diameter in the airway; Carvalho et al., 2011).

Occupational exposure to plastic microfibres results in granulomatous lesions containing acrylic, polyester, and nylon powder (Pimentel et al., 1975), leading to a higher prevalence of respiratory irritation (Warheit et al., 2001). The so-called flock worker's lung is a rare lung disease that occurs in nylon textile workers exposed to breathable-sized fibre dust (Boag et al., 1999; Eschenbacher et al., 1999; Kremer et al., 1994). This and other lung diseases can be chronic.

Stemmer et al. (1975) found that inhaled polyurethane foam dust caused inflammation and scarring in guinea pigs. It is known that plastic additives, colorants and pigments are often incorporated into plastic products, many of which have effects on human health – including reproductive toxicity, carcinogenicity and mutagenicity (Fromme et al., 2014; Linares et al., 2015; Lithner et al., 2011).

Microplastic fibres with a diameter between 7 μm and 15 μm can enter the airways. In deep lung regions, very small microplastics can be picked up by macrophages and epithelial cells (Geiser et al., 2005), and can possibly be transferred to the systemic circulation.

Nanoplastics and microplastics present in animals and plants are likely to enter the human body by ingestion, but there is little data to quantify dietary exposure, which almost always refers to products of marine origin (Lusher et al., 2017).

An additional potential impact may be caused by inhalation of microplastics with microbial colonisation (Kirstein et al., 2016; Zettler et al., 2013). In addition to the risks associated with infections by pathogenic species, inhaled microplastics could cause a change in the structure of the communities of microbes that colonise the lung.

There is little data on the potentially inhalable fraction of microplastics present in the air or in the diet, as well as on the daily intake of nano- and microplastics in humans. The kinetics and biodistribution of microplastics after exposure are also not well known. There is data on the inflammatory effects of plastic dust in animal models, but it is unclear whether these effects are applicable to humans.

It is also unknown whether the fibrous and non-fibrous form of microplastics is related to their possible toxicity – for example, whether small enough fibres could cause effects similar to those of asbestos.

The other route of entry of microplastics into the human body – through food intake – has not been studied much yet. We have already mentioned the presence of microplastics in some commercial species, especially fish. Other routes of entry are through food and beverages that are purchased packaged, or from drinking water distributed by municipal water supply systems.

Out of the analysed tap water samples, 81% contained microplastics, most of which were fibres (98.3%) from 0.1 mm to 5 mm in length, which had from no particles up to 61 part./L, with an average of 5.45 part./L. There were also anthropogenic remains in 12 brands of beer and in 12 brands of sea salt, almost all in the form of fibres. The average person ingests more than 5,800 part./year of microplastics from these three sources, and the largest contribution comes from tap water (88%; Kosuth et al., 2018). Mason et al. (2018) and Schymanski et al. (2018) find microplastics – mainly fragments and then fibres – in various brands of bottled water from different countries. In contrast, water from natural sources showed virtually no microplastics (Mintenig et al., 2019).

Plastic, as well as paper, cardboard, wood, ceramic and metal used to wrap food, allow the passage of material from wrappers to the food (Arvanitoyannis and Bosnea, 2004; Bhunia et al., 2013; Hoppe et al., 2017).

Once the microplastics have gained entry via ingestion, the intake of particles into the intestine (<10 μm) can occur through endocytosis and phagocytosis (Eldridge et al., 1989), or through uptake by larger particles (up to 130 μm; Volkheimer, 1993).

Thus, the consequences of ingesting microplastics and their effects on the human body are not well known yet. They could be excreted without harm to human health, but we do not yet know if these tiny particles could be transferred to organs or tissues. Nevertheless, the main toxicological problem related to the ingestion of microplastics is probably associated with the chemical additives they carry.

Some of these additives, such as phthalates, have been found to be toxic to humans. However, there is a lack of studies that demonstrate the release of additives in the human body and the mechanisms they use. A recent study (Porta et al., 2019) carried out by several Catalan research institutions analysed the urine of 20 volunteers, aged between 22 and 74, in search of the presence of plastic additives. They found more than 15 different phthalates and polyphenols that are common plastic additives. Another study, conducted by the University of Vienna, found plastic fibres in the faeces of several volunteers from different countries (Schwabl et al., 2019). These studies show that plastic additives reach the human body. Some of these additives are known to be endocrine disruptors or even carcinogens. Additives present in urine and faeces are excreted, but it is still unknown whether these chemicals are transferred to the bloodstream, organs, or tissues. And, even if they are excreted, the human body's continued exposure to these chemicals could lead to diseases of which we are not aware yet.

Plastic additives can also be released in wastewater treatment plants where, after chlorination, they can form trihalomethanes, which are harmful to human health (Lee et al., 2020).

In a recent paper, Teles et al. (2020) recall that nanoplastics can affect the composition and diversity of the microbiome. Given that recent research on the interactions between the digestive tract and the brain has revealed the effect of the intestinal microbiota on the endocrine, immune, and nervous systems (Anderson et al., 2020), this disruption of the gut microbiome may have effects on many aspects of human physiology. Most studies on the effect of microplastics have been carried out on a few species of laboratory animals. As stated by the cited authors, to date "we can only speculate on the long-term effects that exposure to nanoplastics may have on human health, but some clues from various studies related to compromised responses, both hormonal and immunological, to stressors in aquatic animals can help" (Teles et al., 2020).

The finding of microplastics in the placenta of pregnant women, both on the outer side (the mother) and on the inside (the foetus) of the placenta (Ragusa et al., 2020), is also worrying. There is currently no indication of the possible effects of this presence on pregnant women.

6
Social, management and legislative aspects

Management and legislative responses to microplastics must be considered in terms of both primary and secondary microplastics. Regarding secondary microplastics, the responses are broad and cover plastic waste in general, i.e. macroplastics. Their ultimate goal is to prevent plastic leakage and damage to the environment, where macroplastics end up degrading into smaller fragments and become microplastics. In recent years, circular economy is being promoted as a way to keep resources in closed loops and make the most of the value of plastics. There are many initiatives, from a global to a local scale, and from both the public and private sectors concerned as well as public-private partnerships.

In the European Union, microplastics that can be generated as a result of partial or non-existent waste management, or as a result of the degradation of larger plastic waste, are addressed by initiatives included in the European Union Plastics Strategy (https://ec.europa.eu/environment/waste/plastic_waste.htm), which aim to reduce macroplastics waste.

In Catalonia, the new law on waste prevention and management and resource efficiency, which is expected to be passed in 2021, should be the benchmark for promoting circular economy and preventing the entry of plastics into the environment.

In the context of this report, responses to primary plastics may be more relevant in view of possible policies, as they are aimed at direct sources of microplastics in the environment. The responses could be explained in terms of their promoters, that is, policy makers, the private sector and society.

6.1. Public management responses

Microplastics, as part of the issue of marine litter, have received worldwide attention in recent years. The UN Environment Assembly (UNEA) was established in 2012 by decisions of the Rio+20 Conference and the United Nations General Assembly (UNGA). UNEA-4 met in Nairobi (Kenya) from 11 to 15 March 2019, and adopted a specific resolution on marine plastic waste and microplastics (UNEP / EA.4 / Res. 6). Resolutions on plastics required lengthy negotiations, as some countries opposed setting targets for the phasing out of single-use plastics, while others were willing to adopt national bans. On marine litter, some countries would have preferred more restrictive agreements. However, the resolution allows for scientific reviews, expert meetings and stakeholder participation in the matter. With regard to the Barcelona Convention for the Protection of the Mediterranean, microplastics are expected to be incorporated into the revision of the Regional Plan for the Management of Marine Litter in the Mediterranean, at the end of 2021.

In the European Union, in September 2018, the European Parliament called on the European Commission to introduce an EU-wide ban by 2020 on cosmetics and detergents that contain intentionally added microplastics, and to take steps to minimise the release of microplastics in textiles, tires, paints and cigarette butts. On 30 January 2019, the European Chemicals Agency (ECHA) published a proposal to restrict the use of microplastics. The proposal is based on the results of the ECHA assessment on the health and environmental risks of microplastics that are intentionally added to products. The process is ongoing, which may lead to an amendment to Annex XVII of the REACH Directive, to make the restriction operational. In Spain, the draft bill on waste and polluted soils establishes a ban on microplastics intentionally added to cosmetics and detergents from 3 July 2021.

The European Commission also looked at options to reduce microplastics that are created by wear during the life cycle of a product, or that are emitted by accidental spills (Hann et al., 2018). Tires, road markings, preproduction plastic pellets and synthetic textile washing are major sources of emissions of microplastics into the environment. When analysing the options to reduce them, the most significant reductions in both source and surface water emissions can be achieved through measures aimed at reducing emissions at source. Accreditation of the pre-production pellet supply chain is likely to have the greatest reduction impact (600,000 t of accumulated reduction in surface water between 2017 and

2035), and is also expected to be the most profitable.

In the case of Catalonia, the new law on waste prevention and efficiency of resources will include a specific chapter on microplastics. At a local level, some councils have launched initiatives to reduce the burden of microplastics in their environment. For example, in 2020 the councils of Calafell, L'Ampolla and Vinaròs, among others, installed buoys in the sea to filter microplastics.

6.2. Private sector responses

Businesses and businesspeople around the world are taking steps to reduce the accidental loss of microplastics and to reduce loss by wear. In this sense, Operation Clean Sweep is aimed at all segments of the plastics value chain (producers of raw materials, logistics chain, recyclers and processors) with the implementation of good environmental practices and the containment of pellet, flake and dust spills.

As for textiles, the problem of pollution by synthetic microfibres is complicated and has a considerable scale. However, switching from synthetic materials to natural materials would entail other substantial environmental costs. The release of plastic microfibres from synthetic clothing calls for a collaborative effort of the textile industry. Fashion brands, as well as all stakeholders in the entire value chain, are testing various solutions, including thread and fabric finishing treatments, washing machine filtration systems, pre-sale washes, detergents and washing conditions, among others.

6.3. Civil society responses

Civil society as a whole and non-governmental organisations (NGOs) have shown great concern about the plastic pollution crisis and have launched many actions and initiatives to make governments, businesses and consumers take responsibility. Particularly in microplastics, the "Beat the microbead" campaign managed to make leading companies such as L'Oréal and Procter&Gamble phase out microbeads from their personal care products.

In Catalonia, civil society is also taking action on plastics. An example is the Foundation for Waste Prevention and Responsible Consumption (Rezero), which carries out numerous campaigns on plastics, such as "Plastic Health" (http://www.caib.es/pidip2front/jsp/adjunto?codi=2333080&idioma=ca).

On the other hand, civic litter picking campaigns, either on the beach or underwater, remove a good number of plastic materials (basically meso- and megaplastics) from the shoreline and transport them to landfills. Citizen science is useful for detecting and collecting microplastics on the Catalan coast (Uviedo et al., 2020; Vilà, 2021). Recently (Sánchez-Vidal et al., 2021), a natural process has been discovered by which meso- and microplastics are returned to the emerging coast, wrapped in the pellets of *Posidonia oceanica*, which is transported to beaches by waves and storms. This is yet another of the many services that this marine phanerogam provides to its environment and to our species (Romero, 2004; Ros, 2001).

7
Catalan teams and researchers

As it can be deduced from the previous pages and the cited bibliography, research on microplastics is one of the most active areas nowadays, especially with regard to the marine environment. Catalonia is no exception to this. The attached Table 3 details the active groups in our country in this field of research.

Institution	Research group	Researchers	Specialities	Microplastic publications from Catalan-speaking territories	
University of Barcelona	Marine Geosciences Consolidated Research Group	Anna Sanchez-Vidal	Floating microplastics	de Haan et al., 2019	https://doi.org/10.1016/j.marpolbul.2019.01.053
		William de Haan	Microplastic sediments	Sanchez-Vidal et al., 2018	https://doi.org/10.1371/journal.pone.0207033
		Miquel Canals	Microplastic sediments	Woodall et al., 2014	https://doi.org/10.1098/rsos.140317
			River microplastics	Constant et al., 2019	https://doi.org/10.1016/j.marpolbul.2019.03.032
			Beach microplastics	Constant et al., 2020	https://doi.org/10.1016/j.scitotenv.2020.136984
			Crowd science, floating microplastics	Camins et al., 2019	https://doi.org/10.1016/j.scitotenv.2019.136178
	IRB-Bio	Odei Garcia Garín	Fauna microplastics	Garcia Garin et al., 2019	https://doi.org/10.1016/j.marpolbul.2019.110648
		Marina Codina-Garcia	Fauna microplastics	Codina-Garcia et al., 2013	https://doi.org/10.1016/j.marpolbul.2013.10.002
		Odei Garcia Garín	Relationship between microplastics and flame retardants in marine	Garcia Garin et al., 2020	https://doi.org/10.1016/j.chemosphere.2020.126569
		Jacob González Solís			
Universitat Autònoma de Barcelona	Department of Animal Biology, Plant Biology and Ecology	Microplásticos fauna	Fauna microplastics	Carreras-Colom et al., 2020	https://doi.org/10.1016/j.envpol.2020.114567
		Maria Constenla	Fauna microplastics	Carreras-Colom et al., 2018	https://doi.org/10.1016/j.marpolbul.2018.05.012
		Maite Carrassón	Fauna microplastics	Rodriguez-Romeu et al., 2020	https://doi.org/10.1016/j.scitotenv.2020.139336
		Oriol Rodriguez-Romeu			

Table 3. List of active research groups in Catalonia that research on microplastics in the environment.

Institution	Research group	Researchers	Specialities	Microplastic publications from Catalan-speaking territories	
	Institute of Environmental Science and Technology	Laura Simón-Sanchez	River microplastics	Simon-Sanchez et al, 2019	https://doi.org/10.1016/j.scitotenv.2019.06.168
		Patricia Ziveri			
	Department of Cell Biology, Physiology and Immunology	Mariana Teles	Effects on human health	Teles er al., 2020	https://doi.org/10.1016/j.scib.2020.08.003
		Joan Carles Balasch			
	Centre for Ecological Research and Forestry Applications (CREAF, CSIC-UAB)	Jordi Sardans	Effects on human health	Teles er al., 2020	https://doi.org/10.1016/j.scib.2020.08.003
		Josep Peñuelas			
Institute of Marine Sciences		Cristina Romera-Castillo	Experiments	Romera-Castillo et al., 2018	https://doi.org/10.1038/s41467-018-03798-5
		Cristina Romera-Castillo	Experiments	Lee et al., 2020	https://doi.org/10.1016/j.watres.2020.115678
		Marta Coll	Fauna microplastics	Pennino et al., 2020	https://doi.org/10.1016/j.marpolbul.2020.111399
		Montse Demestre	Fauna microplastics	Masó et al., 2016	http://dx.doi.org/10.3989/scimar.04281.10A
		Gemma Ercilla	Deep sea microplastics	Mecho et al., 2020	https://doi.org/10.1016/j.marpolbul.2020.110969
		Joan Navarro	Fauna microplastics	Méndez et al., 2020	https://doi.org/10.1007/s11252-020-00995-3
		Ana Isabel Colmenero	Fauna microplastics	Colmenero et al., 2017	http://dx.doi.org/10.1016/j.marpolbul.2017.01.011
		Mercedes Masó	Fauna microplastics	Masó et al., 2003	https://doi.org/10.3989/scimar.2003.67n1107
		Valerio Sbragaglia	Seawater microplastics	Sbragaglia et al., 2020	https://doi.org/10.3989/scimar.05139.05A
		Mercedes Blázquez-Peinado	Fauna microplastics	Brate et al., 2018	https://doi.org/10.1016/j.scitotenv.2018.01.141
Blanes Centre for Advanced Studies		Francisco Luis Orejón	Floating microplastics	Ruiz-Orejon et al., 2016	https://doi.org/10.1016/j.marenvres.2016.08.001
		Rafael Sardà	Floating microplastics	Ruiz-Orejon et al., 2018	https://doi.org/10.1016/j.marpolbul.2018.06.010

Institution	Research group	Researchers	Specialities	Microplastic publications from Catalan-speaking territories	
			Floating microplastics	Ruiz-Orejon et al., 2019	https://doi.org/10.1016/j.envpol.2019.06.063
Institute of Environmental Diagnosis and Water Studies		Marinella Farré	Fauna microplastics	Schirinzi et al. 2020	https://doi.org/10.1016/j.jhazmat.2020.122794
		Marta Llorca	Microplastics in river and sea of the Ebro Delta	Schirinzi et al. 2019	https://doi.org/10.1016/j.chemosphere.2019.07.052
		Gabriella Francesca Schirinzi	Plastics at the mouth of the Llobregat River	Schirinzi et al. 2020	https://doi.org/10.1016/j.scitotenv.2020.136807
		Marta Llorca	Microplastic adsorption experiments with other co-contaminants	Llorca et al. 2018	https://doi.org/10.1016/j.envpol.2017.12.075
		Ethel Eljarrat	Flame retardants in marine fauna	Aznar-Alemany, et al., 2019	https://doi.org/10.1016/j.chemosphere.2019.03.165
		Ethel Eljarrat	Flame retardants in marine fauna	Sala et al. 2019	https://doi.org/10.1016/j.envres.2019.02.027
		Silvia Lacorte	Flame retardants in marine fauna	Escorcuela, et al 2017	https://doi.org/10.1016/j.marpolbul.2018.04.032
IEO Balears	Salud Deudero		Fauna microplastics	Nadal et al., 2016	https://doi.org/10.1016/j.envpol.2016.04.054
	Monsterrat Compa		Fauna microplastics	Compa et al., 2018	https://doi.org/10.1016/j.marpolbul.2018.01.009
	Carme Alomar		Microplastic sediments	Alomar et al., 2016	https://doi.org/10.1016/j.marenvres.2016.01.005
			Fauna microplastics	Alomar and Deudero 2017	https://doi.org/10.1016/j.envpol.2017.01.015
			Fauna microplastics	Deudero and Alomar 2015	https://doi.org/10.1016/j.scitotenv.2020.139336
			Fauna microplastics	Rios-Fuster et al., 2019	https://doi.org/10.1016/j.marpolbul.2019.04.064
			Floating microplastics	Compa et al., 2020	https://doi.org/10.1016/j.marenvres.2020.104945
			Fauna microplastics	Alomar et al., 2017	https://doi.org/10.1016/j.envres.2017.07.043
Catalan Institute for Water Research (ICRA)		Sara Rodríguez-Mozaz	Microplastics in inland waters (review)	Wagner et al. 2014	https://link.springer.com/article/10.1186/s12302-014-0012-7
		Diana Álvarez-Muñoz			

8
Conclusions

1. Microplastics and nanoplastics are present in all environmental compartments, including biota. One part comes from the degradation of all kinds of waste plastics, but another part comes from microparticles produced specifically for different purposes.

2. There begins to be a relatively accurate knowledge of the concentration of microplastics in inland and surface ocean waters. Knowledge of microplastics in air, soil, marine sediments, and deep ocean waters is much scarcer

3. There is very little information on microplastic measurement methods, which should be standardised to make possible comparisons between different geographical areas and countries.

4. Studies on the destination, effects and risks of microplastics – and especially nanoplastics – are still very sporadic and scattered.

5. In terms of risks, it is essential to study the interactions of micro- and nanoplastics with other products and pollutants, such as environmental chemicals, eutrophication and acidification of water, rising temperatures due to climate change, etc.

6. There is very limited knowledge of the transport of micro- and nanoplastics in natural trophic networks and in those that include the human species. In addition, in order to assess the risks to human health, it is necessary to know their concentration in drinking water and in the air, as well as their physical and chemical characteristics.

7. Although there is still insufficient evidence of the effect of nano- and microplastics on natural environmental compartments, or on organisms that are incorporated into the human diet – or on human health itself –, it is likely that the ecological risks of microplastics are reduced.

8. The effects on human health come mainly from inhaled microplastics in specific occupational situations indoors. Studies on the presence and effects of microplastics on human health are still scarce, although they would seem minimal.

9. Despite this, and given the relationship between the intestinal microbiome and the human endocrine, immune and nervous systems, it is necessary to study the possible effects of the incorporation of microplastics into the human microbiome and, in general, into human physiology.

10. Nonetheless, it is advisable – and even essential – to take action to reduce, prevent and mitigate the pollution due to these particles. Administrations, at all levels, have this responsibility.

11. There are several and very active research groups that study microplastics in Catalonia, from distribution to aspects of the effects they have on the natural environment and organisms.

9
Executive Summary

Plastic pollution is one of the major environmental challenges posed by human societies due to the unsustainable use and disposal of products made from plastic materials. It is a global, multidimensional and multisectoral problem, with an impact on the environment, economy, public health, food security, and even culture. The last part of the Anthropocene, the geological epoch characterised by the presence and, above all, the activity of the human species, is named Plasticene. In recent years, researchers in different fields have been identifying sources, quantities, and impacts of plastic pollution, although knowledge is still limited.

The presence of large plastics (macroplastics) in the ocean has serious consequences for marine life and human health. Marine animals often become entangled in or ingest plastic items. Many plastic polymers have a lower density than water, so they float to the surface, making it difficult to exchange oxygen and transmit light through the water column.

Commercial plastics contain many chemical additives to improve their durability and other properties: plasticisers, colorants, stabilisers, flame retardants and antioxidants, among others. These additives can migrate to aquatic environments, alter water chemistry, and affect marine organisms. The magnitude of the leaching of these substances depends on the types of plastic, the chemical properties of the additives, the stage of degradation of the plastic, etc.

It has been estimated that up to 23,600 tons of dissolved organic carbon (DOC) can be released from the plastic that reaches the ocean each year. The washing or leaching of plastics is enhanced by photodegradation caused by ultraviolet radiation, and the released compounds have a molecular weight of less than 350 Da (daltons). About 7% of the weight of plastic can be lost in the form of DOC under ultraviolet radiation. Leached compounds can alter the marine food web by stimulating the growth of marine bacteria, but they can also adversely affect the ability of photosynthetic organisms to photosynthesise and grow, leading to a reduction in the production of organic matter and oxygen.

Another consequence of the presence of plastics in aquatic environments is the introduction of invasive species (bacteria, algae, fungi and various invertebrates) that cover them with a biofilm. Invasive alien species transported by plastic waste pose a threat to biodiversity and ecosystem services.

The presence of plastics in the environment and especially in the ocean is increasing. Among them, microplastics (MP) and nanoplastics (NP) are of particular interest because of their small size (less than 5 mm). But also because they can be another source of pollutants through the release of additives and plasticisers, and through the accumulation of organic and inorganic pollutants, and can be pathogens of the environment (air, water or particles), which makes them an important vector for the transport of these pollutants to aquatic organisms. Due to their small size, similar to plankton, benthic protozoa and bacteria, microplastics and nanoplastics can enter the marine food web through ingestion by aquatic organisms.

Due to the scientific, economic, social and environmental interest in microplastics, there are many studies dedicated to them, both specific works and synthesis works, which offer a general overview at any given time. This report has used these synthesis works (Bowmer and Kershaw, 2010; GESAMP, 2015; Cózar et al., 2015; Lusher et al., 2017; Da Costa, 2017; SAPEA, 2019; ECHA, 2020; Llorca et al., 2020), as well as various specific works, especially by Catalan researchers and researchers from around the Mediterranean basin.

Physical and chemical characterisation

Microplastics are fragments of plastic smaller than 5 mm, from 0.1 μm or 1 μm. Fragments smaller than this size are called *nanoplastics*. For the purposes of this report, we will normally refer to *microplastics*, including nanoplastics. If distinguishing between them is necessary, we will specify it.

Microplastics are solid particles composed of mixtures of polymers (the main component of plastics) and functional additives that improve the properties of these polymers, such as flexibility and durability (i.e. flame retardants, impact modifiers, and antioxidants, among others). In addition, they may also contain impurities due to the manufacturing process. These tiny plastics can be formed indirectly by the wear and tear of larger plastic fragments (miscellaneous items, synthetic textiles, etc.), or they can be manufactured directly as additives to various products, such as pearls in facial or body scrubs.

Microplastics include a wide range of microparticle types (pellets, fragments, fibres, films, foam, etc.), and also have a wide range of sizes, from 5 mm (microplastics) to 1 nm (nanoplastics), as well as a wide variety of polymer types. The most commonly used include polyethylene (PE, high and low density, HDPE and LDPE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including expanded, EPS), polyurethane (PUR), polyethylene terephthalate (PET) and polyamides (PA).

Origin and means of dispersion

Microplastics can be primary or secondary, depending on whether the particles were originally manufactured in this size (primary) or whether they are the result of the fragmentation and decomposition of larger articles (secondary). Primary virgin resin granules or pellets are used in the manufacture of plastic. Other primary microplastics are used as industrial scrubbers, plastic powder for moulding and in cosmetic formulations such as microbeads, among others. Secondary microplastics are the result of the fragmentation and weathering of larger plastic articles during the manufacturing process of different products – or within the environment, subjected to different meteors and radiation.

Microplastics reach the environment from different sources. Primary microplastics are released from factories and wastewater, or lost in a small proportion when transported as virgin pellets. They are also scattered and carried by the wind. In contrast, the main sources of distribution of secondary microplastics are difficult to identify, as they depend on the distribution of macroplastics and the degradation processes once they reach the environment.

In river systems (water and river sediments), the presence of microplastics is due to anthropogenic mechanisms, through the discharge of these products from direct source industries as well as wastewater treatment plants – although water purification effectively removes 80% to 90% of microplastics, because they are trapped in sewage sludge. Microplastics that pass through river systems reach the seas and oceans through river discharge. This is one of the main sources of microplastics in marine environments, along with the direct disposal of larger plastics, among other minor sources. Once there, the low-density polymers remain on the surface of the water, while the high-density polymers sink to the sediments. However, low-density polymers can also reach the sediments, as their physical and chemical characteristics can change due to the effects of the weather, or they can even be modulated by an eco-crown of aquatic organisms that settle on their surface area and increase their density

In terms of terrestrial soils, microplastics reach them through various physical, biological and anthropogenic mechanisms. In the case of agricultural soils, the presence of microplastics is explained by the reuse of sludge from sewage treatment plants as fertilisers (compost) and by irrigation with wastewater, by the weathering and disintegration of plasticulture on crop fields, by the fragmentation of plastic waste and plastic articles, and by the sedimentation of soils from flooded lands.

Finally, microplastics that are widespread in the environment can accumulate in animals by ingestion due to their small size and, ultimately, they can be consumed by humans.

Microplastics in the environment

Recent studies on the “plastics cycle” have been carried out not only from the perspective of transport from terrestrial to oceanic environments, but also including atmospheric sciences and biogeochemistry, trophic transfer, and health and exposure effects on humans. These studies have shown that microplastics can move between different compartments on a large scale, including air, terrestrial habitats, rivers and other inland water environments to eventually reach the ocean.

Inland waters

There are microplastics in different types of inland waters, in concentrations similar to those found in the sea. They are found on the surface of water, in the water column and in the sediments of lakes, rivers and estuaries. Concentrations of microplastics in inland waters vary geographically, from a few items to thousands of items per cubic meter (item/m³). Concentrations of microplastics in inland water sediments are also highly variable and can reach several thousand items per kilogram (it./kg) of sediment. There is a spatial correlation between microplastics in inland waters and human activities.

A study carried out in streams and rivers throughout Spain found microplastics in the surface waters of 70% of the samples. These microplastics are fibres, fragments and films of 33 different polymers. Microplastics, especially fibres, have been found in the Ebro Delta. They accumulate in river sediments, and the salt wedge dynamics of estuaries can facilitate the sinking of microplastics brought in by rivers.

Seas and oceans

Many studies have evidenced the emergence of plastics and, specifically, microplastics in seas and oceans. The average concentration of plastic in the ocean as a whole could be approximately equal to 2 ng/L, but Atlantic beaches near industrial areas, urban areas and/or cargo or port facilities have the greatest accumulation. In the Mediterranean Sea, the presence of these pollutants along the entire coast and, above all, on the beaches has been demonstrated. The Mediterranean Sea could accumulate between 1,000 t and 3,000 t of floating plastic waste, and is one of the marine environments most affected by it.

The impact of tourism on the generation of microplastics directly on Mediterranean beaches is quite significant. During the high season, due to the high number of visitors, the fragmentation of plastic waste is accelerated by the degradation caused by solar radiation and degradation mechanically produced by friction with sand. The accumulation of microplastics is about five times higher in July and August than during the low season. The presence of plastics in the Mediterranean Sea is related to the high anthropogenic pressure combined with the hydrodynamics of its semi-closed basin. A recent study indicates that of all the plastics that have entered the Mediterranean Sea since 2006, between 170 t and 420 t float in surface water, of which between 49% and 63% are found near the coast, and between 37% and 51% have sunk.

The microplastics detected in aquatic systems depend on their physical and chemical properties, such as density and shape, as well as on the polymer composition, the additives used and the characteristics of aging. In general, the polymers found in marine environments are PE, PP, PS, PET, PVC and PA. Environmental characteristics influence the interaction they have with other marine particles, organic matter, and organisms that affect how microplastics float or sink. In general, the largest amounts of microplastics have been detected near industrialised areas. For example, the Atlantic Ocean is one of the most polluted areas, with levels ranging from less than 1,000 it./km² to 1,300,000,000 it./km², and some of its marginal seas, such as the Baltic Sea and the North Sea, have an average of approximately 179,256 it./km² and 14,632,398 it./km², respectively.

From the coast, microplastics are exported to the high seas, where the quantities reported in the eastern Pacific Ocean range from 100,000 it./km² to 1,000,000 it./km², and it is found that the Great Pacific Garbage Patch is rapidly accumulating plastic, while the levels of microplastics in the western seas of the Pacific Ocean, including the Sea of Japan, the Yellow Sea, the Inland Sea of Seto and the East China Sea, are much higher (below 1,000 it./km² and up to 46,334,000,000 it./km²). Microplastic pollution has also reached the waters and even the sea ice of the Arctic Ocean, but with much lower values.

In the Mediterranean Sea, floating plastic debris from the entire region has been estimated at a total of 1,455 t of dry weight. The largest number of microplastics are found in the easternmost part, the Levantine Sea, with values between 100,000 and 37,600,000,000 it./km². – with much lower levels in the Aegean Sea, the Ligurian Sea, the Sea of Sardinia, the Adriatic Sea, the Gulf of Lion and the westernmost and central parts of the Mediterranean Sea, including the Catalan coast, where the quantities of plastics are below 500,000 it./km².

Plastic materials with a density higher than seawater sink and accumulate in the sediments of the seabed, while low-density materials initially tend to float to the surface or remain suspended in the water column. In addition, the association of particles with organic material and organisms (known as biofouling) produces a change in density that makes easier the sinking of plastic and microplastic waste. Microplastics have exceptional mobility once they are found in marine environments, due to the combination of their properties (density, chemical composition, shape) and external hydrodynamics, marine sedimentology and physical oceanographic conditions.

Recent studies indicate that particle shape and biofouling are the main contributors to the sedimentation/suspension behaviour of microplastics. Floating fibres and threads (one-dimensional particles, 1-D) are the first ones to begin to sink, followed by 2-D films and flakes, and then 3-D fragments. Thus, large amounts of microfibres have been detected in sediments from the deep waters of the Bay of Biscay, the Black Sea and the Mediterranean Sea. The amount of microfibres is higher in deep-water sediments (up to four orders of magnitude) than on the surface of the sea in polluted areas of the Atlantic Ocean, the Indian Ocean, and the Mediterranean Sea. The main polymers that have been detected in coastal sediments and higher-altitude sediments are natural and regenerated cellulose and synthetic plastics such as PS, PE, PP, acrylic and polyamide (including nylon), and ethylene-vinyl alcohol copolymers.

In the Mediterranean Sea, the amounts of microplastics detected in marine sediments range from 4 it./kg DW to more than 2,000 it./kg DW of sediment, and in coastal sediments, between 45.9 it./kg DW and 280.3 it./kg DW. In addition, microplastic concentrations are not associated with local sources of pollution. For example, in the sediments of Cabrera, a marine protected area in the Balearic Islands, there are more microplastics than in a touristic and very populated area of Mallorca. The same has been found in the Tyrrhenian and Adriatic seas. One of the most polluted areas of the Mediterranean Sea is the Venetian Lagoon (Italy), followed by the Maremma Regional Park in the Tyrrhenian Sea.

With regard to beach sediments, values of up to 422 it./kg DW have been recorded on the beaches of the Ebro Delta, where fibres are also the most abundant type of microplastic, which is the same as in deep-water sediments or on beaches in the Mar Menor lagoon area and the Tunisian coastal area.

Soils

Sources of microplastics in soil can be divided into three main categories: the contributions of agricultural practices, the influence of surface runoff and deposition, and the fragmentation of larger plastic waste. Agricultural practices are the use of compost and sewage sludge as fertiliser, plastic covering and irrigation.

Compost is widely used in agriculture as a fertiliser. In 2008, 18,000,000 t of compost were produced in the European Union. With a recommended annual application rate between 30 t/ha and 35 t/ha and a range of 2.38-180 mg of microplastics per kilogram of compost, this could represent an annual contribution to cultivated soils of 0.016 kg/ha to 6.3 kg/ha of microplastics on a European scale.

The use of sewage sludge as fertiliser is a very common practice in agriculture. In Europe, approximately 50% of the total sewage sludge produced is used in agriculture, a proportion that can reach 79% in Spain. The concentration of microplastics in sewage sludge varies from 1,500 particles per kilogram (part./kg) to 24,000 part./kg. This could represent an annual load of between 63,000 t and 430,000 t of microplastics in the case of the European Union.

The amount of microplastics found in agricultural land in Spain that come from the use of sewage sludge can be estimated to be between 21,000 t and 150,000 t, a value that can be compared to the pollution caused by plastics that float in the surface waters of the world ocean, which is between 93,000 t and 236,000 t.

With about 120,000 ha of agricultural area covered by plastic (plasticulture), Spain is the first European country in the use of this covering, which represents approximately 28% of the total covered agricultural area in Europe. Plastic coverings contain between 50 mg/kg and 120 mg/kg of phthalates (a harmful additive), leading to a phthalate concentration 74% to 208% higher in plastic-covered soils compared to uncovered soils.

In the near future, due to climate change, the direct use of partially treated or untreated wastewater may be the only source of water for agriculture in many parts of the world. Concentrations of microplastics in wastewater range from 1,000 part./m^3 to 627,000 part./m^3, of which approximately 75% are fibres. Depending on the type of crop and whether we consider developing countries or developed countries, the annual number of microplastics reaching the soil per hectare of crop could range from 2.2 × 106 part./ha to 3.1 × 109 part./ha for the former and from no particles to 625 × 106 part./ha for the latter. In Spain, with a crop area of 12.4 Mha, the annual load of microplastics related to irrigation could represent 7.75 × 1015 particles.

Along roads and urban areas, plastic debris that is not captured by sewer systems can pollute the surrounding soil. However, there are virtually no studies evaluating the amount of plastic introduced into the ground by litter or illegal dumping, although an estimate of 0.85 kg/ha to 6.6 kg/ha of litter swept along by water from highways during storms can be considered. The fine particles caused by the abrasion of vehicle tires on roads must be added to this. Estimates vary from 10,000 t to 100,000 t of microparticles in European countries, but no estimate is available for Spain.

Wastewater

Municipal wastewater is polluted with microplastics, with concentrations ranging from 10 part./m^3 to 107 part./m^3. Microplastics enter sewer systems from domestic sources in the form of synthetic textile fibres, cosmetic microbeads, and disintegrated parts of larger consumer products that are flushed down the toilet.

Wastewater treatment plants (WWTPs) are an important entry point into the aquatic environment for microplastics.

Plastics and other particulate matter are removed from liquid waste by sedimentation and end up in sewage sludge. As sewage sludge is used as a fertiliser in many EU member states, microplastics are introduced into agricultural land, from where they affect terrestrial ecosystems and – at least in theory – end consumers (livestock and humans).

Air

There are microplastics both in the air inside dwellings and outside. Atmospheric deposition is two orders of magnitude higher in closed, indoor environments: 11 000 microplastics/m². A study carried out on the roofs of Paris found microplastic fibres in sizes ranging from 7-15 µm to 100-500 µm. Atmospheric precipitation was estimated to range from 2 part./m² to 355 part./m² per day, with higher rates in urban areas compared to suburban areas. The amount of precipitation was estimated at between 3 t/year and 10 t/year for an area the size of Paris.

The highest values of microplastics in air correspond to road areas, due to the wear of vehicle tires, as well as the wear of the road itself. They represent from 0.05 mg/m³ to 0.70 mg/m³ of the fraction of particles of 10 µm or less. The evaluation of the air inside factories indicates high concentrations of microfibres of polyvinyl chloride (PVC): 7 mg/m³. Even in natural areas far from industrial and urban areas, rain and wind introduce microplastics – more than 1,000 t/year.

There may be other sources of microplastics in the atmosphere – the formation of sea salt aerosols, plastic particles from dry sewage sludge from agricultural soils, urban dust, etc. Inhalation of these microparticles must be an important route of entry into the respiratory system of animals and humans.

Impact of microplastics

In aquatic environments, plastic materials can concentrate hydrophobic pollutants up to ten million times the concentrations in the surrounding water. These chemicals could be released in other areas when environmental conditions change or after passing through the interior of the body of aquatic animals.

Aquatic ecosystems

Microplastics and nanoplastics can be ingested by aquatic organisms and can therefore be introduced into the marine food web. Some species ingest them unconsciously or passively (suspension and filtering feeders) and others, such as different species of fish, selectively. This can also pose a risk to human health due to the potential accumulation in commercial species such as bivalves and fish.

Plastics can reach concentration factors of a million or more inside organisms. A recent study shows that 60% of sardines and anchovies caught in the northeastern Mediterranean Sea had plastic in their digestive tract, and individuals with higher amounts of plastic also had a large amount of parasites. The fractions of fish that contain microplastics in the gastrointestinal tract are very variable: in ascending order, 0.0025% in fish from the North Sea, 17.5% in fish from the Spanish Atlantic and Mediterranean coasts, 19.8% in fish from the Portuguese coast, 58% in Turkish territorial waters, and 100% in fish from the South China Sea. The differences depend on the species, the concentration of plastics present in water, the size of plastics and the methodology used.

Studies in a planktonic copepod show that the intake of microplastics (polystyrene) reduces the rate of microalgae intake, fertility and perhaps the survival of the species. The transfer of microplastics along the food chains of marine plankton – from mesozooplankton species to macrozooplankton species – has also been studied. In the case of benthic organisms, there is a transfer of microplastics along the food chains (from mussels to crabs), but in a very small concentration, which disappears after about 20 days. The effect is a decrease in the energy available to animals and a reduction in their feeding activity.

In corals, microplastic pollution leads to reduced growth, a marked reduction in detoxifying and immune enzymes, increased activity of antioxidant enzymes, high mucus production, reduced biological efficacy, and negative effects on the relationship between corals and their symbiont microalgae.

As for the incorporation in grey seals and the fish they eat (herring), there is transfer, but in very small amounts. Laboratory studies in zebrafish indicate that microplastics accumulate in the liver cells of adult animals, and that their larvae accumulate them in the digestive tract and pancreas, but that this does not affect their survival.

NNot much is known about the translocation of plastic or its additives into the tissues, organs or blood of organisms. Translocation to the liver and gills of different species has been reported, but the presence of microplastics in the edible part of fish that is consumed by humans is not well known. For mussels, the translocation of microplastics into the circulatory system and their persistence for 48 days has been observed. A study in sea bass found that even if microplastics from 1 µm to 5 µm were able to transfer to fillets commonly eaten by humans, they did so at relatively low levels given the high levels of ingestion.

However, the main risk to wildlife and human health associated with the presence of plastic in seafood is probably the leaching of its additives, which are chemicals that can be released inside the body and translocated. The body can be easily affected, which can affect its growth and physiological functions.

Soils

Once in the soil, microplastics can be ingested and transferred to the organisms that live there. Earthworms exposed to polybrominated diphenyl ether (PBDE), a derivative of polyurethane foam, accumulate it in the body and transfer it from there to the soil. Also, when exposed to low density polyethylene (LDPE), earthworms are affected by high concentrations of microplastics, they retain and transfer microplastics to other organisms in the soil ecosystem through the food chain, and they also retain and transfer microplastics to the deeper layers of the soil – and possibly to groundwater. Microplastics can serve as a pathway for bioavailable metals, including zinc (Zn), in soil ecosystems, and those ingested by earthworms can be transferred to humans through the food chain: earthworm-fed poultry show higher concentrations of microplastics in faeces, but also in the gizzard, which is used for human consumption.

In addition to the impact on soil organisms and ecosystems, other effects are beginning to be investigated. For example, microplastics are mostly composed of carbon, which has a slow rate of renewal, and their presence in soil ecosystems should represent a carbon source unrelated to photosynthesis and net primary production. This should be taken into account in assessments of soil carbon storage, a key function of the ecosystem.

From a biophysical point of view, microplastics can affect the total density, water retention capacity, and functional relationship between microbial activity and stable water aggregates in soils. Also, by reducing the total soil density, microplastics can lead to greater plant growth, because the roots experience less resistance to growth. But negative effects on plants, related to plastic additives, are also possible.

Human beings

There is little data on the potentially inhalable fraction of microplastics present in the air or in the diet, as well as on the daily intake of nano- and microplastics in humans. The kinetics and biodistribution of microplastics after exposure are also not well known.

There is data on the inflammatory effects of plastic dust in animal models, but it is unclear whether these effects are applicable to humans. Microplastic fibres with a diameter between 7 µm and 15 µm can enter the airways. Occupational exposure to plastic microfibres causes granulomatous lesions that contain acrylic, polyester and nylon powder, which causes respiratory irritation. Flock worker's lungs may be present as a rare lung disease in nylon textile workers exposed to breathable-sized fibre dust. This and other lung diseases can be chronic. Plastic products often contain additives, colorants and pigments, many of which have effects on human health, including reproductive toxicity, carcinogenicity and mutagenicity.

In deep lung regions, very small microplastics can be picked up by macrophages and epithelial cells, and can possibly be transferred to systemic circulation. Nanoplastics and microplastics present in animals and plants can enter the human body by ingestion, but there is little data to quantify dietary exposure, which is almost always referred to products of marine origin.

An additional potential impact may be caused by inhalation of microplastics with microbial colonisation. In addition to the risks associated with infections by pathogenic species, inhaled microplastics could cause a change in the structure of the communities of microbes that colonise the lung.

It is also unknown whether the fibrous and non-fibrous form of microplastics is related to their possible toxicity – for example, whether small enough fibres could cause effects similar to those of asbestos.

The other route of entry of microplastics into the human body – through food intake – has not been studied much yet. The presence of microplastics in some commercial species, especially fish, has already been mentioned. Other routes of entry are through food and beverages that are purchased packaged, or from drinking water distributed by municipal water supply systems.

Plastic, paper, cardboard, wood, ceramics and metal used as food packaging allow the passage of material from packaging to food. Once microplastics gain entry via ingestion, the intake of particles (<1 µm) in the intestine can occur by endocytosis and phagocytosis or, for larger particles, by persorption.

Thus, the consequences of ingesting microplastics and their effects on the human body are not well known yet. They could be excreted without harm to human health, but we do not yet know if these particles could be transferred to organs or tissues. Nevertheless, the main toxicological problem related to the ingestion of microplastics is probably associated with their chemical additives.

Some of these additives, such as phthalates, are toxic to humans. A recent study carried out by several Catalan research institutions analysed the urine of volunteers in search of the presence of plastic additives. They found more than 15 different phthalates and polyphenols that are common plastic additives. Another study, conducted in Austria, found plastic fibres in the faeces of several volunteers from different countries. These studies show that plastic additives reach the human body. Some of these additives are known to be endocrine disruptors or even carcinogens. Additives present in urine and feces are excreted, but it is unknown whether these chemicals are transferred to the bloodstream, organs or tissues. And, even if they were excreted, the human body's continued exposure to these chemicals could lead to diseases of which we are not aware yet.

Plastics additives can also be released in wastewater treatment plants where, after chlorination, they can form trihalomethanes that are harmful to human health.

Nanoplastics can also affect the composition and diversity of the human microbiome. Since there is an effect of the intestinal microbiota on the endocrine, immune, and nervous systems, this involvement of the intestinal microbiome can have effects on many aspects of human physiology. The finding of microplastics in the placenta of pregnant women, both on the outer side (the mother) and on the inside (the foetus) of the placenta, is also worrying. There is currently no indication of the possible effects of this presence on pregnant women.

Social, management and legislative aspects

Management and legislative responses to microplastics must be considered in terms of both primary and secondary microplastics. As for the secondary ones, responses are broad and cover plastic waste, in general, or macroplastics. Their ultimate goal is to prevent plastic leakage and damage to the environment, where macroplastics end up degrading into smaller fragments and become microplastics. In recent years, circular economy is being promoted as a way to keep resources in closed loops and make the most of the value of plastics. The initiatives are many, from a global to a local scale, and come both from public and private sectors concerned, including public-private partnership initiatives.

In the European Union, microplastics that can be generated as a result of partial or non-existent waste management, or as a result of the degradation of larger plastic waste, are addressed by initiatives included in the European Union Plastics Strategy for reducing macroplastic waste.

In Catalonia, the new law on waste prevention and management and resource efficiency, which is expected to be passed in 2021, should be the benchmark for promoting circular economy and preventing the entry of plastics into the environment. Responses to primary plastics may be more relevant in view of possible policies, as they target direct sources of microplastics in the environment and could be explained in terms of policy makers, the private sector and society.

Public management responses

Microplastics have received worldwide attention in recent years. The UN Environment Assembly (UNEA) was established in 2012 by decisions of the Rio+20 Conference and the United Nations General Assembly (UNGA). UNEA-4 met in Nairobi in March 2019 and adopted a specific resolution on marine plastic waste and microplastics (UNEP / EA.4 / Res. 6). With regard to the Barcelona Convention for the Protection of the Mediterranean, microplastics are expected to be incorporated into the revision of the Regional Plan for the Management of Marine Litter in the Mediterranean at the end of 2021.

In September 2018, the European Parliament called on the European Commission to introduce an EU-wide ban on intentionally added microplastics to cosmetics and detergents by 2020, and to take steps to minimise the release of microplastics in textiles, tires, paints and cigarette butts. In January 2019, the European Chemicals Agency (ECHA) published a proposal to restrict the use of microplastics. It is based on the results of ECHA's assessment on the health and environmental risks of microplastics that are intentionally added to products. The process is ongoing and may lead to an amendment to Annex XVII of the REACH Directive. In Spain, the draft bill on waste and polluted soils establishes a ban on microplastics intentionally added to cosmetics and detergents from 3 July 2021.

The European Commission also looked at options to reduce microplastics that are created by wear during the life cycle of a product, or that are emitted by accidental spills – tires, road markings, preproduction plastic pellets, and synthetic textile washes are significant sources of microplastic emissions into the environment.

In the case of Catalonia, the new law on waste prevention and efficiency of resources will include a specific chapter on microplastics. At a local level, some councils have launched initiatives to reduce the burden of microplastics in their environment (for example, in 2020 the councils of Calafell, L'Ampolla and Vinaròs, among others, installed buoys in the sea to filter microplastics).

Private sector responses

Companies around the world are taking steps to reduce the accidental loss of microplastics or to reduce leakage due to wear and tear. Operation Clean Sweep is aimed at all segments of the plastics value chain (raw material producers, logistics chain, recyclers and processors) with the implementation of good environmental practices and the containment of pellet, flake and dust spills.

Regarding textiles, the problem of pollution by synthetic microfibres is complicated and of a considerable scale, and the change from synthetic to natural materials would entail other environmental costs. The release of plastic microfibres from synthetic clothing calls for a collaborative effort of the textile industry. Fashion brands, as well as the stakeholders in the entire value chain, are testing various solutions, including thread and fabric finishing treatments, washing machine filtration systems, presale washes, detergents and washing conditions, among others.

Civil society responses

Civil society and non-governmental organisations (NGOs) have shown great concern about the plastic pollution crisis and have launched many actions and initiatives to make governments, businesses and consumers take responsibility. The "Beat the microbead" campaign led companies like L'Oréal and Procter&Gamble to phase out microbeads from their personal care products.

In Catalonia, civil society is also taking action on plastics. An example is Rezero, which carries out numerous campaigns on plastics, such as "Plastic Health".

10
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