THE PRESENCE AND IMPACT OF PLASTIC LITTER IN THE MEDITERRANEAN SEA

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SUMMARY & TAKE-HOME MESSAGES

Plastic debris, including litter, is ubiquitous in the world's oceans. It floats on the surface, is present in the water column and is buried in the sediment of every ocean. There are many sources, including poor waste management, lost fishing gear and deliberate dumping of litter.

The Mediterranean Sea is a semi-enclosed body of water with a surface area of 2.6 million km^2 and access to the Atlantic Ocean through the Strait of Gibraltar. The region is recognized for its rich biodiversity, and supports about 7.5% of known marine species.

Its terrestrial coastal states have some 427 million inhabitants (approximately 7% of the world's population), as well as 25% of the international annual tourist trade, and 30% of global shipping traffic. The topography of the region, the extent of anthropogenic activities and the limited flow of water between the Mediterranean Sea and the Atlantic Ocean undoubtedly contribute to the quantity of litter in the basin.

This technical report is primarily concerned with plastic litter, but anthropogenic marine litter also includes metal, glass, wood, clothing, paper, cardboard, rubber and clinker (the reside of burnt coal). Research papers address a number of aspects, including surveys of the water column, sea floor and beaches, and impacts to flora and fauna. A selection of background and further reading is presented in Section 8. Tabulated findings from selected peer-reviewed papers, which form the basis of this report, are included in Annex 1.

ABUNDANCE OF FLOATING LITTER

It is now widely recognised that the Mediterranean basin is heavily polluted with plastic litter. Field studies and computer models report widely varying estimates for total amounts of plastic present, in part because of differing methods and assumptions applied and in part because such estimates are, by their very nature, highly uncertain.

- Findings from surface net tow surveys using a 0.2mm mesh have been used to estimate that the average density of plastic (micro- meso- and macro-size) in the Mediterranean basin is 1 item in every 4 m^{-2}, which is comparable to the accumulation of plastic litter in the five subtropical ocean gyres that have received a lot of attention and concern in recent decades. This adds up to an estimated total abundance of floating litter in the Mediterranean Sea of 3.1 x 10^{12} (3.1 trillion) particles.

- Another paper that takes all types of 'macrolitter' (items greater than 2cm in length or diameter) into account estimates that in excess of 62 x 10^6 (62 million) of these larger, more visible items are floating on the surface of the Mediterranean Sea. Such visual surveys cannot account for heavier items that have sunk to the seafloor, or for microplastics, such as fragments, filaments, microbeads, fibres, etc.

- A further study, based on the range of results from three different models, estimates the quantity of microplastics (smaller than 5mm in length or diameter) in the Mediterranean basin to be in the range 3.2×10^{12} and 28.2×10^{12} (3.2 to 28.2 trillion) particles.

In practice any estimate is inherently impossible to verify with accuracy; what is clear from all of those available, however, is that plastic pollution has become a very significant problem for the Mediterranean Sea.

LITTER ON THE SEAFLOOR

- Canyons and gullies in the Mediterranean basin could become a conduit to transport particles from the coastal regions to the abyssal plain. The floor of two canyons in the northwest Mediterranean Sea were found to have mean litter densities greater than 8,000 items km^{-2}. In other locations, a site along the coast of the Tegnùe of Chioggia in the northwest Adriatic had a mean litter density of 3.3 items 100 m^{-2}. And the rocky sea bottom of the Tyrrhenian Sea off the coast of Sicily had a median litter abundance of 0.12 items m^{-2}.

SOURCES OF LITTER

- The terrestrial coastal states have some 427 million inhabitants (approximately 7% of the world's population), as well as 25% of the international annual tourist trade, and 30% of global shipping traffic. This intensity of population, development and use of the sea, within a relatively enclosed water body, has contributed to the growing problem of plastics pollution in the Mediterranean.

- Litter is not evenly distributed in the Mediterranean Sea; it tends to accumulate near coastal regions, particularly urbanized developments, along shipping lanes and areas that attract recreational boat traffic, as well as in submarine canyons.

- One study noted a significant difference in the abundance of plastic particles in coastal areas (less than 25km from land) than further out to sea in the central and western Mediterranean Sea, suggesting that input from rivers, tourism and intensive coastal development may be major contributors to marine litter.

- 83% of plastic items in samples collected from the surface of the Mediterranean Sea using a neuston net were microplastics (smaller than 5mm in length or diameter). These include both primary microplastics, i.e. particles manufactured in that size range (such as microbeads) and secondary microplastics, i.e. formed from the fragmentation of larger items under the influence of waves, sediment abrasion and UV light

- Of plastic beach litter, cigarette filters are often reported to be the most abundant in numerical terms, but are by no means the whole story. Other commonly found items are bottles and bottle caps, cutlery and bags, indicating pollution from beach users as well as that washed up on the beaches from other areas.

IMPACTS OF PLASTIC LITTER

- Plastic litter is known to have been ingested by many different species that inhabit the Mediterranean, including swordfish, Atlantic blue tuna, albacore tuna, blackmouth catshark, the Mediterranean basking shark, fin whale and loggerhead sea turtle.

- Concerns are that plastic microplastics could transfer or accumulate within the food chain if predators ingest prey that has consumed plastic.

- It is not yet known whether there are health implications for humans consuming seafood contaminated with microplastics, though the concerns are clear. In addition, there is currently no regulatory framework concerning the presence of microplastics in seafood.

- Abandoned or lost fishing gear can lodge on reefs and smother coral or trap marine animals. For example, a remotely operated video survey in the South Tyrrhenian Sea reported that abandoned fishing litter was visible in 62% of the video frames, and noted severely damaged coral communities.

UNCERTAINTIES AND PRIORITIES FOR FUTURE RESEARCH

There are a number of uncertainties relating to marine litter and there are several avenues for future research, including:

- The Mediterranean Sea is, in some ways, one of the most investigated maritime regions of the world, and yet data on marine litter are still incomplete for the region.

- More data are needed to understand the sinks, sources, fate and residence times of different polymers in the water column and sediment.

- To gain more accurate estimates of the plastic load in the Mediterranean Sea will require more extensive survey and long-term monitoring data.

- More data are needed from the eastern Mediterranean Sea, in particular.

- Awareness campaigns and education will help to maintain public interest in marine pollution. Campaigns to highlight the problems with microbeads in toiletries and cosmetics provide an example of how members of the public can be engaged with environmental issues and how this can make a difference. More research is needed into how best to educate and inform the public on a global level to stem the tide of plastic and other forms of litter.

- Measures such as education programmes and recycling schemes may help to reduce the quantities of plastics and other forms of litter entering the ocean, but to tackle the problem effectively will need far greater efforts at source to stop wasteful use of plastics, including single-use plastics for packaging, by seeking alternative and more sustainable materials.

1. BACKGROUND

Scientific literature relating to the presence and impacts of anthropogenic litter in the Mediterranean Sea is extensive. This technical report presents a selection of the available data that has been published over the past decade.

1.1 CONCERNS SURROUNDING PLASTIC LITTER IN THE MARINE ENVIRONMENT

Plastic materials were developed in the 1930s and 1940s and mass production began in the 1950s. Over the past half a century or so, the popularity of and uses for different plastics have continued to increase and projections suggest that the trend will continue. In 2015, the demand for plastics in Europe was 49 million tonnes and the highest proportion (39.9%) was used for packaging. Plastics production in Europe is expected to increase by a further 1.5% in the current year alone (Plastics Europe, 2016).

But for all its merits of being lightweight, durable, convenient and versatile, there is a downside that had not been predicted: vast amounts of litter. Plastic debris has become ubiquitous in the world's oceans. It floats on the surface, is present in the water column and is buried in the sediment of every ocean (GESAMP, 2015). The presence of plastic debris in the marine environment is because of its continued manufacture and use but also from poor waste management, notably in emerging economies. Education programmes, recycling schemes and efforts to minimise the use of single-use plastics by seeking alternative and sustainable materials, particularly for packaging, can help to mitigate the tide of plastic entering the ocean. Globally, plastics comprise 60-80% of all marine litter (Derraik, 2002) or even 90% in some beach litter surveys (Pasternak *et al.,* 2017). But the problem of how to remove the existing litter from our oceans is challenging.

High-level political meetings such as G7 and international bodies such as the United Nations are formally acknowledging the issues presented by plastic marine litter (see Section 1.5). The extent that human-induced changes – including those relating to land use, composition of the atmosphere, and abundance of plastic litter – are affecting the Earth's ecosystem has even prompted discussion among earth scientists to formally acknowledge a new geological epoch: the Anthropocene (Lewis & Maslin, 2015).

1.2 TERMS OF REFERENCE

This report has been structured around the following terms of reference:

i. Prepare a review of the scientific literature documenting the presence of plastic litter and marine plastic debris in the marine environment of the Mediterranean region (on beaches, in sediments, in the water column and in biota).

ii. As part of that process, compile a list of research groups and institutions involved in conducting and publishing research on marine litter.

iii. Identify any temporal or spatial trends that can be discerned from available studies.

iv. Review available information relating to the effects of litter pollution on species, habitats and/or ecosystem processes.

v. Identify key gaps and uncertainties in scientific knowledge in relation to the topics above.

1.3 Definition of marine litter

Marine litter is defined by the OSPAR Commission (www.ospar.org) as: "any solid material which has been deliberately discarded, or unintentionally lost on beaches and on shores or at sea, including materials transported into the marine environment from land by rivers, draining or sewage systems or winds. It includes any persistent, manufactured or processed solid material."

This technical report is primarily concerned with plastic litter, but anthropogenic marine litter also includes metal, glass, wood, clothing, paper, cardboard, rubber and clinker (the reside of burnt coal).

There is currently no formal system that classifies the size of marine litter. Individual papers consulted during the research for this report generally adopt the following: microplastics less than 5mm in length or diameter; mesoplastics 5–10mm; macroplastics greater than 10mm. GESAMP (2015) defines microplastics as 1 nm to 5 mm.

1.4 The Mediterranean basin

The Mediterranean Sea is a semi-enclosed body of water with a surface area of 2.6 million km^2 and access to the Atlantic Ocean through the Strait of Gibraltar. It has two deep basins of water separated by the 400m-deep Strait of Sicily. The deepest part of the Mediterranean Sea is the Hellenic Trench in the Ionian Sea. Studies of the geomorphology show that the area has a network of canyons and gullies, which could become a conduit to transport particles from the coastal regions to the abyssal plain. The water in the basin can have a residency time of up to 100 years (Ramirez-Llodra *et al.,* 2013; Cózar *et al*., 2015; Tubau *et al*., 2015).

The Mediterranean region is recognized for its rich biodiversity, and supports about 7.5% of known marine species (Ramirez-Llodra *et al.,* 2013). The Mediterranean's terrestrial coastal states have some 427 million inhabitants (approximately 7% of the world's population), as well as 25% of the international annual tourist trade, and 30% of global shipping traffic (UNEP/MAP, 2015; Eurostat, 2017). The coastal zones are densely populated and the region attracts thousands of tourists, particularly during the summer months. The high level of activity in the region has led to the accumulation of anthropogenic debris such as plastic, glass, wood and rubber in the Mediterranean Sea – litter has been found in the water column, on beaches and on the deep sea floor. The topography of the region and the extent of anthropogenic activities mean that the likelihood of pollution by plastic and other types of man-made litter is high. The flow of water between the Mediterranean and the Atlantic Ocean is limited, which leads to the accumulation of floating litter in the Mediterranean basin.

The Mediterranean Sea can be considered as a zone in which floating plastic debris accumulates. Findings from surface net tow surveys using a 0.2mm mesh have been used to estimate that the average density of plastic in the Mediterranean basin is 1 item 4 m^{-2}, which is comparable to the accumulation of plastic litter in the five subtropical ocean gyres (Cózar *et al.*, 2015).

As one of the first to quantify litter floating in the Mediterranean Sea, Morris (1980) reported that approximately 2,000 pieces of small-size litter (>1.5 cm) per km^{-2} were in the area 40 miles southwest of Malta and that 60-70% of the debris was plastic. Suaria *et al.* (2016) analysed plastic debris floating in the central Mediterranean Sea and concluded that the basin was severely polluted with a complex mixture of polymers. Sixteen different types of synthetic materials were identified and it was estimated that the total abundance of litter in the Mediterranean Sea was 3.1×10^{12} particles. Another paper reports a similarly high figure and taking all litter types into account estimates that in excess of 62 million macro-litter items are floating on the surface of the Mediterranean Sea (Suaria & Aliani, 2014).

Sources of plastics in the marine environment include runoff from landfill, discarded fishing gear, intentional dumping, accidental spillage and discarded containers, often from ships (Derraik, 2002). Low-density polymers such as polyethylene, polypropylene and polystyrene tend to float and are therefore more likely to be found near to the sea surface, whereas high-density plastics such as polyvinyl chloride, polyester and polyamide are more likely to be found lower in the water column and in sediment (Cole *et al.,* 2011). Polyethylene is commonly used for packaging – in the ocean, polyethylene is most likely to originate from plastic bags and bottles (Avio *et al.,* 2015).

A primary reason for the extent of litter in the ocean is mismanaged waste – that is, anthropogenic litter that has been deliberately dumped or irresponsibly disposed of – and the problem is extensive and global. Jambeck *et al.* (2015) estimated that in 2010, in the region 4.8-12.7 million metric tonnes of plastic entered the ocean from 192 coastal countries across the world. Should waste management strategies remain unchanged, the team predicts that the amount of plastic entering the oceans from those 192 countries will increase by an order of magnitude by 2025.

1.5 LEGISLATION

United Nations Convention on the Law of the Sea (UNCLOS)

Part XII of the United Nations Convention on the Law of the Sea details the requirements of the Protection and Preservation of the Marine Environment. There is no specific mention of plastic litter, but general reference to the obligations of States in Article 194 is "to take measures to prevent, reduce and control pollution of the marine environment" and in article 204 to monitor the risks or effects of pollution (UNCLOS, 2017).

European Union Marine Directive 2008/56/EC

The legal framework that was put in place to protect the marine environment across Europe is the European Union's Marine Directive 2008/56/EC, which came into effect on 17 June 2008. The aim of the Marine Strategy Framework Directive is to achieve what it states as 'good environmental status' by 2020. Good environmental status is defined in the directive as: "The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive." To achieve good environmental status, each member state is obliged to develop a strategy to manage human activities that impact upon the marine environment. The Marine Directive has adopted an adaptive management approach and the member states must review and update its marine strategy every six years. Descriptor 10 focuses specifically on marine litter, and states that good environmental status is only achieved when "properties and quantities of marine litter do not cause harm to the coastal and marine environment" (EU, 2008).

MARPOL Convention

Pollution from ships and the disposal of litter in the ocean are regulated by the International Maritime Organization under the International Convention for the Prevention of Pollution from Ships (MARPOL). The MARPOL convention came into effect in 1983. Of particular note is Annex V: Prevention of pollution by garbage from ships, which came into effect on December 31, 1988, and bans the disposal of any form of plastic into the sea (IMO, 2017a).

The London Convention and London Protocol

The London Protocol, short for the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, entered into force in 2006. Its objective is to "promote the effective control of all sources of marine pollution" (IMO, 2017b). The LC/LP agreed a resolution on marine litter in 2016 (IMO, 2016).

Barcelona Convention

The Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean was adopted in 1995. There are 22 contracting parties that are committed to achieving sustainable development. One of its main objectives is to assess and control marine pollution (EC, 2017).

United Nations Environment Assembly (UNEA)

At their session in Nairobi from May 23–27, 2016, the United Nations Environment Assembly discussed marine plastic litter and microplastics. Concerns expressed included the ability of microplastics to enter marine food chains and the potential risk for the environment and human health, and that plastics contain and can adsorb and emit chemicals (UNEA, 2016).

G7

The G7 meeting in Germany in 2015 acknowledged that marine litter, particularly plastic litter, poses a global challenge. The G7 leaders stressed the need to address land- and sea-based sources of litter, removal of litter, as well as education and research (G7, 2015).

1.6 Limitations to this review

- Does not include in-depth analysis of chemical pollution.
- Does not examine in-depth the sources of marine litter.
- Does not examine in-depth solutions to the problem, aside from an outline of the main points in Section 5.3.

2. LITTER IN THE MEDITERRANEAN SEA: A SUMMARY OF THE LITERATURE

The presence of plastic debris in the marine environment is an established global problem. Environmental implications including entanglement, strangulation and ingestion of marine litter have been reported over the past three decades (Gregory, 2009). Scientific monitoring and observational studies in the Mediterranean Sea have been a valuable source of information on the abundance of marine litter. Additional sources of information include anecdotal reports from members of the public and beach clean schemes.

This section presents examples of findings from the literature and is not exhaustive.

2.1 MASS AND QUANTITY OF PLASTIC LITTER

No definitive figure on the abundance of plastic in the world's oceans exists, but a quantitative theoretical model estimates that there are 5.25 trillion pieces of plastic debris weighing in the region of 268,940 tons floating in the world's oceans, not including pieces on the seabed or on beaches.

Estimates of microplastic load in the world's oceans vary. Van Sebille *et al.* (2015) report the range of results from three different models: in the Mediterranean basin are an estimated 3.2 x 10^{12} and 28.2 x 10^{12} microplastic particles; the North Pacific basin has between 7.3 x 10^{12} and 15.9 x 10^{12} particles; and the South Atlantic basin is between 1.0 x 10^{12} and 2.6 x 10^{12} particles.

Visual surveys suggest that the Mediterranean Sea has a high density of marine litter. Based on such surveys, an estimated 62 million items of macrolitter are floating on the Mediterranean Sea (Suaria & Aliani, 2014), which doesn't account for heavier items that have sunk to the seafloor.

Eriksen *et al.* (2014) estimate that the mass of surface plastic litter in the Mediterranean Sea is 23,150 tons. Van Sebille *et al.* (2015) calculate the global mass of floating marine microplastic to vary substantially from 93,000 to 236,000 metric tonnes, with the mass of microplastic in the Mediterranean Sea varying from 4.8 to 30.3 thousand metric tonnes, depending upon the model used. The estimated figures from Eriksen *et al.* (2014) and Van Sebille *et al.* (2015) contrast with another group, which estimates a much lower mass of surface plastic litter in the Mediterranean Sea. Cózar *et al.* (2015) estimate that in the region 756 to 2,969 tons of plastic are floating on the surface of the Mediterranean Sea.

In practice any estimate is impossible to verify with accuracy. However, even though the Mediterranean Sea is one of the most investigated maritime regions of the world, data on marine litter are still incomplete for the region, which is why estimates relating the mass or quantity of plastic litter differ widely (Tubau *et al.*, 2015). The disparity in estimated plastic load is because of the different computer model formulations. For this reason, estimates, particularly the higher figures, should be treated with caution. Cózar *et al.* (2015) suggest that more extensive sampling of plastic particles will be needed to develop accurate estimates of the Mediterranean plastic load.

2.2 LITTER SURVEYS

Surveys employ different methods to attempt to quantify Mediterranean marine litter on the sea floor, surface water and beaches. Surface seawater samples are typically collected using a neuston net or a manta net that is dragged behind or alongside a ship; on beaches, litter is collected by hand; and on the seabed trawlers collect and remote operated vehicles assess litter that has accumulated.

Some examples of litter surveys follow below:

2.2.1 SURFACE-WATER SAMPLING

In comparison to other oceans, the Mediterranean Sea has a high proportion of floating debris, of which microplastics are most abundant. Cózar *et al.* (2015) found that 83% of plastic items in samples collected from the Mediterranean Sea using a neuston net were microplastics (that is, they were smaller than 5mm in length or diameter). They conclude that the average plastic contamination in the surface waters of the Mediterranean water is 423 g km^{-2} or 243,853 items km^{-2}. The authors compare the Mediterranean figure with the inner regions of subtropical ocean gyres, which ranged from 281 to 639 g km^{-2}.

Collignon *et al.* (2014) sampled surface water several times per month in the Bay of Calvi, Corsica, for one year. The team found plastic particles in 74% of the 38 samples. The annual average of the total number of plastic particles measuring less than 10 mm diameter was 6.2 particles per 100 m^2. The highest abundance of all sizes of plastic particles was observed in the summer months, and the lowest abundance was in the winter months. Large microplastic (2-5 mm) was the most abundant size class, and represented 54% of plastics recorded.

2.2.2 BEACH LITTER SURVEYS

Several research groups have conducted beach litter surveys. As well as affecting flora and fauna, litter deters tourists and persistently litter-strewn beaches can have a negative impact on the income generated by a country or region's tourist industry.

Published data from beach litter surveys report that, in general, plastic litter dominates. At the higher end of the scale as much as 90% on Israeli beaches (Pasternak *et al.,* 2017) and 81.1% on beaches in eastern Italy (Munari *et al*., 2016) of collected litter was plastic. Others found slightly lower figures of 64% plastic on Slovenia's beaches (Laglbauer *et al.,* 2014), and 43% in 2006 and 51% in 2007 on Greek beaches (Kordella *et al*., 2013).

Of plastic beach litter, cigarette filters are often reported to be the most abundant in numerical terms (Laglbauer *et al.,* 2014; Munari *et al.,* 2016). An analysis of macrolitter on Slovenian beaches by Laglbauer *et al.* (2014) suggests that the high proportion of cigarette filters (median figure 41.9% of all plastic litter from the total sample data) are left there by visitors. They suggest that improved litter disposal, beach cleaning and education are needed to help prevent littering by beachgoers. Munari *et al.* (2016), who analysed litter on Italian Adriatic beaches, also suggest that the presence of items including small fragments, bottles and bottle caps, cutlery and mesh bags indicates pollution from beach users.

Laglbauer *et al.* (2014) analysed macrodebris and microplastics (less than 5mm in length or width) in sediment from five Slovenian beaches in July 2012. They found a total of 5,870 items of macroplastic, which they categorized as plastic (64%); paper (19%); glass and ceramics (11%); metal (2%); rubber (1%). Of the plastics, the greatest portion of the litter (median value 41.9%) was cigarette filters, which the authors suggest is an indication that beachgoers leave the rubbish in situ rather than taking home or disposing of responsibly. When the authors analysed the microplastic samples, they found secondary microplastics only and no primary microplastics. Most microplastics were fibres (75% in samples from the shore; 96% in samples from the infralittoral zone).

2.2.3 Trawler studies

Trawl surveys disturb sediment, flora and fauna on the seabed. However, this type of survey enables recovery of debris items and detailed hands-on analysis, including accurate determination of mass, of marine litter.

Strafella *et al.* (2015) collected marine litter over a period of two years from the central and northern Adriatic Sea. Using trawler studies, the team found that there was a higher mass of all types of litter on the seabed at locations closer to the shore than at greater depths further out to sea. To a depth of 50m, plastic was the most abundant category of litter found on the seabed.

Ramirez-Llodra *et al.* (2013) conducted a deep-sea survey and found litter at all depths sampled, ranging from 900–3,000m, on a trans-Mediterranean voyage. Plastics were present in 92.8% of the samples collected.

A greater mass of litter was collected from the seafloor at locations closer to the shore than further out to sea in trawler studies of ten sites across the west, central and eastern Mediterranean by Pham *et al*. (2014). The authors note that distribution of marine litter is affected by factors including wind and wave action, currents and weather systems such as storms. One reason why litter may not accumulate at the continental shelf (the Gulf of Lion in this study) is a strong current transporting litter to deep waters. Canyons had the highest litter density – this observation is of environmental concern because such regions are often Vulnerable Marine Ecosystems.

2.2.4 Visual observations

Suaria & Aliani (2014) carried out visual surveys on 167 transits across the central and west Mediterranean Sea to assess floating debris. They observed anthropogenic debris on 87% of all transects. Of the litter sighted, 78% was anthropogenic (including plastic, Styrofoam and man-made objects) and 22% was naturally occurring (including fallen trees and algae).

2.2.5 Remotely operated vehicles surveys

Surveys carried out using remotely operated vehicles (ROV) can be used to scope any seabed formation, but are particularly useful for rocky bottoms. Unlike trawl surveys, ROV studies do not disturb sediment, flora or fauna on the seabed. Although trawling enables recovery and hands-on analysis of marine litter, ROV surveys are able to provide detailed, high-res photo and video footage to allow accurate measurement and identification of marine organisms and ecosystems, and can be used to identify the type, extent, quantity and location of litter that accumulates on the seabed (Tubau *et al.,* 2015).

- Tubau *et al.* (2015) found that the sea floor of two canyons (La Fonera and Cap de Creus) in the northwest Mediterranean Sea have mean litter densities greater than 8,000 items km^{-2}.

- Melli *et al.* (2017) surveyed a site along the coast of the Tegnùe of Chioggia in the EU Site of Community Interest (SCI) in the northwest Adriatic and found a mean density of litter from all sections of 3.3 items per $100m^2$. The paper concludes that the SCI studied, which is a sanctuary of marine biodiversity, is heavily polluted by marine litter, particularly discarded fishing gear.

- Angiolilli *et al.* (2015), assessing the rocky bottom of the seabed in the Tyrrhenian Sea around Campania, Sicily and Sardinia, found a high incidence of anthropogenic debris on the rocky sea bottom of the Tyrrhenian Sea. Sicily had the highest range of debris abundance, with a median abundance of 0.12 items m^{-2}.

- Fabri *et al.* (2014) reported a total of 199 items of lost fishing gear, observed during ROV surveys in the Ligurian Sea and Gulf of Lion. Because of technical constraints in measuring surface areas, in this study the researchers estimated abundances along the ROV navigation tracks. The highest abundance of litter was in Toulon canyon in the Ligurian Sea (up to 12 items/km^{-1}). The highest abundance of litter was in the Gulf of Lion in the Grand-Rhône canyon (up to 5 items/km^{-1}).

2.3 Ecologically important areas / marine reserves / IUCN Red List

Marine species are known to be affected my plastic and other litter by ingesting it, entanglement or suffocation. Areas of the ocean intended to protect marine organisms are not immune from the effects of litter. A selection of examples follows:

- Melli *et al.* (2017) report that a Site of Community Interest in the northwest Adriatic is heavily populated with marine litter.

- Of concern is a report that micro- meso- and macroplastic has been found in the stomachs of two species of tuna in the central Mediterranean Sea: *Thunnus thynnus* (Atlantic bluefin tuna, listed as Endangered on the IUCN Red List of Threatened Species) and *Thunnus alalunga* (albacore tuna, listed as Near Threatened on the same list). Both species have been found to ingest macro- and microplastics (Romeo *et al.,* 2015a).

- Plastic particles were found by Anastasopoulou *et al.* (2013) in the stomach contents of *Pagellus bogaraveo* (blackspot seabream) from the Ionian Sea. The species is listed as Near Threatened on the IUCN Red List of Threatened Species.

- Microplastics were found in the sediment in the marine protected area of the Cabrera Archipelago National Maritime-Terrestrial Park off the Balearic islands in the western Mediterranean by Alomar *et al.* (2016). The majority of the plastic particles were plastic fragments. One of the zones sampled was a no-take zone with no boating or activity allowed, and the other site had restricted use. The authors comment that strong currents or wind may transport plastic litter from its source to the MPA. Contrary to expectations, the study found more microplastics in the MPA than in the urban site sampled.

- Biopsies of the blubber of fin whales (*Balaenoptera physalus*) that spend the summer in the Pelagos Sanctuary in the northwest Mediterranean indicate exposure to plastic additives as a result of direct and indirect ingestion of microplastic, macroplastic and contaminated prey (Fossi *et al.,* 2016). Fin whales have a long lifespan and are also listed as Vulnerable on the IUCN Red List of Threatened Species because the number of individuals is declining. The area of the Mediterranean in which fin whales congregate in the summer months is a Specially Protected Area of Mediterranean Importance, which has been reported to have a high concentration of microplastic.

- Blašković *et al.* (2017) analysed litter in the sediment in different areas of the Natural Park of Telaščica bay, Croatia. The study found microplastic in 88.71% of all sediment samples and mesoplastic in 11.29% of all sediment samples. No macroplastic was found in the sediment. The analysed plastic samples comprised 90.07% filaments, 7.45% film, and 2.48% classified as other.

3. Data trends

3.1 Temporal

Time and other constraints have limited this technical report to focus (primarily) on research papers that have been published largely in the past ten years. Others have conducted literature reviews that have analysed papers from as far back as the 1970s and report an increase in litter abundance over time (Tubau *et al.*, 2015).

- Ruiz-Orejón *et al.* (2016) report that plastics were responsible for 96.87% of all floating debris in the Mediterranean Sea in net trawls conducted in 2011 and 2013. The authors note that this percentage is higher than previous estimates and suggest that microplastic abundance in the region studied is increasing.

- A study of loggerhead turtles inhabiting the central Mediterranean spanning 2005-2015 reported an increase in debris ingestion over the 11-year period studied (Casale *et al.,* 2016).

- Collignon *et al.* (2014) studied the seasonal change in abundance of plastic particles off the coast of Corsica over one year from August 2011 to August 2012. The highest number of plastic particles was recorded on September 30, 2011 (56.7 particles/100m^2) and on April 10 2012 (68.8 particles/100 m^2). The lowest values were recorded in the winter months (0 particles).

- Fluctuations in the abundance of microplastic particles (0.3-5mm) were recorded by van der Hal *et al*. (2017) in Israeli coastal waters during the sample period, which ran from July 2013 to May 2015. The highest abundance of microplastics was recorded at the Neve Yam site in summer 2014, when there were 324.10 particles/m^3. However, in the previous summer of 2013 the abundance of microplastics was much smaller, at 0.94 particles/m^3. The temporal and spatial variation in microplastic abundance in this study was perhaps because of regional sea conditions and coastal morphology, but may be a typical characteristic of this type of pollution.

3.2 Spatial

Litter is not evenly distributed in the Mediterranean Sea. Litter tends to accumulate near coastal regions, particularly urbanized developments, along shipping lanes and areas that attract recreational boat traffic, and in submarine canyons (Pham *et al.,* 2014; Ruiz-Orejón *et al.*, 2016).

3.2.1 Geographical: Western and central Mediterranean

In a study by Suaria *et al.* (2016), samples collected from the western Mediterranean were dominated by low-density polymers including polyethylene and polypropylene. Samples collected from the Adriatic included paint chips, polystyrene, polyvinyl chloride, polyvinyl alcohol and polyamides. The group analysed spatial trends and found no significant correlation between salinity or water temperature and the abundance of floating plastic particles with a width >700 µm. They reported that there was a negative correlation between surface-plastic particle abundance and high wind speed.

Angiolilli *et al.* (2015) noted a positive relationship between abundance of litter and population density in the area they studied (the Italian Tyrrhenian Sea around Campania, Sicily and Sardinia).

Ruiz-Orejón *et al.* (2016) report a significant difference in the abundance of plastic particles in coastal areas (less than 25km from land) than further out to sea in the region studied (central and western Mediterranean Sea). They suggest that input from rivers, tourism and high coastal development may contribute to higher concentration of marine litter.

Pasquini *et al.* (2016) analysed 1,013 items of marine litter from the seabed in the central and western Adriatic Sea that had been collected using a trawler study. The study found that there was a higher quantity of all litter in regions closer to the shore than out to sea. They found that plastic items were more abundant in coastal regions and there was a higher quantity of metal and glass in the deeper regions (51-100m). Of all the plastic items, plastic bags were the most abundant item collected, comprising 25% of the litter at 0-30m depth, 24% at 31-50m and 44% at 51-100m. The authors suggest that there is a high incidence of litter on the sea floor for a number of reasons, including that the coastline is highly populated, has intensive shipping, is popular with tourists, fishing and aquaculture, and there's limited water exchange from the Adriatic to the wider Mediterranean.

Ramirez-Llodra *et al.* (2013) used trawler studies to analyse litter in the deep sea in Blanes canyon, northwest Mediterranean. They report that at 900m depth, 10km from coast, the litter was mainly plastics, glass and clinker. At 1,500m the litter was mainly hard and soft plastics. At 2,250 m, at a distance of 80 km from coast, the litter was mainly clinker, metal and soft plastics. The deeper site was on a shipping route, which explains the predominance of clinker.

Laglbauer *et al.* (2014) found that there was no difference in the quantity of microplastics collected from beach sediments from tourist beaches compared to non-tourist beaches in Slovenia, which suggests more diffuse sources for this type of plastic litter.

Debris is likely to accumulate in regions where ocean currents converge. Suaria & Aliani (2014) found that both anthropogenic and natural debris accumulated in similar locations, leading to the idea that the currents and tides play a part in distributing marine debris.

Alomar *et al.* 2016 analysed sediment samples from three locations off the Balearic islands and found microplastics in marine shallow coastal sediments – including urbanized coastal areas and Marine Protected Areas with a no-take policy. One area, the Santa Maria no-take zone, had the highest mass of microplastics per gram in the sediment sample. The authors comment that strong currents or wind may transport plastic litter from its source – this would apply particularly to litter that floats on the surface water. Currents including the Algerian current may carry litter from the Atlantic towards the Balearic islands. The two zones in the marine protected area had a higher percentage of plastic fragments in the analysed sediment samples, and Andratx (a location off Mallorca Island) had a majority of filaments. The authors suggest that the filaments could be because of the sewage inlet to the water bringing laundry water with many clothing fibres.

There was an inverse relationship between the number of lost/abandoned long line fishing gears observed in an ROV survey of the Tyrrhenian Sea and the distance from the coast (Bo *et al.,* 2014)

3.2.2 Geographical: Eastern Mediterranean

Fewer studies on marine litter have been conducted in the eastern Mediterranean Sea, which is understandable given the current political climate in the region. Studies report a high presence of marine litter.

Pasternak *et al.* (2017) studied the Israeli coast in the eastern Mediterranean. The team found that a high proportion of plastic bags were found on the Israeli coast and was twice that reported in the rest of the Mediterranean Sea and three times that reported globally. The authors suggest that the discrepancy is possibly due to the lack of legislation concerning plastic bag usage or plastic bag tax in Israel. Legislation on plastic bag use was due to change Jan 2017.

Another eastern Mediterranean study (van der Hal *et al.*, 2017), also along the Israeli coast, found that the Israeli coastal waters have a high abundance of microplastic pollution. The study analysed 108 samples of sea surface water and recorded a total of 94,417 microplastic particles (0.3–5 mm) between 2013 and 2015. The team noted spatial fluctuations, with the highest abundance of microplastic particles at the Carmel coast. They suggest this might be because the Carmel coast region has rocky beaches and lagoons in which particles could become trapped. They also note a temporal variation: at one site in the study (Betzet and Shavey Zion in the northern part of Israel) the mean abundance of plastic particles was 1.46 particles/m^3 in the first year, and a greater mean abundance of 16.52 particles/m^3 in the second year.

Ramirez-Llodra *et al.* (2013) carried out a transect west to east across the Mediterranean Sea. Paint pots were collected in the central and eastern Mediterranean, which the authors note could be a long-term source of chemical contamination. They also reported that the mass of the litter, all of which was collected by trawl samples, was often equivalent to biomass and, in some cases (the deep central Mediterranean and the sampled three depths in the eastern Mediterranean), was higher than biomass collected in the same sample.

3.2.3 VERTICAL DISTRIBUTION

The literature contains more papers that report the presence of litter in the water column and on the beach or near-shore sediment than in deep-sea sediment or on the deep sea floor, largely because of the practical, logistical and financial constraints associated with deep-sea research.

SEA SURFACE

- Suaria & Aliani (2014) estimate that there are 62 $\times 10^6$ items of macro-litter floating on the Mediterranean Sea. The authors note that their figure is a 17-fold increase in marine debris when compared to an estimate published more than 25 years ago (in 1988) that estimated 3.6 x 10^6 items of floating litter in the Mediterranean basin. It's not clear whether the discrepancy in items of floating litter is because there are more items of debris or whether methods of estimating the quantity of litter have improved.

- Collignon *et al.* (2014) found an annual average of 6.2 plastic particles with a diameter less than 10mm per 100 m^2 in the neuston (surface water) of the Bay of Calvi, Corsica, during a sampling period running from August 2011 to August 2012.

BEACH, SHALLOW-WATER SEDIMENT AND DUNE SYSTEMS

- Laglbauer *et al.* (2014) found microplastics in the beach sediment in Slovenia. The study reports a median density of 155.6 particles kg^{-1} in the infralittoral zone and of 133.3 particles kg^{-1} in the shoreline zone.

- Poeta *et al.* (2014) studied the distribution of litter on the beach and dune system of five sites along the central west coast of Italy. The authors compared litter accumulation with habitat type and noted a spatial distribution of litter at the sites studied. The upper beach was least polluted, which may be because the action of the sea removes the litter. The fore dunes had the highest abundance of litter of all the zones in the dune system. The authors say that the waves rarely reach this dune type, and so they can become an area in which litter accumulates. Litter from the fore dunes can be distributed inland by wind action. The fixed dunes, which contain shrubs and forest vegetation, had little or no litter, which suggests that this habitat can act as a barrier against litter moving inland.

DEEP-SEA SEDIMENT AND DEEP SEA FLOOR

- Alomar *et al.* (2016) found microplastics in sediment in marine protected areas off the Balearic Islands. The authors suggest that these particles are available for ingestion by organisms that feed in that area and could provide a mechanism for microplastics to be transferred through the food web.

- Pham *et al*. (2014) report the findings from scientific seabed trawl surveys that were carried out in the Mediterranean Sea at ten different locations from 1999 to 2012. Every survey found litter, with plastic present in every sample. The authors note that there were limitations to the study. One limitation was that not all the surveys used the same equipment, though data collected was all standardized before comparing the results. Another limitation was that litter was assessed by weight not quantity, which means that it is difficult to compare the abundance of lighter litter, such as plastic, with heavy types, such as glass or clinker (clinker which is the residue of burnt coal, typically dumped at sea from coal-fired ships from the 18th to 20th centuries). They report that their study was valuable in spite of its limitations because it highlights the types of litter found at different locations.

- Vianello *et al.* (2013) found widespread distribution of microplastics in the sediment in Venice Lagoon. FT-IR analysis showed that the majority of the polymers were either polyethylene (48.4%) or polypropylene (34.1%). They report that the highest concentrations of microplastics were in the confined areas along the lagoon border, which are also influenced by freshwater inputs. They suggest that rivers are potential sources of microplastics to the marine environment.

- An ROV survey covering three deep canyons and continental shelf areas in the northwest Mediterranean by Tubau *et al.* (2015) found that the highest litter abundance was seen on the floor of all three canyons studied. The authors identify submarine canyons as zones in which litter can accumulate. They suggest continued and regular monitoring of the areas to give a better idea of residence time of particular types of litter and the effect of high-energy events to enable analysis of temporal trends. Tubau *et al.* (2015) did not observe clinker, but this could be because clinker would have been dumped around a century ago and has since been covered in sediment – an observation reported by Pham *et al.* (2014) who compared trawl survey data with video footage collected by ROV and noted that clinker was present in trawl surveys but was undetected in the video footage.

3.3 SIZE OF LITTER

Examples of the effects of macroplastics, which include plastic bags, fishing nets and bottles, are entanglement, choking, strangulation and malnutrition and typically involve marine mammals and seabirds. Microplastics can also have a negative impact on marine life – these tiny pieces of plastic, measuring less than 5mm in length or diameter, have a large surface area and could adsorb toxic contaminants or leach chemical additives, and because they are so small they have the potential to be ingested by many more organisms (adsorb is the term used when a piece of plastic attracts a chemical compound that 'sticks' to the plastic; desorption occurs when the plastic 'releases' the adsorbed chemical.) Microplastics can be spheres, fragments or filaments and are either primary (they were manufactured that size, such as the pre-production plastic pellets known as 'nurdles') or secondary (they have been degraded in size from larger pieces by exposure to the elements, such as wind, waves and ultraviolet light).

- Blašković *et al.* (2017) report the presence of meso- and microplastic in the sediment off the coast of Croatia in the Marine Protected Area of Telaščica Bay but found no macroplastic in the sediment.

- Fastelli *et al.* (2016) analysed deep sediment from the Aeolian archipelago and found 94.3% of all samples were microplastics. Only one sediment sample contained macroplastic, with a mean 1.8 particles per kg dry weight.

- Collignon *et al.* (2014) found that large microplastic (2-5 mm) was the most abundant size class in surface water sampled in the Bay of Calvi, Corsica, Microplastic represented 54% of the total number of plastics recorded (three size classes were analysed, 0.2-2mm; 2-5mm; less than 10mm). The annual average abundance of large microplastics (2-5 mm) was $3.4/100m^2$.

- Tubau *et al.* (2015) observed that almost half of all litter on the seabed in three canyons near the Catalan coast in the northwest Mediterranean was medium-size (10-50cm). The study used video footage from a remote operated vehicle and did not assess microplastics, but observed that the large items (greater than 50cm) comprised 32% and small items (less than 10cm) were 18.4% of the total litter count.

4. IMPACTS OF MARINE LITTER

Litter in the Mediterranean Sea has widespread impacts such as to marine biodiversity, ecosystem services, social and visual, and economic value. Over the past two decades research papers, environmental reports and campaigns have highlighted the impact made by plastic debris on marine animals (including Laist, 1997). Specifically, plastics have been reported in the Mediterranean Sea sediment (Blašković *et al.,* 2017), on the rocky seafloor (Melli *et al.*, 2017), on beaches (Pasternak *et al.,* 2017) in the water column (Suaria *et al.,* 2016), ingested by marine organisms (Casale *et al.,* 2016; Alomar & Deudero, 2017) and entangled with cold-water corals (Orejas *et al.,* 2009).

The following section has been organized into subsections to highlight the ways in which biota can be affected by marine litter and how different types or sizes of litter can cause an impact. There is overlap between the two sections. For more detail on the papers analysed, please see Table 1 in Appendix 1: Tabulated findings from peer-reviewed literature assessing anthropogenic litter in the Mediterranean Sea.

The impact of marine litter has different consequences depending on the type of material and the marine organism involved. Some examples of the impacts on biota and habitats are from areas outside the Mediterranean Sea, but could apply to different geographical regions and have been included here as examples.

There are diverse examples in which a particular species can be affected by marine litter. For example, ingestion can lead to transfer of microplastic through the food chain, macro- or meso-size debris can smother or entangle, and in other examples a species (usually a microorganism) 'hitch-hikes' on an item of debris and be transported to an area outside of its usual habitat.

A review by the Alfred Wegener Institute's Litterbase project that analyses published reports and state that, as of May 30, 2017, globally an estimated 1,341 species have interacted with marine litter by colonisation, ingestion, entanglement, smothering or other (Tekman *et al.*, 2017). The Litterbase figure is more than double the number of species cited by Kühn *et al.* (2015), in which 557 species are listed as being affected by marine litter. The discrepancy highlights the rate at which research is advancing.

A review of 340 original research papers found that 92% of recorded encounters between marine litter and organisms were with plastic. 71% of the entanglement incidents were between individual organisms and plastic rope or netting, and 37% of ingestion incidents were between individual organisms and plastic fragments. Approximately 17% of species that had ingested or become entangled in marine debris were listed on the International Union for Conservation of Nature Red List of Threatened Species (Gall & Thompson, 2015).

4.1 IMPACTS TO BIOTA

Globally there are hundreds of species that are affected by marine litter. Chapter four in the book Marine Anthropogenic Litter (Kühn *et al.,* 2015) reviews the effects of litter on marine flora and fauna and though not specific to the Mediterranean presents a comprehensive outline of the situation. The authors report that examples from 100% of all seven species of marine turtle, 67% of seals (22 of 33 species), 31% of whales (25 of 80 species) and 25% of seabirds (103 of 406) have been reported entangled in marine litter. The chapter includes a list of 557 marine species that are reported in the literature to have been affected by marine debris. The latest figure, as of May 30, 2017, estimating the number of species affected by marine litter is 1,341 (Tekman *et al.*, 2017). The ingestion of marine debris can be a direct cause of death to different marine species, but at sub-lethal levels ingestion can cause dietary dilution and reduced energy intake (Lazar & Gračan, 2011).

Analysing toxicological effects of ingesting marine litter is complex and such studies are in their infancy, but an example of a toxicological study using field samples is included in Fossi *et al.,* 2014, section 4.1.2:

4.1.1 INVERTEBRATES

The physical effect of microplastic ingestion is seen in the common shore crab, *Carcinus maenas.* After ingestion of food containing plastic microfibers, *C. maenas* exhibited reduced food consumption and had less energy available for growth (Watts *et al.,* 2015).

The common mussel (*Mytilus edulis*) is a filter feeder and has been shown to retain plastic micropellets (3 μm or 9.6 μm). The micropellets accumulated in the gut then translocated from the gut to the circulatory system within three days and remained in the mussel for more than 48 days following ingestion. Short-term exposure did not result in any adverse biological effects (Browne *et al.,* 2008).

In laboratory feeding experiments, Norway lobster (*Nephrops norvegicus)* caught in the Clyde Sea were kept in tanks and fed plastic-seeded fish. 100% of *N. norvegicus* had the introduced plastics in their stomachs 24 hours later. The paper notes that plastic has the potential to accumulate in the lobster (Murray & Cowie, 2011).

Ramirez-Llodra *et al.* (2013) found evidence of ghost fishing in the bathyal northwestern Mediterranean – one trawl collected nine dead *Geryon* crabs in a lost/discarded fishing net.

4.1.2 FISH

Battaglia *et al.* (2016) examined the stomachs of 115 individuals of the commercial fish species *Trachinotus ovatus* caught in the central Mediterranean and found plastic particles in the stomachs of 28. The plastic particles were categorized as microplastics (83.3%) and mesoplastics (24.3%). The authors suggest that the fish feeding behaviour of looking immediately below the surface, where there are floating plastic particles, could mean this species is vulnerable to plastic particle ingestion. The authors suggest that the occurrence of plastic debris in fish stomachs could be a risk to this species.

Analysis of 121 individual fish drawn from the commercial species *Xiphias gladius (swordfish), Thunnus thynnus* (Atlantic bluefin tuna) and *Thunnus alalunga (albacore tuna) from* the central Mediterranean Sea found plastic debris in 18.2% samples: 7 swordfish, 11 bluefin tuna fish and 4 albacore tuna (Romeo *et al.,* 2015a).

Microplastics were found in 21 of 125 individual blackmouth catshark (*Galeus melastomus*) fish that were caught off the coast of Mallorca, Balearic islands, Spain (Alomar & Deudero, 2017).

Fossi *et al.* (2014) looked at the toxicological effects of microplastics in filter-feeding megafauna in the Mediterranean Sea off the coast of Italy – the Mediterranean basking shark (*Cetorhinus maximus*) and fin whale (*Balaenoptera physalus*) – and concluded that both organisms are chronically exposed to persistent and emerging contaminants associated with microplastic ingestion and ingestion of contaminated plankton prey.

4.1.3 Cetaceans

Fossi *et al.* (2016) found that fin whales in the Pelagos Sanctuary in the northwest Mediterranean seem to be exposed to plastic additives as a result of direct and indirect ingestion of microplastic, macroplastic and contaminated prey. Fin whales are listed as Vulnerable on the IUCN Red List of Threatened Species. The area of the Mediterranean in which they congregate in the summer months is a Specially Protected Area of Mediterranean Importance.

4.1.4 Turtles

The loggerhead sea turtle (*Caretta caretta*) is an indicator species used to monitor trends in spatial and temporal marine litter. The species is listed as Vulnerable on the IUCN Red List. Monitoring is carried out by examination of fecal pellets with live animals or dissection of deceased animals (EC, 2013).

Loggerhead sea turtles (*Caretta caretta*) accidentally ingest plastics and other forms of marine litter such as rope, fishing line and Styrofoam. Lazar & Gračan (2011) performed necropsies on 52 turtles and found marine litter in the guts of 19. The mean number of pieces per turtle was 4.3, with the range 1 to 27 items. The turtle that had ingested 27 items of debris was a female – the authors report that there was no evidence to suggest that ingestion of plastic caused the turtle's death. Plastic – the most commonly ingested type of debris – had been ingested by 13 of the turtles.

4.1.5 Seals

The Mediterranean monk seal (*Monachus monachus*) is listed as Endangered on the IUCN Red List. There are an estimated 350-450 mature individual seals in the population, with fewer than 250 individuals in the eastern Mediterranean. Karamanlidis *et al.* (2008) report that one of the main reasons for low population levels of Mediterranean monk seals is accidental entanglement in fishing gear.

4.1.6 Flora and sessile fauna

Abandoned or lost fishing gear can lodge on reefs and smother coral or trap marine animals (Knowlton *et al*., 2012).

Fabri *et al.* (2014) report that, on an ROV study in the Ligurnian Sea and Gulf of Lion, they observed *Callogorgia verticillata* (an Alcyonacea), which is unusual to see in the Mediterranean Sea. It is fragile and colonies were seen tangled with fishing nets and lines. The authors suggest that this species should be protected. They also observed high densities of lost fishing gear with cold-water corals in Lacaze-Duthiers and Cassidaigne canyons.

Bo *et al.* (2014) assessed the impact of fishing gear on coral in the Tyrrhenian Sea using ROV surveys. They report that the Vedove Shoal site, which is 12 nautical miles off the coast of Capri in the South Tyrrhenian Sea, represented the worst case of marine fishing litter of the four sample sites. They report that 62% of the Vedove Shoal ROV video frames showed abandoned fishing debris. They also report a severely damaged coral community. They also note that at Vedove Shoal, 50% of the impacted frames showed plastic bags filled with stones and attached to floating polyester ropes, which is a form of disposable mooring that is used by locals during purse seine fishing. The temporary moorings are then deliberately abandoned.

Angiolilli *et al.* (2015) surveyed the Tyrrhenian Sea around Campania, Sicily & Sardinia using an ROV and report that fishing gear was the litter type with the highest abundance. Anthropogenic debris had a major impact on benthic communities, particularly gorgonians and corals. More than half of the recorded debris items negatively affected benthic organisms by covering or abrading their tissues.

4.2 Impacts of litter types

4.2.1 Fishing gear

Fishing gear is predominantly made from plastic components. Fishing gear that has been accidentally lost, deliberately dumped or abandoned can result in ghost fishing, which is when fishing equipment traps marine fauna when it is no longer under human control. Lost fishing gear could entangle human swimmers, snorkellers and scuba divers. Abandoned or lost fishing gear can also lodge on reefs and smother coral or trap marine animals.

A drifting fishing net can trap megafauna including cetaceans (Knowlton *et al*., 2012) and even presents a threat to remotely operated vehicles used in science research to survey the seabed (Tubau *et al.,* 2015). Abandoned or lost benthic longline fishing gear has been observed entangled with cold water coral in the north-west Mediterranean (Orejas *et al.,* 2009). Bo *et al.* (2014) report that abandoned fishing gear has becoming entangled with corals in the Tyrrhenian Sea. Ramirez-Llodra *et al.* (2013) found evidence of ghost fishing in the bathyal northwestern Mediterranean, observed a fishing net that contained nine dead *Geryon* crabs.

A campaign to remove lost fishing gear from the ocean was the successful 2016 collaboration between Greenpeace and charity Ghost Fishing, which collected 1.5 tonnes of lost fishing gear from Sylter Aussenriff, a marine protected area in the North Sea.

- Some interactions between lost or abandoned fishing gear and biota show usage of the anthropogenic debris by marine organisms. Tubau *et al.* (2015) report on a remotely operated vehicle survey of the northwest Mediterranean in which observations include longline fishing gear colonized by coldwater coral, and net ropes supporting communities of *Phycis blennoides* (greater forkbeard fish), the deep-sea crab *Bathynectes maravigna* and *Cerianthus membranaceus* (cylinder anemone).

- Angiolilli *et al.* (2015) also report that marine organisms utilize marine litter as a substrate on which to grow, and observed that 80% of debris observed by ROV survey in the Tyrrhenian Sea around Campania, Sicily & Sardinia had been colonized by invertebrates. The authors note that such colonisation can hamper efforts to maintain and conserve biodiversity and habitats if it alters community structure and spatial heterogeneity or enables the settlement of non-indigenous species.

- In a trawler study in the north and central Adriatic, Pasquini *et al.* (2016) found that plastic was the dominant type of litter, comprising 80% of the number of items of litter collected. Of the plastics collected, mussel nets comprised 20% and other fishing gear comprised 3% of the total litter collected.

- Fabri *et al.* (2014) reported that lost fishing gear had impacted upon structure-forming fauna and was observed to have broken Cnidaria colonies in the Ligurian Sea and Gulf of Lion in the northwest Mediterranean Sea. Long lines had also become tangled around rocks.

- Bo *et al.* (2014) also reported the damage caused by lost or abandoned fishing equipment to benthic communities. The authors note that the ability of benthic species to cope with the impact of fishing and lost fishing debris depends on its fragility and ability to recover. The paper concludes that lost fishing gear is a major cause of mechanical degradation to the benthic rocky ecosystem in the Tyrrhenian Sea. They observed nets covering and choking benthic flora and fauna, and lines entangling the corals causing them to bend under the tension. They also note that there has been the disappearance of deep, slow-growing corals in the area studied.

4.2.2 Macro- and mesolitter including plastics

Macro-, meso- and microplastics have been found in the guts of swordfish and bluefin tuna in a study that focused on the central Mediterranean Sea in the

Eolian Islands, Strait of Messina (Romeo *et al.,* 2015a. Large items of litter (plastic and other materials) can also cause physical harm to marine organisms, which can become trapped, smothered or tangled.

The literature details flora and fauna that have been affected as a result of marine litter. Bo *et al.* (2014) found that lost fishing gear (predominantly nets and long lines) and temporary moorings was affecting organisms in the Tyrrhenian Sea, reporting that nets can cover and choke the benthic flora and fauna, and lines can entangle corals and cause them to bend under the tension. In their ROV study, they report that at Vedove Shoal, 50% of the ROV frames that contained marine litter showed temporary moorings (plastic bags filled with stones and attached to floating polyester ropes). They also reported that at Mantice Shoal, an area dominated by shallow water corals, there was approximately 8 m^2 of lost or abandoned fishing nets per 100 m^2 of explored sea floor.

Blašković *et al.* (2017) assessed the presence of plastic particles in the sediment in the Croatian Marine Protected Area of the Natural Park of Telaščica bay. They found mesoplastic in 11.29% of the samples analysed. Microplastic was in 88.71% of all samples but no macroplastic was found.

4.2.3 Microplastics

The ingestion of microplastics by marine organisms is widespread. One estimate suggests that, globally, least 170 marine vertebrate and invertebrate species ingest anthropogenic debris (Vegter *et al.,* 2014).

Transfer in the food web

- Concerns are that plastic microplastics could transfer or accumulate within the food chain if predators ingest prey that has consumed plastic; this scenario may not be limited to marine animals if land species ingest contaminated fish or shellfish. Concerns seem to be twofold: (i) the physical presence of the microplastics; and (ii) the toxicity of plastics and associated or adsorbed chemicals.

- Microplastics were found to have translocated from the gastrointestinal tract in the commercial fish species *Mugil cephalus* (mullet) to liver tissue (Avio *et al.,* 2015). Polystyrene spheres 10 µm in diameter were demonstrated to transfer to a higher trophic level when zooplankton were fed to mysid shrimp, which suggests that the microplastics could accumulate in the food chain (Setälä *et al*., 2014).

- In a laboratory study, Setälä *et al*. (2014) found that when zooplankton that had ingested microplastics were fed to mysid shrimp, the shrimp were subsequently shown to contain the microplastics. The results suggest transfer of microplastics in the food web. The mysid shrimps egested the microspheres but the authors point out that the spheres could have the potential to accumulate in the organisms.

- In another laboratory study, mussels contaminated with microplastic beads that were then fed to crabs suggested that microplastics could transfer in the food web from prey to predator (Farrell & Nelson, 2013).

The impact on health should humans consume microplastics is unclear. In addition, there is currently no regulatory framework concerning the presence of microplastics in seafood (EFSA, 2016).

Please refer to Santillo *et al*. (2017) and Miller *et al.* (2016) for technical reports on the occurrence, fate and effects of microplastics in fish and shellfish.

4.3 HABITAT

The full impact of deep-sea litter on habitats and fauna is not well understood. Marine litter can lead to ecosystem-wide impacts through ingestion, entanglement, entrapment and smothering of marine organisms. In some cases anthropogenic litter can lead to entire or partial destruction of a habitat. Long fishing lines can damage fragile flora and fauna, particularly sessile organisms. Habitat destruction can be caused by incoming transport of non-native species or by crushing or smothering existing habitats.

HABITAT CREATION AND 'HITCH-HIKING'

Marine litter can accelerate the introduction of a non-indigenous species to a habitat in a process called 'hitch-hiking'. Movement of marine species on naturally occurring objects such as fallen trees or algae has for millennia been a slow-moving means of transport for species across oceans. The increasing abundance of marine litter, in particular plastics that are durable in the marine environment and float, is accelerating the phenomenon (Gregory, 2009).

Studies suggest that marine litter can provide a vector for species to 'hitchhike' or 'raft' to new habitat. A non-native species can then travel to an area beyond its natural boundary (Barnes, 2002) and could potentially risk human health (Keswani *et al.,* 2016). Data from long-term monitoring studies of the impact of the transport of non-indigenous marine species is limited (Galil *et al.*, 2014).

Floating plastic particles persist for longer periods of time in the marine environment than natural materials and can become a floating reef for microbes (Collignon *et al.,* 2014).

COLONISATION

Clinker was found in 68.3% of samples trawled from the Blanes slope in the northwest Mediterranean Sea at depths ranging from 900 to 2700 m. The clinker was often colonized by the brachiopod *Grypheus vitreus* (Ramirez-Llodra *et al.,* 2013).

4.4 Other impacts

Marine litter carries economic consequence including beach cleans, the cost of lost items, those relating to aquaculture and fishing, and to the tourist industry.

The social and visual impact of beach litter deters visitors and tourists. In a survey of 200 people interviewed on two Greek beaches in the Attica region of Athens, 91% said they were very annoyed by the presence of beach litter, and 44% said that beach litter would be a reason not to revisit a particular beach. In spite of disliking the litter, 45% of respondents said that they would not participate in a voluntary beach clean (Brouwer *et al.,* 2017).

Human health can be affected if, for example, a swimmer or diver becomes entangled in fishing equipment or injured by standing on a syringe or cut glass. We don't yet know what the implications could be on health should humans consume microplastics – that's an area where much more research is needed. It is also worth noting that there is currently no regulatory framework concerning the presence of microplastics in seafood intended for human consumption (Miller *et al.,* 2016).

5. WHERE TO GO FROM HERE

5.1 UNCERTAINTIES AND KNOWLEDGE GAPS

- Sinks, sources, fate and residence times of different polymers (Ruiz-Orejón *et al.,* 2016).

- More data are needed from the eastern Mediterranean Sea.

- Relatively little is known about the extent of litter in the deep water of the eastern Mediterranean (Anastasopoulou *et al.,* 2013) or the surface floating litter (Suaria & Aliani, 2014).

- Research is needed to investigate whether microplastics can translocate from fish intestinal tract to other tissues to determine the extent and potential threat to humans consuming fish flesh (Nadal *et al.,* 2016).

- Data analysing the long-term impact to marine species that have been transported to a new environment by 'hitch-hiking' on plastic marine litter.

- To achieve more accurate estimates of plastic load in the Mediterranean Sea will require more surveys with improved resolution and coverage (Cózar *et al.,* 2015).

5.2 SCOPE FOR FUTURE RESEARCH

Regular and continued programmes of long-term monitoring – to identify changes in the abundance of marine litter, to identify areas that accumulate debris, to determine the source of the litter, to understand the impacts of marine litter (plastic or otherwise). Strafella *et al.* (2015) discuss the difficulty of comparing the results of monitoring studies carried out by different research groups who use different methodologies in data collection, reporting and classification.

- Ruiz-Orejón *et al.* (2016) suggest that future marine plastics research should aim to understand the fate, sinks and fragmentation patterns of different polymers. Also, spatial–temporal studies are needed to understand the Mediterranean environment as a whole (surface, water column and seafloor). Suggest more legislation/policy to attempt to curb/reduce/limit additional plastic pollution.

- Awareness campaigns and education will help to maintain public interest in marine pollution. The Greenpeace 2016 campaign to ban microbeads in toiletries cosmetics is an example of how to encourage the public to engage with an environmental topic. More research into how best to educate and inform the public in developed and developing countries to stem the tide of plastic and other forms of litter.

- Relatively little is known about how litter impacts organisms that inhabit the seafloor.

- Continued monitoring of marine plastic, particularly with a view to standardized protocols (Ryan *et al.,* 2009; Pham *et al.*, 2014).

- Studies to assess the impact of accumulated litter, including assessment of the impact of different types of litter (Ramirez-Llodra *et al.,* 2013).

5.3 Solutions

A number of ideas to address the issue of marine litter have been proposed in the literature. Some highlights include the following:

- One way of approaching the problem of marine litter is to address the most common type/s of debris and develop legislation or ways encourage removal/recycling of those items.

- Removal of marine plastic from the ocean at strategic coastal locations (Sherman & van Sebille, 2016).

- Education and public campaigns, especially for school-age children, to help curb the problem of irresponsible littering at source. Kühn *et al.* (2015) cite as an example the loss of industrial pellets in the oceans in the early 1980s. Campaigns to highlight the problem that resulted in improved shipping practices and less loss of pellets meant that by the early 2000s the number of pellets found in seabirds' stomachs had halved. Their point is that it is possible to reduce the quantity of plastic entering the environment through education and awareness.

- Improved waste management and recycling facilities for all forms of litter, not only plastics (Jambeck *et al.,* 2015).

- Education campaigns to prevent littering on beaches, more regular beach clean-ups (especially in summertime on tourist beaches), and more awareness to help prevent the (deliberate or accidental) disposal of waste at sea (Laglbauer *et al.,* 2014; Munari *et al.,* 2016; Suaria *et al.*, 2016).

- Encouraging members of the public to engage with their local beach and participate in beach clean-ups, which can help people to form a connection with their natural environment (Kordella *et al.,* 2013).

- One of the most prevalent types of plastic litter on beaches is cigarette butts (Laglbauer *et al*., 2014; Munari *et al*, 2016; Pasternak *et al*, 2017). Cigarette butts are predominantly made from a synthetic polymer called cellulose acetate and can take up to 18 months to break down. Trillions of cigarettes are manufactured and consumed each year around the globe. Irresponsible disposal of cigarettes by smokers is a major global problem because not only is such litter unsightly and detrimental to marine fauna that ingest them, but toxic chemicals in cigarette butts can leach into the environment. Solutions include education to promote responsible disposal by smokers and novel ways to recycle cigarette butts (Mohajerani *et al.,* 2016).

- Legislation to ban or limit the use of plastic bags in non-EU countries (Pasquini *et al.,* 2016).

- Establishment of protected areas (Bo *et al*., 2014).

- The plastics industry has pledged to address marine plastic litter and launched a Global Declaration for Solutions on Marine Litter in 2011 (marinelittersolutions.eu).

6. GROUPS AND INDIVIDUALS CONDUCTING AND PUBLISHING RESEARCH ON PLASTIC LITTER IN THE MEDITERRANEAN SEA

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Francois Galgani	Institut Français de Recherche pour l'Exploitation de la Mer, La Seyne sur Mer, France (French Research Institute for Exploitation of the Sea) Research interests include marine litter. Contact through the website: http://wwz.ifremer.fr
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Aikaterini Anastasopoulo u	Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Greece kanast@hcmr.gr
Groups and institutions – work on a global scale	
Alfred Wegener Institut	Works globally. Established the AWI Litterbase to collate all published research to produce a map of the extent of the world's marine litter. The Litterbase database is an ongoing project. https://www.awi.de/en/focus/marine-litter.html

	http://www.litterbase.org
United Nations Environment Programme Mediterranean Action Plan	The objectives of the UNEP–MAP include "protection of the marine environment and coastal zones, through prevention of pollution, and by reduction and as far as possible, elimination of pollutant inputs whether chronic or accidental". A Regional Plan was developed to "prevent and reduce the adverse effects of marine litter on the marine and coastal environment". The Regional Plan came into effect in 2014. The background to the framework of UNEP's marine litter programme is presented in the organisation's Marine Litter Assessment in the Mediterranean (UNEP/MAP, 2015). http://www.unep.org/unepmap/
Plastics Europe (2016)	Association of plastics manufacturers. Produces reports www.plasticseurope.org
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)	An advisory body established in 1969 that advises the United Nations on marine environmental protection. Reports on plastic litter in the ocean in general are available for free download form the website. www.gesamp.org
Marine Litter Solutions	69 companies in the plastics industry from 35 countries committed to reducing the amount of plastic waste that enters the waterways through a number of measures and strategies including beach clean-ups and recycling programmes and partnerships with NGOs as explained on their website. www.marinelittersolutions.com
Blue Marine Foundation	London-based NGO established in 2010 that works towards protecting 10% of the world's oceans by 2020. http://www.bluemarinefoundation.com/2016/08/18/9379/
International Maritime Organization	The International Convention for the Prevention of Pollution from Ships (MARPOL) is an international convention that works to prevent pollution of the marine environment by ships from operational or accidental causes. The MARPOL convention came into effect on November 2, 1973. Of particular note is Annex V – Prevention of pollution by garbage from ships, which came into effect on December 31,

	1988, and bans the disposal of any form of plastic into the sea. www.imo.org
OSPAR	Protecting and conserving the north-east Atlantic and its resources. Regional Action Plan for Marine Litter, adopted in 2014, sets out the policy for 2014–2021 "to substantially reduce marine litter in the OSPAR maritime area to levels where properties and quantities do not cause harm to the marine environment" (OSPAR, 2017). https://www.ospar.org/work-areas/eiha/marine-litter/regional-action-plan
ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), Italy	ISPRA is the Italian National Institute for Environmental Protection and Research and is responsible for the technical aspects of the EU Marine Strategy Framework Directive implementation and reporting. ISPRA experts are formally involved in implementation of the Barcelona Convention for the protection of the environment of the Mediterranean region and related protocols.
Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS)	Established in 2012 to develop oceanography in the Mediterranean Sea. The website lists the names of 32 partnering institutions in Mediterranean coastal states. http://www.mongoos.eu/
Institut Français de Recherche pour l'Exploitation de la Mer, La Seyne sur Mer, France	French Research Institute for Exploitation of the Sea. http://wwz.ifremer.fr
Institute of Marine Biological Resources and Inland Waters, Greece	Public research institute. http://www.hcmr.gr/en/
Ocean Conservancy	A US-based NGO. Organising an international coastal cleanup on September 16, 2017.

	http://www.oceanconservancy.org/our-work/marine-debris/
Institute of Oceanography and Fisheries, Croatia	Institute of Oceanography and Fisheries, Split, Croatia +(385) (21) 408000 office@izor.hr
Fisheries Research Institute of Slovenia	Fisheries Research Institute of Slovenia, Ljubljana +386 1 24 43 400 https://www.zzrs.si/en/
European Union Hermione project	The European Union-funded the Hermione project with an €8m grant. The project ran from 2009 to 2012 and investigated the marine environment including the impacts of climate change and human activities. In total, 41 partners across 13 countries were involved. Details and links to published work is available online at: http://www.eu-hermione.net
Mapping the Deep Project	The Mapping the Deep Project, led by Kerry Howell, Associate Professor of Marine Ecology at Plymouth University in the UK, is a large-scale analysis of the seafloor using multibeam and remote operated vehicles to assess the environment of the deep sea. kerry.howell@plymouth.ac.uk

Table 1 | Groups and teams with an interest in marine litter.

7. Technical publications, online resources and further reading

- Miller, K., Santillo, D. & Johnston, P. (2016) Plastics in Seafood – full technical review of the occurrence, fate and effects of microplastics in fish and shellfish. Greenpeace Research Laboratories Technical Report (Review) 07-2016 (GRL-TR(R)-07-2016): 47 pp.

- Santillo, D., Miller, K. & Johnston, P. Microplastics as Contaminants in Commercially Important Seafood Species. *IEAM* 13, 516–521 (2017).

- The Honolulu Strategy: A global framework for prevention and management of marine debris https://5imdc.files.wordpress.com/2011/03/honolulustrategy.pdf

- Map of human impacts on the world's oceans http://science.sciencemag.org/content/319/5865/948.full

- Interactive global maps showing litter in the oceans and interactions between marine organisms and litter, from the Alfred Werner Institut Litterbase project:
  http://litterbase.awi.de

- Medits (Mediterranean International Trawl Survey)

- International bottom trawl survey of the Mediterranean, Black and Azov seas. The website lists papers and details of the work protocol. http://www.sibm.it/SITO%20MEDITS/principaleprogramme.htm

- Book: Bergmann, M., Gutow, L. & Klages, M. (Eds.) Marine Anthropogenic Litter. Springer International Publishing: Cham, Switzerland (2015). ISBN 978-3-319-16509-7

- UNEP and GRID-Arendal, 2016. Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal. www.unep.org, www.grida.no

- A protocol for marine monitoring is described in Galgani *et al.* (2013).

APPENDIX 1

TABLE 1 | TABULATED FINDINGS FROM PEER-REVIEWED LITERATURE ASSESSING ANTHROPOGENIC LITTER IN THE MEDITERRANEAN SEA.

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