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Programmed biodegradation capability of bio-based materials and products, validated in specific environments

MAGICBIOMAT

Manufacturing Guiding Tool for Circular and Programmed Biodegradable Materials Under Open Environment Conditions

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Acronyms

AI	Artificial Intelligence
ALDFG	Abandoned, Lost, or Discarded Fishing Gear
ATM	Automated Teller Machine
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EU	European Union
FAO	Food and Agriculture Organisation
GA	Grant Agreement
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
IOC	Intergovernmental Oceanographic Commission
IUCN	International Union for the Conservation of Nature
LDPE	Low Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MARPOL	International Maritime Organization's Marine Pollution Convention
MSFD	Marine Strategy Framework Directive
Mt	Million Tonnes
NOAA	National Oceanic and Atmospheric Administration
OSPAR	Oslo and Paris Conventions
PBAT	Polybutylene adipate terephthalate
PE	Polyethylene
PLA	Polylactic Acid
ROV	Remotely Operated Vehicle

UNEP	United Nations Environment Programme
UV	Ultraviolet
WP	Work Package

Executive Summary

Bioplastics have emerged as a potential solution to address the pressing issue of plastic pollution, primarily due to their capacity to be designed as biodegradable materials. However, biodegradability is currently only guaranteed under specific controlled conditions, such as industrial composting or anaerobic digestion. Under these conditions, plastics degrade over a sufficient period of time and at defined temperatures into biomass, carbon dioxide and water (aerobic conditions), or biomass, carbon dioxide, methane and water (anaerobic conditions). Some biodegradable plastics are also marketed as suitable for home composting, although this remains uncertain due to the variability and lack of control over environmental conditions, which are highly dependent on climate.

Importantly, biodegradable plastics are not meant for disposal in the open environment. While biodegradable plastics are expected to degrade faster than conventional plastics under natural conditions, there is still limited evidence on whether their degradation rates are sufficient to prevent the formation and impacts of micro- and nanoplastics (Afshar et al., 2023). As such, they cannot be considered a solution to littering. At the same time, littering is a persistent human behaviour that cannot be fully eliminated, meaning that a portion of plastic products will inevitably enter the environment, either unintentionally or through improper disposal.

This makes it essential to understand the pathways through which plastics enter the environment, as well as the product categories and sectors most associated with leakage. Such understanding can inform targeted research and development efforts, particularly in identifying applications where biodegradable plastics may provide environmental benefit by reducing persistence after leakage. For products with high environmental leakage potential, degradation rates therefore need to be optimised to minimise environmental harm.

Within this context, the MAGICBIOMAT project aims to “program” the biodegradability of bio-based and biodegradable plastics to ensure optimal performance during their service life followed by rapid biodegradation under open-environment conditions. To achieve this, the project is developing an Artificial Intelligence (AI)-supported manufacturing tool that can identify the optimum composition for biodegradable plastics manufacturing, depending on their eventual application and thus the required biodegradability timeframe.

MAGICBIOMAT focuses on two product groups with high littering potential:

- Agricultural mulch films, which are frequently left in fields due to degradation or collection challenges. In many cases, they are incorporated into soils through ploughing, contributing to

microplastic accumulation. The project aims to develop films that maintain functional integrity over a crop cycle and then biodegrade effectively in soil after use.

- Plastic-lined paper packaging, such as paper cups and plates, where plastic coatings ensure structural integrity but prevent conventional recycling. These products are often littered. The project aims to develop coatings that biodegrade rapidly under open-environment conditions.

To validate the environmental performance of these products, MAGICBIOMAT will conduct extensive biodegradation studies across freshwater, marine, and terrestrial environments in at least four European climate zones.

This deliverable provides a comprehensive analysis of uncontrolled waste littering in open environments, with a focus on plastic litter due to its persistence, ubiquity, and potential to form micro- and nanoplastics. It examines the main pathways through which plastics enter the environment, including consumer, commercial, industrial, agricultural, and fishing-related sources, with particular attention to sectors and products most associated with leakage.

A comprehensive literature review (2000–2026) was conducted to assess litter abundance and composition across beaches, coastal zones, the seabed, freshwater systems, and terrestrial environments. The analysis identifies dominant litter categories, spatial and temporal trends, and key drivers of accumulation. Findings confirm that plastics dominate across all environmental compartments. Single-use consumer items, such as packaging, bottles, bags, wrappers, cups, and caps, are consistently the most prevalent. Population density, tourism, riverine inputs, hydrodynamic processes, and the effectiveness of waste management drive marine litter accumulation.

In terrestrial environments, agricultural activity is a major source of plastic pollution. Mulch films and greenhouse plastics frequently remain in soils after use, contributing to both macro- and microplastic contamination. The application of sewage sludge to agricultural land represents an additional contamination pathway, as does roadside littering.

These findings highlight the strong interconnection between environmental compartments and the influence of climatic variability on litter distribution and degradation. These insights, and the following key conclusions, provide the scientific basis for selecting representative exposure scenarios for MAGICBIOMAT's open-environment biodegradation studies:

- Consumer packaging predominantly enters marine and freshwater systems
- Beaches act as major accumulation zones for littered packaging
- Rivers act as key transport pathways, while lakes and reservoirs act as sinks

- Agricultural soil is the dominant compartment for agricultural plastics
- Environmental compartments are highly interconnected
- Climate conditions significantly influence litter accumulation and degradation dynamics

Based on these findings, the priority environments for MAGICBIOMAT biodegradation studies can be determined. For plastic-coated paper packaging, the priority environments are (i) the coastal marine environment, as this is a major sink for consumer litter, (ii) beach sand/sediment, as high accumulation of packaging waste is observed in this environment, (iii) freshwater, particularly rivers/streams, as they are major transport pathways for packaging waste, and (iv) terrestrial surface soil, as land is the initial littering environment. For agricultural mulch film, the priority environments are (i) agricultural soil, both surface and buried, since this is a main end-of-life environment for mulch films, (ii) freshwater, as this is a secondary transport pathway for fragments, and (iii) marine environment, which is a lower priority environment, but relevant for transported fragments.

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1. Introduction

The main economic model in today's society follows the linear make – use – waste approach, stemming from the perceived abundance and low cost of many materials and products, particularly plastics. As the effects of inappropriate waste management and the unsustainability of the linear consumption pattern became increasingly evident in littered environments and the depletion of resources, the discussion started shifting to the need to change our predominant economic model from a linear to a circular one, i.e. one where resources are used to make products that are reused or refurbished to ensure that they remain within the economy for as long as possible, before being recycled to extract and reuse as much of the original resource as possible. While this concept of the circular economy has been around for several decades, it was popularised by the Ellen MacArthur Foundation (https://www.ellenmacarthurfoundation.org/) in 2012. This circularity approach has since been incorporated into European policy through the Circular Economy Action Plan[1] and later the Green Deal[2] and relevant policy instruments.

1.1. Focus on Plastics

During the Second World War, plastics emerged as a cheap and much lighter alternative to glass and metal, and great strides in research and development of new plastic polymers, materials, and products were made. Since then, the versatility, longevity, and low cost of plastics made them a suitable replacement for many applications, resulting in a 900% increase in plastic production from 1950 to 2024 (Figure 1). There are no signs that plastic production is slowing down. In fact, oil demand for plastics production is expected to increase considerably in the coming decades (Figure 2).

In the early 2000s, scientists began to raise awareness that our seas were becoming polluted by litter as a direct result of human activity. Marine litter, which has been defined as any persistent, human-made material that is accidentally lost or purposefully discarded in the marine and coastal environment (UNEP, 2009), has been extensively studied since (Figure 3).

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
[2] https://www.consilium.europa.eu/en/policies/european-green-deal/

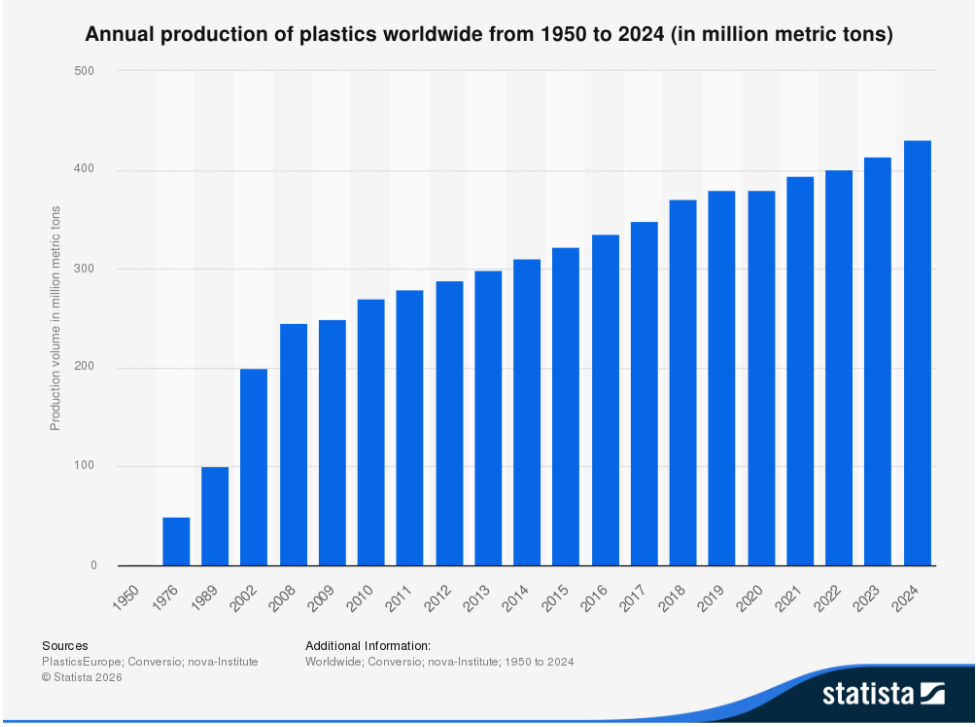


Figure 1. Annual global plastics production from 1950 to 2024 (PlasticsEurope, 2025).

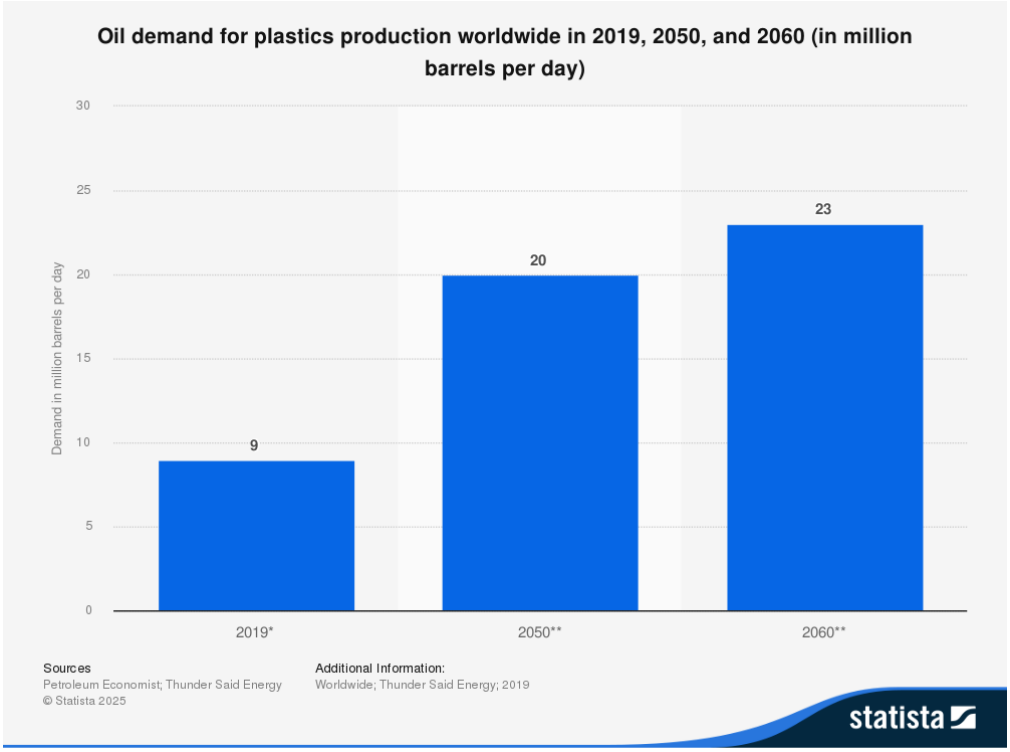


Figure 2. Global oil demand for plastic production up to 2060 (Petroleum Economist, 2019).

Plastics consistently make up the highest proportion of marine litter, with most of this plastic litter stemming from activities that take place on land. Due to their persistent nature, plastic materials are also the ones that cause the most detrimental impacts on ecosystems. Most of the plastics made to date are still available in the environment in some form. Of the approximately 8300 Mt of plastic waste produced between 1950 and 2015 (primary production), circa 6300 Mt of plastic waste has been generated (Figure 4). Of this, only 9% has been recycled, 12% incinerated, and around 79% is accumulated in landfills or the natural environment (Geyer et al., 2017).

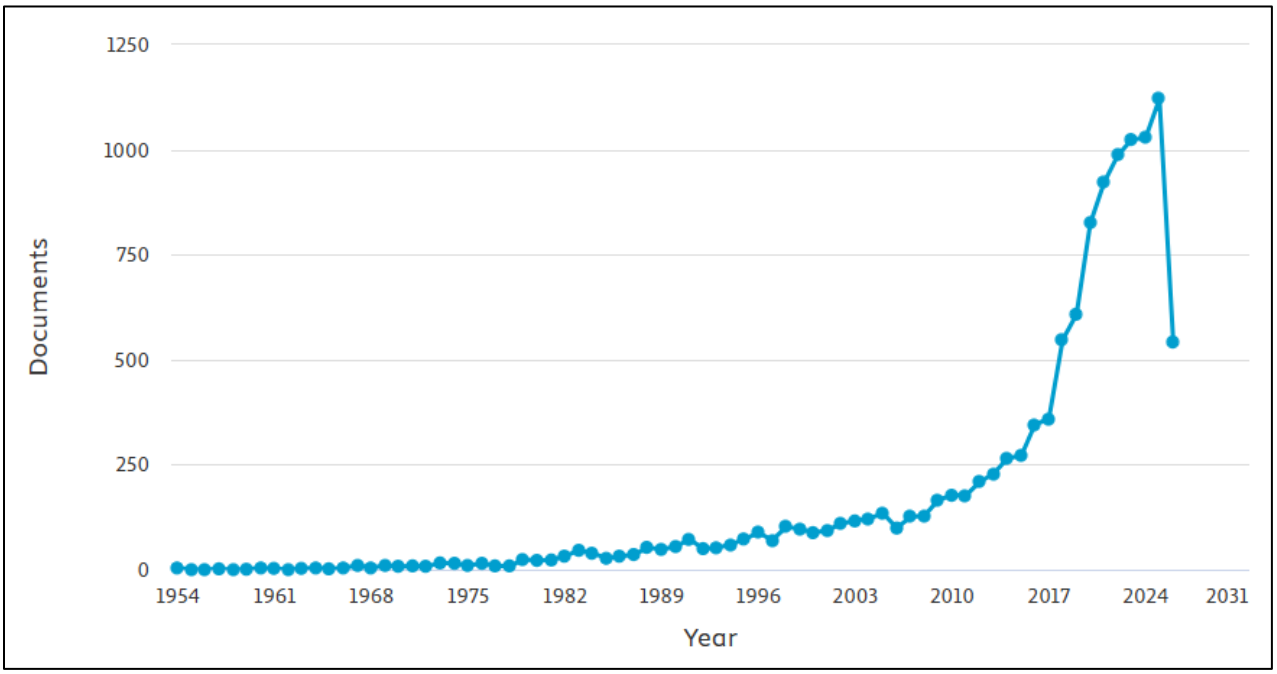


Figure 3. Documents published per year, available in Scopus, including the terms “marine AND litter OR debris”.

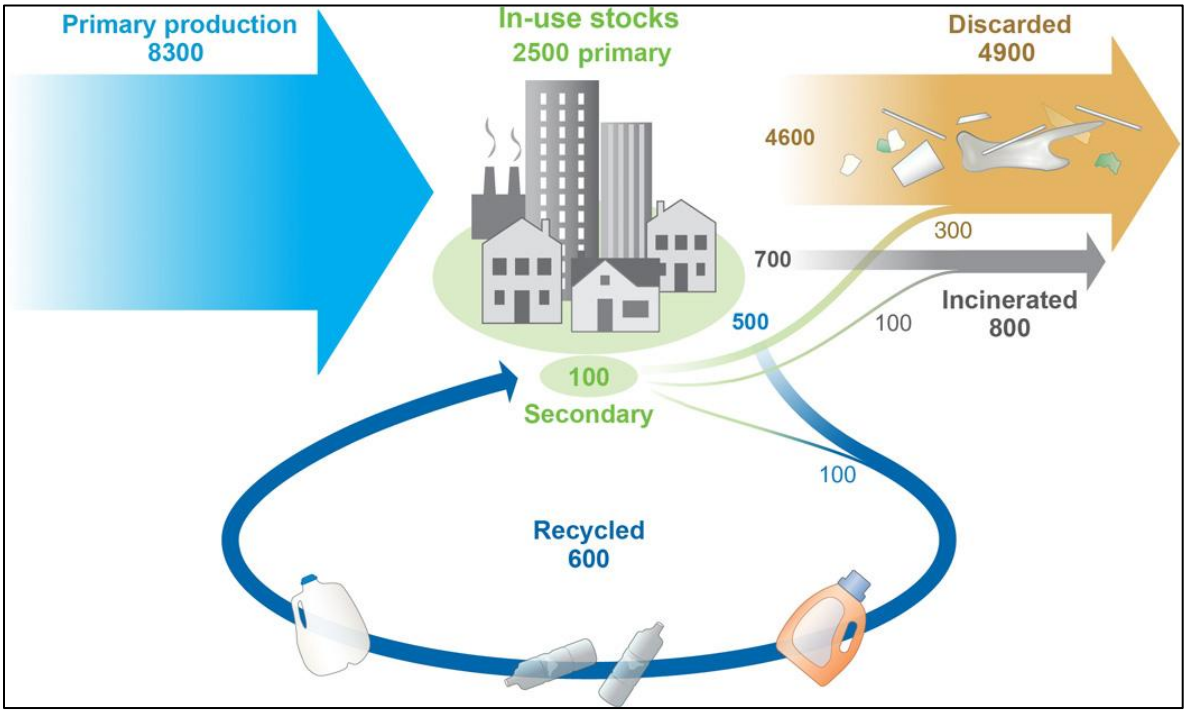


Figure 4. Plastic waste production, use and management flows (Geyer et al., 2017).

1.2. Impacts of Plastic Litter

Oceans contain roughly 25 million tonnes of plastic waste (Isobe & Iwasaki, 2022). Over 90% of all marine litter is located on the seafloor (Sherrington, 2016). In the environment, plastics break down into increasingly smaller pieces as a result of physical and chemical processes, such as UV degradation and abrasion. The resulting plastic particles are called macroplastics if they are larger than 2.5 cm on their longest side, mesoplastics if they are between 5 mm and 25 mm, microplastics if they are between 1 µm and 5 mm, and nanoplastics if they are below 1 µm. Microplastics are ubiquitous in the marine and terrestrial environments. Recent work has found evidence of microplastics even in Canadian Arctic sea ice, at around 23 microplastics per litre (D'Angelo et al., 2023), and very high concentrations of 1127 to 3215 items/kg in deep-sea sediments (Rynek et al., 2025). While research is limited, estimates suggest that terrestrial microplastic pollution is orders of magnitude higher than marine microplastic pollution.

An overwhelming volume of research demonstrates the variety and severity of this plastic pollution. Encounters between marine litter and 693 species of marine organisms have been reported, nearly 90% of which involve plastic litter (Gall & Thompson, 2015). Such encounters have detrimental impacts on marine

organisms. One the one hand, macroplastics such as plastic bags and fishing-related items can be ingested by larger marine organisms, blocking their intestinal tract and leading to starvation and reduced health (Bjorndal et al., 1994; Ryan, 1988; Spear et al., 1995). They can also cause entanglement of marine organisms, leading to incapacitation, reduced preying/feeding abilities, lacerations, suffocation, and drowning (Derraik, 2002; Gregory, 2009; Laist, 1997). On the other hand, microplastics ingested by marine wildlife cause various health impacts, ranging from physical damage such as tissue scarring and fibrosis (Charlton-Howard et al., 2023) to biochemical process disruption (Banaee et al., 2024) and reduced energy reserves (Rochman et al., 2013; Wright et al., 2013). Microplastics have been identified in marine organisms destined for human consumption (Browne et al., 2008; Digka et al., 2018; Nadal et al., 2016; Van Cauwenberghe and Janssen, 2014), indicating potential negative impacts on human health (Karbalaei et al., 2018) through toxic chemical accumulation (Tanaka et al., 2020; Rochman et al., 2014). Microplastics in the terrestrial environment have been linked with reductions in soil fertility, adverse effects on soil biota, and potential transfer through terrestrial food webs (Nuñez-Rubio et al., 2025; Wang et al., 2022a).

1.3. The Potential Role of Bioplastics to Address Plastic Pollution

Bioplastics have emerged as a potential solution to address the pressing issue of plastic pollution. As the term ‘bioplastic’ can be ambiguous, the definitions provided by Dilkes-Hoffman et al. (2019) are presented here for clarity:

- Bioplastic: a plastic that is biobased and/or biodegradable
- Biodegradable plastic: a plastic that can be completely biodegraded through biological activity resulting in biomass, CO_2 and water under aerobic conditions, and biomass, CO_2, methane and water under anaerobic conditions.
- Biobased plastics: plastics that are either wholly or partly derived from biomass.

Therefore, depending on the feedstock used to produce them, bioplastics can be biobased but not biodegradable, biobased and biodegradable, or fossil-based and biodegradable.

Global bioplastics production makes up a very small percentage of the total global plastics production. Nonetheless, the market is growing (Figure 5). In an era marked by uncertainty about the availability and cost of fossil fuels, the industry is exploring alternative feedstocks for producing plastic materials. Bio-based plastics can be produced by first-, second-, or third-generation feedstocks. Most bioplastics are made from first-generation feedstocks, which are rich in carbohydrates and starch. These, however, are products that

could be used for food or animal feed, meaning that they compete with agricultural land for human and animal sustenance. Second-generation feedstocks partly address this concern as they use inedible plant matter, such as agricultural residues and forestry byproducts. Third-generation feedstocks are organic waste and algae, which could be considered the most sustainable feedstock but can be quite difficult and complex to produce.

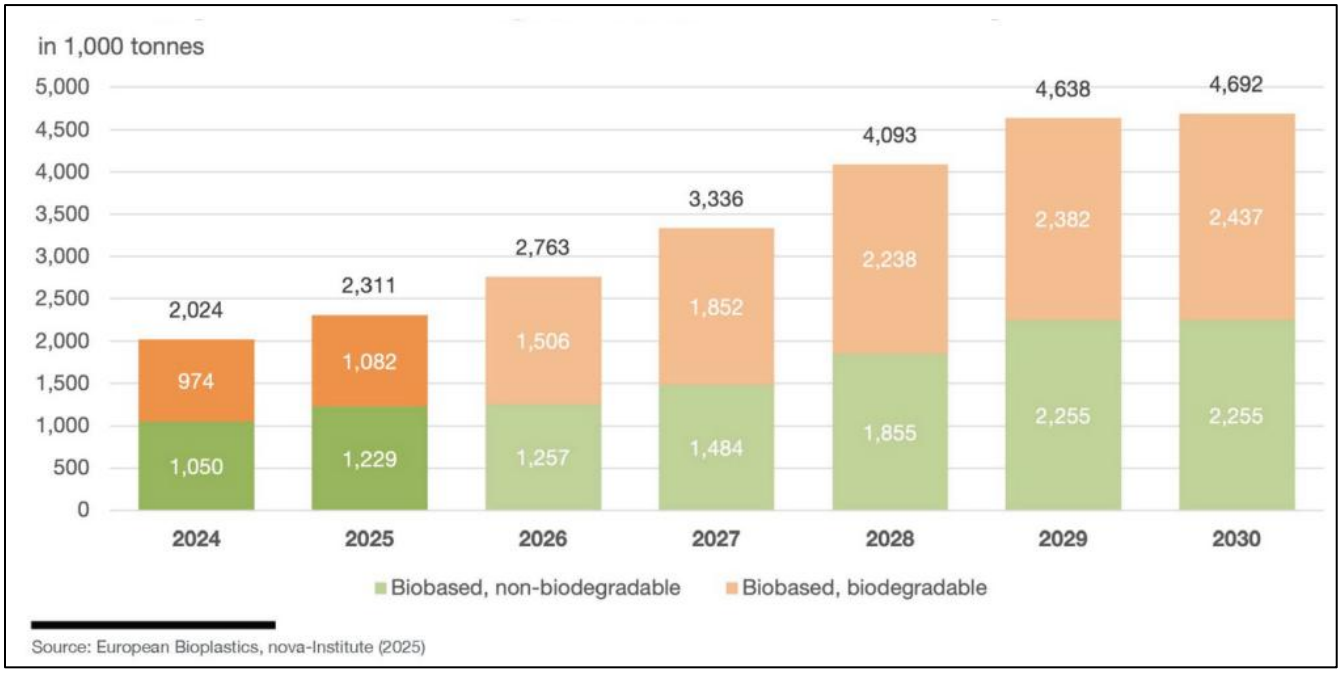


Figure 5. Global production capacity of biobased plastics 2025-2030 (European Bioplastics, 2025).

The property that makes bioplastics a potential solution to plastic pollution is their potential to be designed to be biodegradable. However, to date, the biodegradability of plastics is only guaranteed under specific conditions. These are normally anaerobic digestion or industrial composting conditions, where the plastics are exposed to specific temperature conditions over a sufficient period of time to ensure that they are effectively broken down into biomass, carbon dioxide and water (under aerobic composting conditions) or biomass, carbon dioxide, methane and water (under anaerobic digestion conditions). Some biodegradable plastics are also marketed as being suitable for home composting. However, there are uncertainties around this as home composting conditions are uncontrollable and can vary significantly depending on climate.

Biodegradable plastics are not meant for disposal in the open environment. While they will most likely degrade faster than conventional plastics under natural environmental conditions, there is uncertainty about whether the rate of degradation is fast enough to prevent negative impacts associated with microplastic and

nanoplastic creation. While available data are limited (Afshar et al., 2023), research suggests that open environment conditions might not always be conducive to their full disintegration (Janik et al., 2018; Liao & Chen, 2021; Napper & Thompson, 2019; Weinstein et al., 2020). Therefore, biodegradable plastics cannot be considered as a solution to littering. Other solutions, focusing on awareness-raising and behaviour change interventions, should be prioritised to resolve the plastic littering issue.

However, littering is a human behaviour, and it is unlikely to be completely halted. Some plastics will always find their way into the environment. It is therefore important to understand the pathways through which plastics end up in the open environment, and which types of plastic products are most likely to end up in which environments. This will provide important information to understand whether there is merit in focussing research and development efforts as well as resources on the design of biodegradable plastics for these applications. For plastic products likely to end up in the environment, their degradation rate must be optimised to ensure negative environmental externalities are minimised.

1.4. The MAGICBIOMAT Project

A key aim of the MAGICBIOMAT project is to program the biodegradability of biobased and biodegradable plastics to ensure that, on the one hand, they perform optimally over their useful lifetime, while on the other hand, they completely biodegrade within a predefined timeframe under specific open environment conditions. To do so, an AI-supported manufacturing tool is being developed by the project. The project is focusing its efforts on two products with high littering potential:

- Agricultural mulch films: these films, used to protect crops, are very often too littered or degraded to be collected and recycled at the end of their useful life. In fact, in many cases, they are so degraded that farmers plough them into the soil, where they contribute to microplastic pollution. MAGICBIOMAT aims to design agricultural mulch films that can maintain their integrity for a crop cycle and then effectively biodegrade when they are ploughed into soil.
- Plastic-lined paper packaging: this sort of packaging is used in food applications, such as paper cups and paper plates, where the plastic film is added to ensure that the paper maintains its integrity. This type of packaging cannot be recycled through conventional mechanical recycling. Furthermore, it often ends up in the environment through littering. MAGICBIOMAT aims to develop biodegradable plastic lining for paper packaging, which effectively biodegrades under open environment conditions within a short timeframe.

To test the effective biodegradation of these two products, MAGICBIOMAT will implement extensive open environment biodegradation studies in various environmental compartments, including freshwater, the marine and terrestrial environments, in at least four different European climate zones. This work has two objectives: (i) to prove the effective biodegradation of the two products, and (ii) to feed the AI manufacturing tool with data from the open environment studies.

The open environment disintegration studies will start in late 2026 - early 2027 and will run through to the end of the project (M48). To help define an appropriate study protocol that will ensure that the selected environments are representative, it is important to understand the pathways through which plastics end up in the environment, and which types of plastic products are most likely to end up in which environments.

1.5. Scope of this Deliverable

This Deliverable undertakes an analysis of cases of uncontrolled waste littering in various environmental compartments. It begins with an overview of litter pathways to the environment, briefly looking at consumer waste, commercial and industrial waste, agricultural waste, and fishing and aquaculture waste. It then undertakes extensive literature reviews to map the abundance and distribution of different types of litter found on beaches, the seabed, in rivers and other freshwater environments such as lakes, and finally in the terrestrial environment. While this study focuses on macro-litter, a section exploring the abundance and distribution of microplastics in agriculture is also provided, due to its relevance to the upcoming work within the MAGICBIOMAT project.

2. Litter Pathways to the Environment

The inappropriate disposal of waste can result in littering, whether this is purposeful or inadvertent. This section aims to present the main pathways through which products find their way into the natural environment, thus becoming litter. There are myriad ways in which this can occur, and this section does not aim to present all of them, but rather to focus on those that are most important and contribute the greatest volume of litter. While all litter in the natural environment is detrimental, this literature review focuses on plastics for three reasons: (i) it is the material that has the potential to cause the most negative environmental impacts due to the release of microplastics and nanoplastics and the impacts described above, (ii) it is ubiquitous in the environment, found in every compartment, in very large quantities, and (iii) it

is the material of focus of the MAGICBIOMAT project, which aims to design biodegradable alternatives for plastic products that regularly end up in the environment.

This section aims to identify the pathways through which this plastic waste ends up in the environment. To facilitate the discussion, waste is split into four categories – consumer waste, commercial and industrial waste, agricultural waste, fishing and aquaculture waste – and pathways for each type of waste are discussed.

2.1. Consumer Waste

Most of the plastic produced today is destined for consumer products, especially packaging (Figure 6). While plastics used for industrial machinery, transportation, and building and construction are locked into use for decades, and plastics used for electrical and electronic equipment and textiles are used for years, plastics used for packaging and consumer products are used for very short periods of time, sometimes even just months (Figure 7). Consequently, most plastic resources are used to develop a product category – packaging – that is used for the shortest period of time, before becoming obsolete and thus waste. These are the types of plastics that are most likely to find their way into the environment.

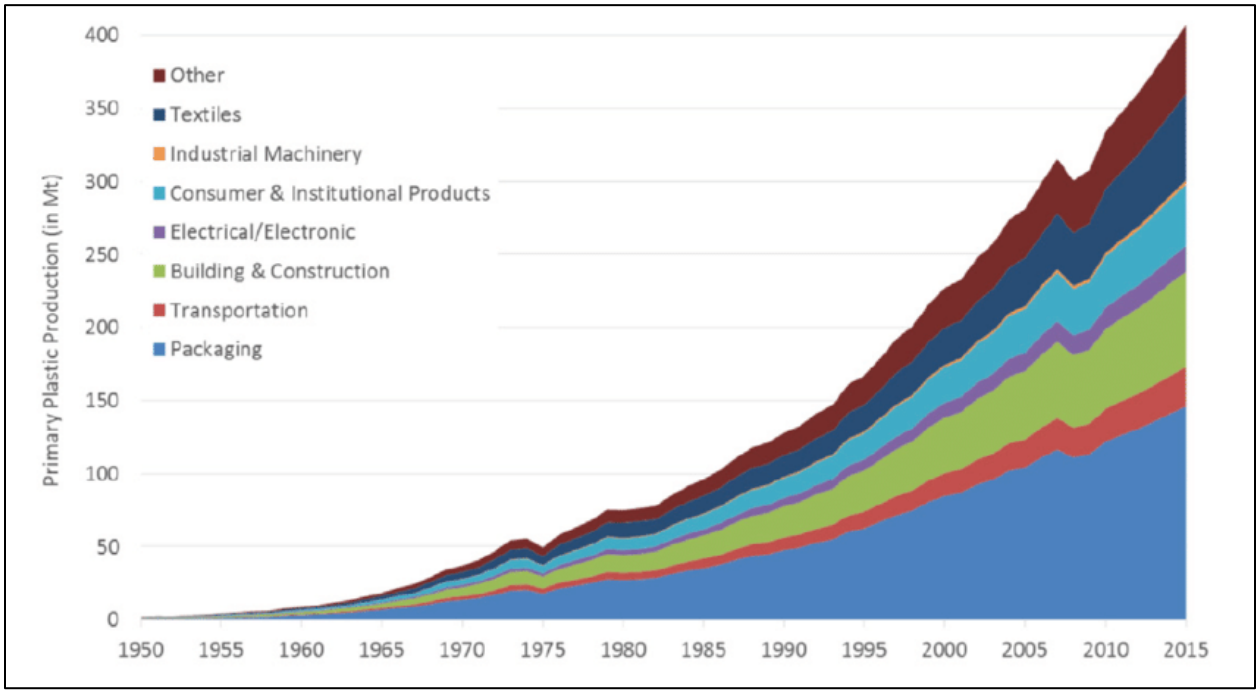


Figure 6. Global primary plastics production according to industrial use sector from 1950 to 2015, in million metric tonnes (US Department of Agriculture, In: Frontier Technology Quarterly, 2019).

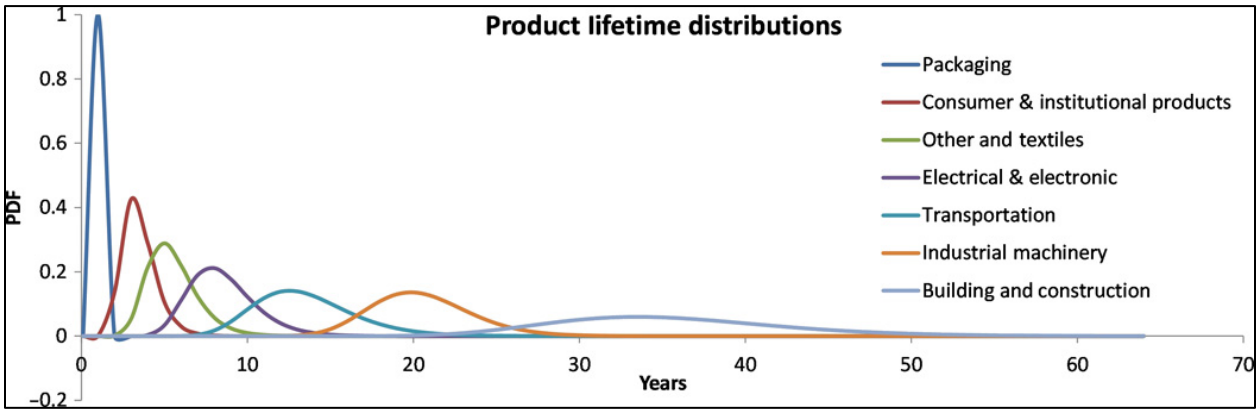


Figure 7. Log-normal probability functions for the product lifetime distributions of main industrial use sectors (Geyer et al., 2017).

There are several ways in which this might occur. The most immediate way is through direct littering, for example, consumers throwing a candy wrapper out of a car window. Such release into nature might also happen inadvertently, for example, if waste is placed in an overflowing or uncovered waste bin. If such littering occurs in the coastal zone, then litter will end up in the sea, where it will be further dispersed by weather conditions, such as wind or rain, and wave action (Akarsu et al., 2022; Yan et al., 2022) or even by birds or animals into the environment. It is, for example, not uncommon to see food wrappers dispersed on the floor by seagulls in coastal cities or by cats or squirrels in residential areas or parks. Waste entering stormwater drains will end up in the nearest aquatic environment, be it a stream, a river or the sea (Kasa et al., 2025).

Lack or inefficiency in waste management processes is also a way through which plastic waste can be released into the environment. Disposal in uncontrolled landfill sites remains an issue in many countries, particularly those with less developed waste management infrastructure. It is estimated that 30% of global waste is disposed of in open dump sites and about 29% is landfilled (Cook et al. 2026). However, even in the European Union, where open landfilling is banned and restrictions are imposed on the landfilling of waste, some historical landfill or dumping sites remain open or not yet remediated. As a result, landfilled waste, whether recent or historical, that has not been appropriately covered can be dispersed into the environment through wind, rain or animals.

Disposal of sanitary products, like Q-Tips, tampons or pads, down sewage drains is another way through which consumer products can be released into the environment. This typically happens during heavy storms, when sewerage overflows can occur, leading to untreated waste washing out to the sea.

2.2. Commercial and Industrial Waste

Waste from commercial and industrial activities can be inadvertently or purposefully released into the environment, much in the same way as consumer waste. There are, however, certain types of commercial and industrial waste that warrant specific mention.

2.2.1. Vehicle Tyres

Vehicle tyres contribute to plastic and microplastic pollution in a number of ways. Normal wear and tear of tyres, particularly car tyres, releases microplastics into the environment. The annual per capita amount of this release has been estimated at up to 4.7 kg, contributing between 5 and 10% of the total plastics in our ocean (Kole et al., 2017).

Every year, about 29 million metric tonnes of waste tyres are generated globally. Large numbers of waste tyres are used as fenders on small and medium-sized vessels, including fishing vessels. Loss of these tyres is quite common as they are subject to heavy wear and tear. In fact, tyres are a common marine litter item in ports and other marine environments. The Gondolier Divers Association of Venice reported that during 38 cleanup dives in the Venice canals, they collected over 40 tonnes of litter, including 2500 end-of-life tyres (ISOTECH Ltd, 2026). It is also not uncommon for tyres to be purposefully placed in the marine environment by amateur (spear) fishermen to act as artificial reefs, specifically hideout places for octopus. Once in the marine environment, waste tyres contribute to microplastic pollution.

Around 90% of all waste tyres are repurposed either for material recovery, energy recovery or civil engineering and backfilling (WBCSD – World Business Council for Sustainable Development, 2019). One of the ways in which tyres are repurposed is by grinding them to make the cushioning material used on synthetic football turfs and playgrounds. These small plastic particles are easily carried or washed away by rain, entering the terrestrial environment and contributing to microplastic pollution, with a study conducted in Norway estimating that the annual loss of these granules is 1187 tonnes (Sundan et al., 2025).

2.2.2. Plastic Pellets

Plastic pellets or nurdles are another type of industrial waste that often finds its way to the marine environment. These small plastic spheres are transported globally to be melted and pressed into the required shapes for making plastic products. Accidental spills and release of these pellets as a result of operational leakages or accidental spills during transportation on land and at sea are significant to the extent that they form the second largest source of microplastics in the marine environment and are found across the globe (Folbert et al., 2025). It is estimated that, within the EU, between 52,000 tonnes and 184,000 tonnes of plastic pellets are unintentionally released into the environment every year (European Commission, 2023).

2.1. Shipping, Fishing and Aquaculture Waste

This section presents the key types of wastes stemming from the shipping, fishing and aquaculture activities and their pathways to the environment.

2.1.1. Shipping Waste

The management of ship waste has consistently been among the top ten environmental priorities of European ports since 2013 (European Sea Ports Organization [ESPO], 2022). However, shipping is a global industry, making waste management optimisation particularly challenging, as the legislative framework and implemented practices vary significantly between home ports and ports of call across the world. The International Maritime Organization's Marine Pollution Convention (MARPOL) is the main international policy instrument concerning ship waste management at sea. MARPOL mandates minimum waste segregation and management requirements in its Annex V, which, inter alia, completely prohibits the disposal of plastic waste at sea. Nonetheless, proper waste segregation onboard is often inadvertently disincentivised by the lack of proper waste segregation at port reception facilities (European Commission, 2018). This issue is addressed by the Port Reception Facilities Directive (European Union, 2019), which focuses on what happens to ship waste once it comes on land. The 2019 amendment of the Port Reception Facilities Directive aims to harmonise the Directive with the provisions of the International Maritime Organisation and MARPOL, and to better align it with other advancements in European policy, including the 2018 revision of the Waste Framework Directive and the EU Circular Economy policy. Yet, every year, in the European Union, between 7 and 34% of ship-related waste, amounting to between 60,000 and 300,000 tonnes, is not delivered at ports (European Commission, 2018), and by extension is likely lost or disposed of at sea. The most common type

of waste from the shipping industry is plastic (Mohee et al., 2012). Furthermore, the World Shipping Council reports that in 2025, approximately 1,478 containers and their contents were lost at sea[3]. While this is a very small proportion of the over 280 million containers transported within the same year, it exemplifies another route of marine litter from the shipping industry.

2.1.2. Fishing Waste

Nearly 2% of fishing gear used globally is lost to the marine environment each year (Richardson et al., 2022). This can occur accidentally, for example during severe weather events or as a result of damage caused by marine wildlife (Richardson et al., 2021). Gear may also be discarded unintentionally when it becomes irretrievably entangled on rocky seabed or marine organisms, forcing fishers to cut it free to minimise further losses. In other cases, fishing gear is intentionally discarded at the end of its useful lifetime because fishers have no incentives, or in some cases are disincentivised by disproportionally high costs and the lack of alternative management solutions, to properly dispose of it. This abandoned, lost, or discarded fishing gear (ALDFG) continues to trap marine organisms, a phenomenon commonly referred to as 'ghost fishing'. It is estimated that 46 % of species listed on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species have been affected by ALDFG, primarily through entanglement or ingestion (FAO, 2020). In the Mediterranean, Perroca et al. (2024) analysed videos from digital media and documented ALDFG entanglement involving 86 species, including at least ten that are threatened with extinction. The impacts of entanglement by ALDFG are substantial, causing considerable mortality among marine organisms (Lively & Good, 2019) and damaging vulnerable Mediterranean habitats, including coral reefs (Angiolillo & Fortibuoni, 2020; Consoli et al., 2019; Consoli et al., 2020). Ghost fishing can also have serious economic consequences for fishing communities by reducing commercial fish stocks (Scheld et al., 2016), while abandoned gear may also pose a significant hazard to navigation (Hong et al., 2017). In addition, the gradual wear and tear and degradation of ALDFG in the marine environment releases plastic microfibres, further contributing to microplastic pollution (Sharma et al., 2024).

2.1.3. Aquaculture Waste

While global fishing production has remained relatively constant in the past twenty years, aquaculture fish production has been steadily increasing (Figure 8).

[3] https://www.worldshipping.org/containers-lost-at-sea

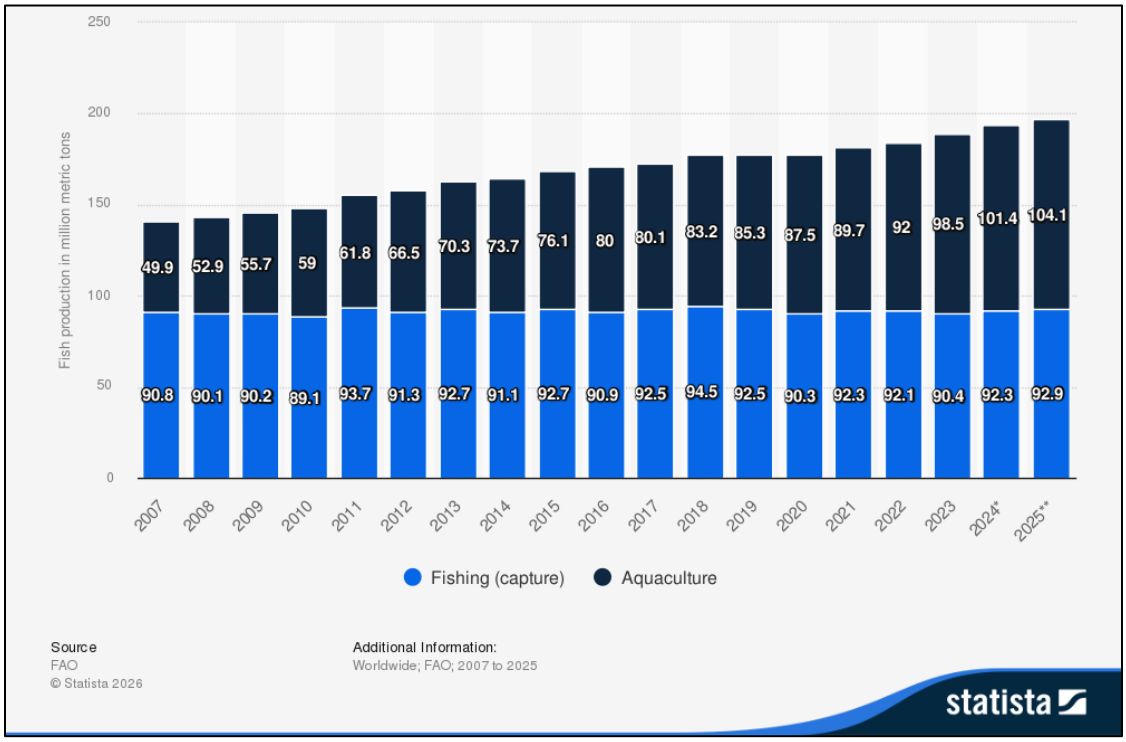


Figure 8. World fish production by fishing and aquaculture (FAO, 2025).

Similar to the fishing industry, the gear used by the aquaculture industry is mostly made of plastics, including nets, cages, ropes, etc. Poor waste management, poor siting, installation and maintenance, farm decommissioning and lack of awareness and training are the key causes of accidental loss of aquaculture waste as a result of mismanagement; extreme weather conditions result in inadvertent loss, whereas deliberate discharge can be an additional cause (Huntington, 2019). The lack of access to waste collection and recycling facilities for aquaculture waste has also been identified in literature as a contributing factor to waste mismanagement (Skirtun et al., 2021).

There is limited data in the literature on the contribution of aquaculture waste to plastic pollution, mainly because it is not always straightforward to accurately distinguish whether the source of a rope is aquaculture or fishing, for example. Nonetheless, estimates suggest that waste from fishing and aquaculture in EU Member States, Norway and Iceland ranges from 3,000 to 41,000 tonnes/year, of which 72% plastics (Sherrington et al., 2016). The same source estimates that around 7% of this is deliberately discarded. Aquaculture gear in the marine environment has the same impacts as fishing gear.

2.2. Agricultural Waste

Plastic terrestrial pollution is closely linked to intensive agriculture. Agriculture is in fact the biggest contributor to plastic terrestrial pollution, which has been estimated to be between 4 and 23 times more severe than marine plastic pollution (Horton et al., 2017). As can be seen from Figures 9 to 11, there is a large variety of different types of plastics that are used in agriculture and farming, from single-use containers for fertilisers and feed, to greenhouse covers and agricultural mulch. According to the Food and Agriculture Organisation (FAO, 2021), there is a general lack of available guidance and information on how agricultural plastics should be managed and a lack of systematic collection and management of these plastics. There is also a lack of awareness.

Greenhouse covers and plastic mulch films are used in agriculture to protect crops from pests or extreme weather conditions, including drought and cold. They are a significant part of the plastic products that are used in agriculture and farming (Figure 13) and a market that continues to increase. At the end of their useful lifetime, which is typically only a few months (Figure 14), these films are either heavily degraded or heavily soiled, meaning that they are not easily recyclable. In most countries, there are no collection schemes available for such agricultural plastic waste. Generally, farmers collect them and place them in bins to be disposed of as waste, although very often they are so degraded that their collection is practically impossible, resulting in farmers ploughing them into the soil, which leads to the accumulation of microplastics in the terrestrial environment. The impact of microplastics on agricultural land on farmed crops is a topic of current scientific investigation but could affect the uptake of nutrients by plants and thus plant growth (Rillig et al., 2019). A short review of the role of non-biodegradable and biodegradable mulch films in agricultural soil plastic pollution is available in section 9.

Another practice that contributes to microplastic accumulation in agricultural soils is the use of treated sewage sludge, a product of the anaerobic digestion of wastewater, as a fertiliser. As noted earlier in this report, plastics can find their way into wastewater treatment stations, either through the inappropriate disposal of sanitary waste, or through the collection and treatment of drain water. During the anaerobic digestion process, plastics are separated with the solid fragment of sewage. Through a combination of biological and mechanical processes, this plastic waste is broken down into smaller pieces, forming microplastics. It is estimated that between 4,196 and 15,385 microplastics/kg dry mass remain in the treated sewage sludge biosolids (Mahon et al., 2017). When treated sludge is spread onto agricultural land as a fertiliser, so are thousands of pieces of microplastics. In Europe, estimates suggest that 125-180 tonnes

of microplastics per million inhabitants are added to agricultural soils through sewage sludge applications (Nizzetto et al., 2016). A more recent study estimates that up to 7.2×10^{12} microplastic particles could be added to Scottish land annually through the application of biosolids from sewage sludge (Rimmaudo et al., 2026).



Figure 9. Types of plastics used in agriculture for crop production (FAO, 2021).

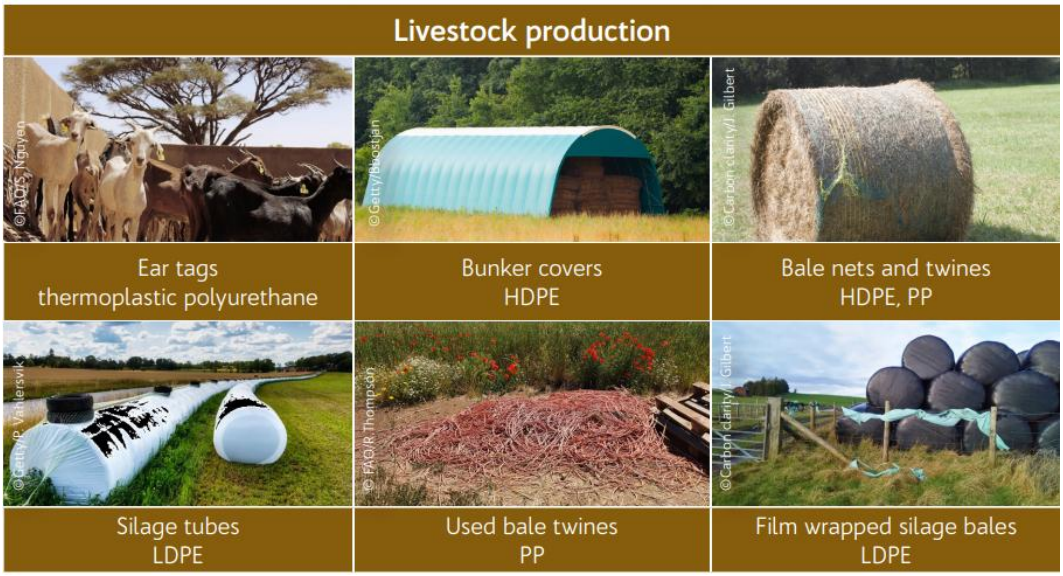


Figure 10. Types of plastics used in agriculture for livestock production (FAO, 2021).



Figure 11. Types of plastics used in forestry (FAO, 2021).

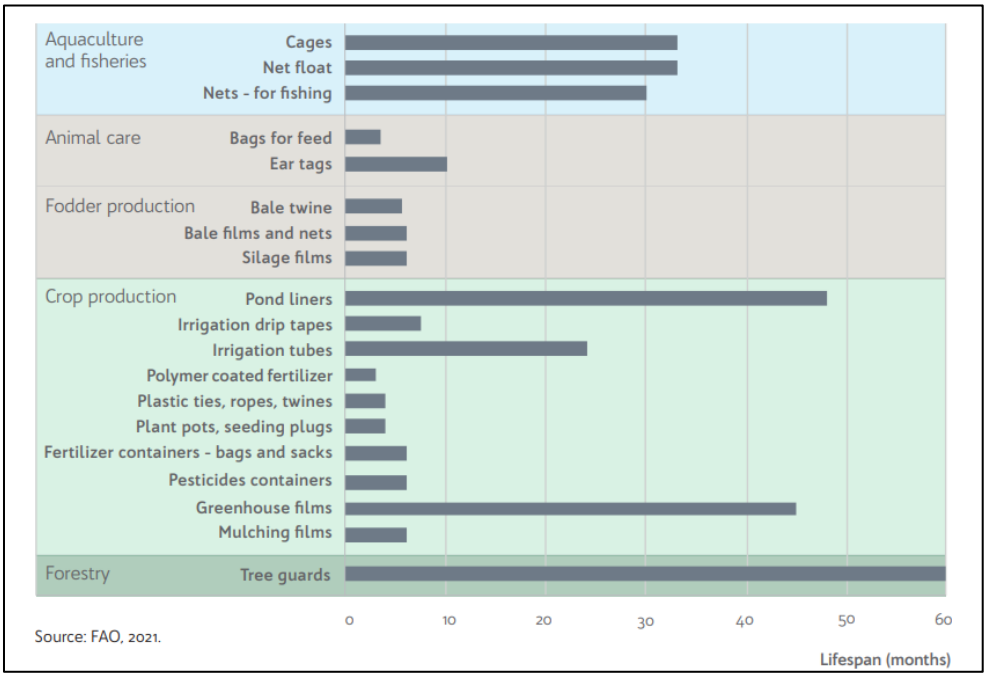


Figure 12. Typical lifespan of agricultural plastic products (FAO, 2021).

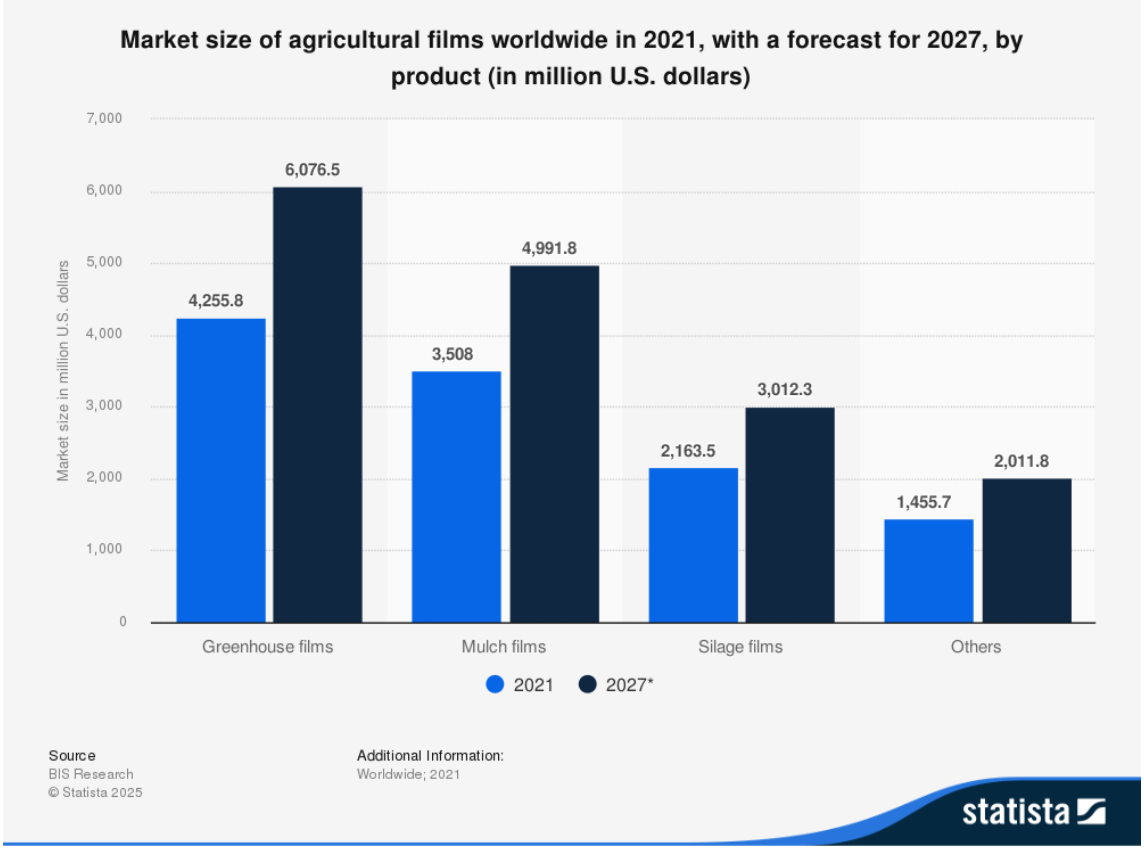


Figure 13. Global market size of agricultural films in 2021 with 2027 forecasts (BIS Research, 2023).

3. Literature Review Method

To identify the relevant literature for the reviews included in sections 4 to 8, specific keyword searches were undertaken in Scopus and Google Scholar. The focus was on articles that contained information on the abundance and composition of litter in various environmental compartments. Specifically, the following keyword combinations were searched:

- For litter on beaches: (marine litter OR marine debris) AND (beach OR coast) AND NOT (microplastic)
- For seabed litter: (seabed) AND (litter OR debris) AND (composition)
- For litter in riverine environments: (river* OR stream* OR freshwater OR riverine) AND (aquatic litter OR riverine litter OR anthropogenic litter OR solid waste OR plastic debris OR floating debris OR floating litter) AND (composition OR characterisation OR characterization OR classification OR categorization OR typology) AND NOT (leaf litter OR leaf debris OR woody debris OR detritus)
- For litter in other freshwater environments: (waste OR litter OR debris) AND (lake OR pond OR freshwater) AND (composition) AND NOT (microplastic) AND NOT (leaf)
- For litter in terrestrial environments, it was particularly difficult to identify relevant studies; therefore, several keyword combination searches were undertaken:
    - A search for (plastic) AND (pollution) AND (terrestrial environment)
    - A search for (litter OR debris OR waste) AND (land OR terrestrial environment) AND (composition) AND NOT (microplastic)
    - A search for (littering) AND (land) AND NOT (microplastic)

All the literature review searches were limited to articles written between 2000 and 2026. Conference papers and non-peer-reviewed sources were excluded to ensure quality. The titles and abstracts of all resulting articles were manually screened to verify their relevance to the study. This step was important to ensure that articles that included the keywords in an unrelated context were excluded from further analysis.

The review also included relevant studies that were not captured by the keyword-based search due to indexing limitations or terminology variations. These additional studies were found through reference tracking and contextual reading during the screening. This allowed the refinement of the relevant dataset.

The articles contained within the resulting datasets were reviewed in detail, and information pertinent to this work was extracted and summarised in different tables. Brief discussions of the literature review findings were undertaken, focusing on highlighting the main types of litter items that can be found in each environmental compartment, and any trends relevant to geography, seasonality, or weather conditions. It is important to note that while efforts were made to ensure that most of the relevant literature was captured, some articles might have been missed. However, this is not considered to be an important limitation to the work, since the literature identified and reviewed is significant, allowing confidence in the drawn conclusions.

4. Composition and Abundance of Beach Litter

The research related to marine litter on coastal environments is very extensive. A Scopus search for the following terms: (marine litter OR marine debris) AND (beach OR coast) AND NOT (microplastic), limited to articles in English published from 2000 to 2026, resulted in the identification of 1,798 potentially relevant documents. As Figure 14 demonstrates, over the last 26 years there has been a great increase in the number of articles published on this topic, from around 10 articles per year in 2000 to over 175 articles in 2025. The greatest number of articles has been published in the last 10 years, demonstrating the importance of this topic for the international research community. Most of the articles originated from research teams in the United States (Figure 15), however, a breakdown of the documents based on geographical continents (Figure 16) highlights that most of the undertaken research was authored in Europe, specifically in Italy, the United Kingdom and Spain (Figure 17).

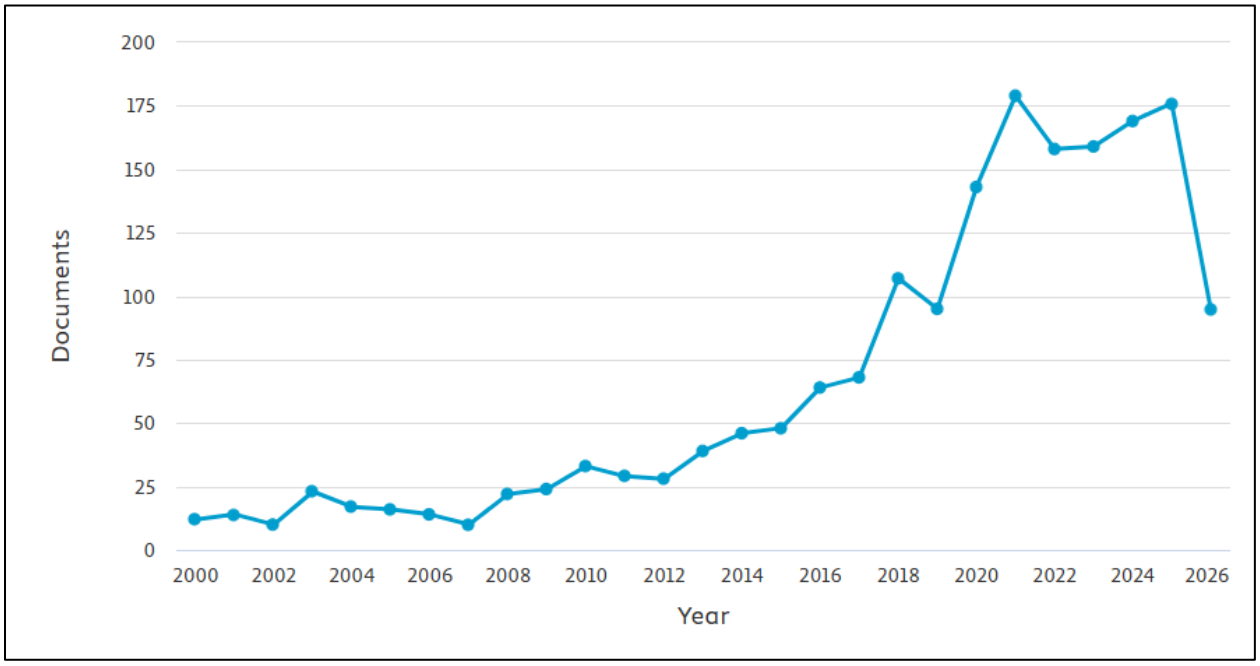


Figure 14. Trends in the number of published articles per year on beach/coastal marine litter (2000-2026).

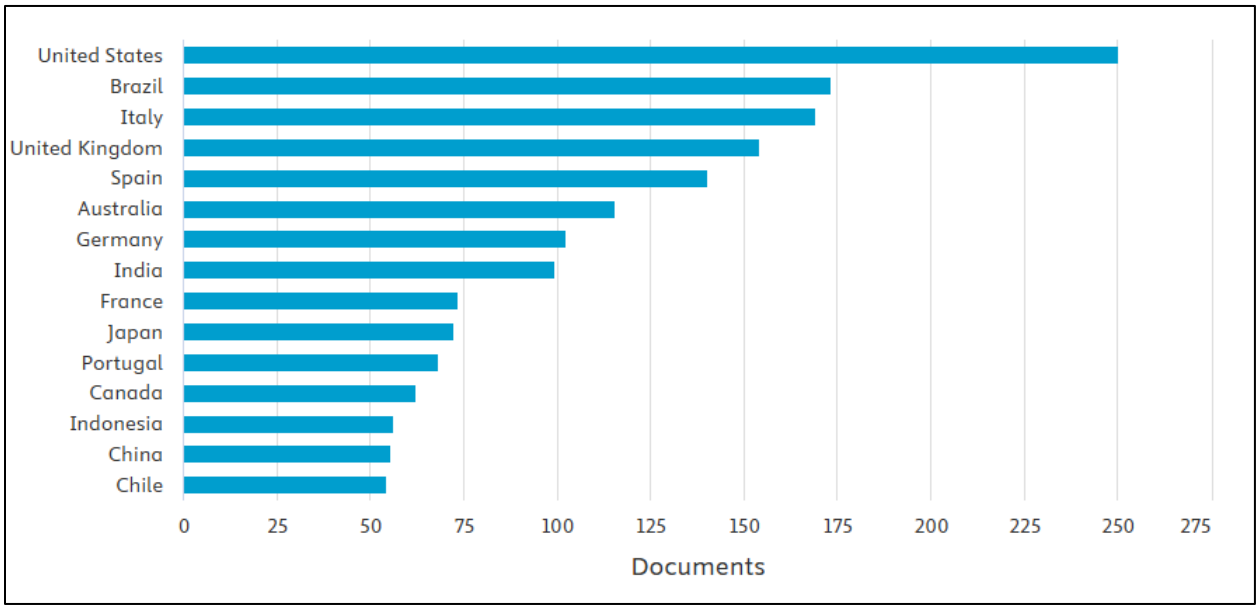


Figure 15. Published articles on beach/coastal marine litter by country of study origin (Top 15 countries only).

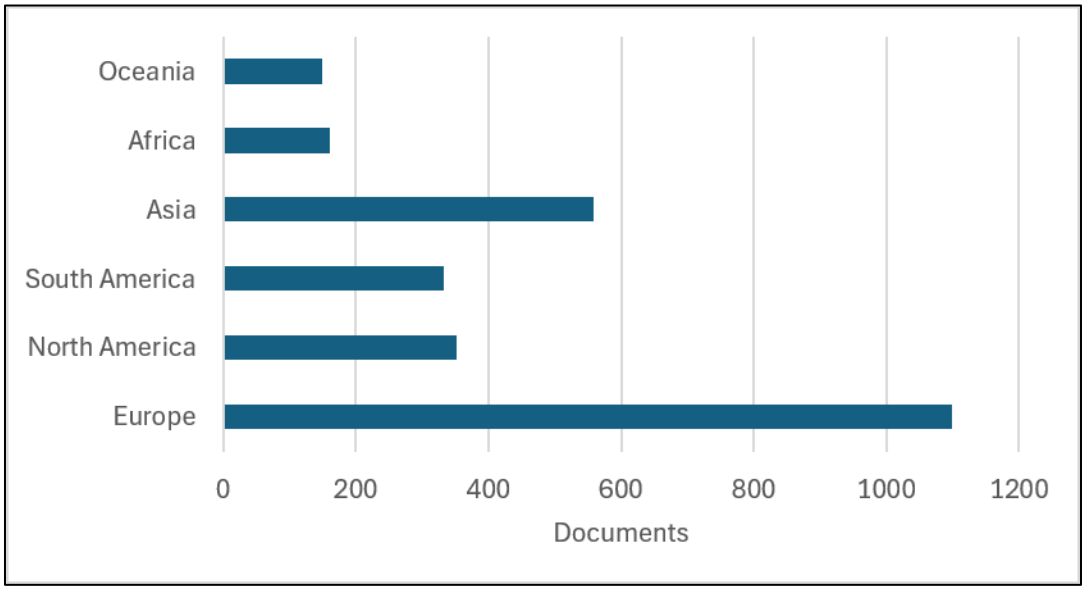


Figure 16. Documents by Continent (2000-2026).

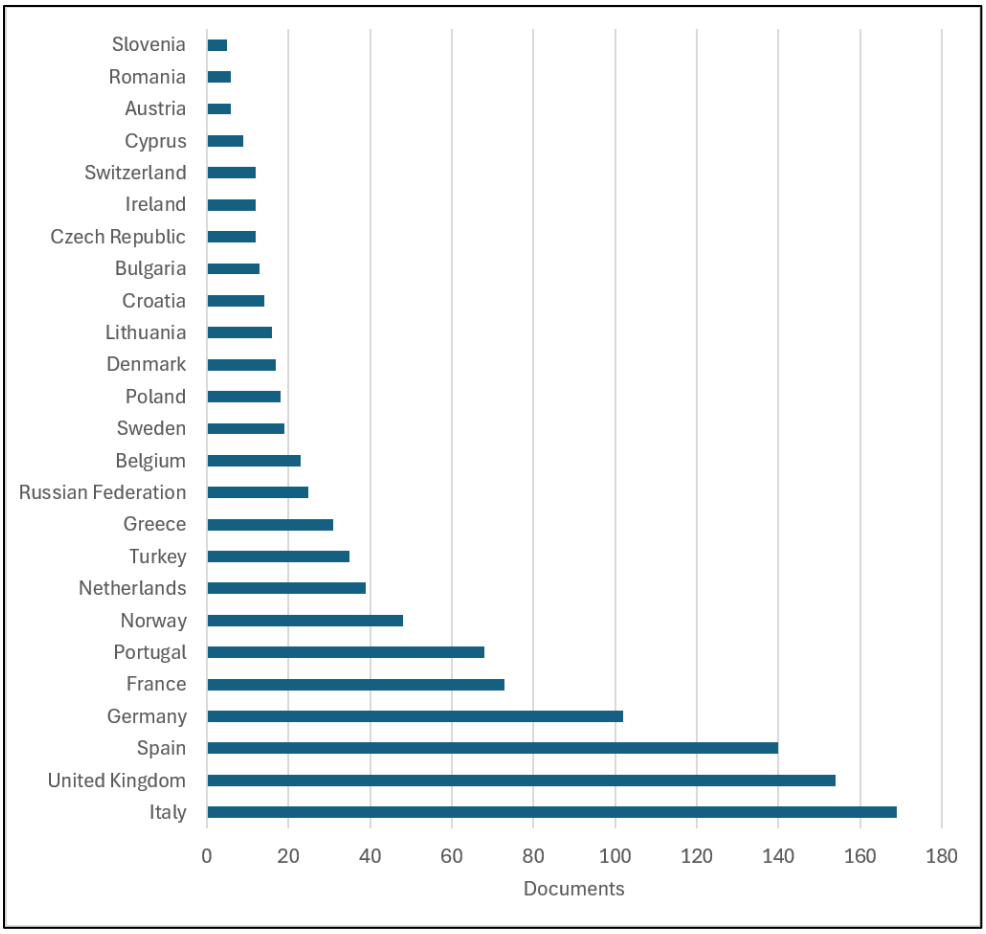


Figure 17. Documents published in European countries (only countries with at least 5 publications shown) (2000-2026).

The titles and abstracts of the papers identified through Scopus were reviewed, and papers that did not fit the scope of this work (i.e. presenting types and quantities of anthropogenic litter) were excluded from further analysis. Each of the remaining papers was reviewed in more detail, and if it was deemed relevant, its main information, including that pertaining to abundance and composition, was summarised in Table 1. In total,157 papers have been analysed. It is possible that some studies were missed. Nonetheless, the table provides a very comprehensive summary of the completed work over the past 26 years.

While the table is extensive, some key points become immediately apparent. Plastic overwhelmingly dominates beach litter worldwide, accounting for 60-97% of all recorded items, across geographic regions, habitat types, and monitoring protocols. While the specific plastic items may vary, single-use consumer plastics are among the most frequently recorded litter items globally. Among these, beverage containers, food packaging, bottle caps, straws, cups and plastic bags are particularly common, especially on urban, recreational and tourist beaches. Importantly, while plastic bags were important contributors to beach litter found around the globe, this type of litter was not among the top 10 identified items in recent research from Europe (e.g. Vlachogianni et al., 2020), suggesting that this is a direct impact of the restrictions imposed by European policy.

Plastic fragments are another litter item category that is abundant on beaches globally. Studies comparing the density of mesoplastics and macroplastics, identified a higher density of mesoplastics, proposing that plastic fragments stem from larger plastic items breaking into smaller pieces (Andreussi et al., 2025; Waluda et al., 2020), highlighting the longevity of plastics in the marine and coastal environments. A 10-year citizen science study on British beaches found that small plastic fragments increased 2.3-fold over the study period (Nelms et al., 2017). Small plastic fragments are ubiquitous around the globe, even reaching remote areas. They represented a significant amount of marine litter collected in Midway Atoll by Ribic et al. (2012) as well as an important amount of marine litter collected (26% of items) during weekly coastal cleanups on the remote Alphonse Island in the Seychelles (Duhec et al., 2015).

Urbanisation has a clear effect on marine litter, with most beaches near urban centres and tourist destinations exhibiting higher litter density. In fact, tourism is a major driver of beach litter. Overall, urban, residential and tourist beaches typically contain higher proportions of consumer-related waste. In contrast, rural and remote beaches tend to contain proportionally more waste that is related to ocean transport, including fishing-related litter.

The impact of human activities is evident in the world's most remote areas. For example, in the northern Antarctic Peninsula, remnants of items such as toothbrushes and sledge dog food bags, dating as far back as 1980, could be found (Lozoya et al., 2026; Anfuso et al., 2020). Numerous studies from remote islands, protected areas and sparsely populated coastlines report substantial litter accumulation, highlighting the importance of long-distance transport by ocean currents and local retention processes (e.g. Cerqueira, 2025; Lozoya et al., 2026; Monràs-Riera et al., 2025). This is further exemplified by litter on uninhabited islands, such as the island of Juan de Nova in the Mozambique Channel, where significant depositions of marine litter, between 0.25 and 29 tonnes, were noted (Jaquemet, 2024).

While it is not the purpose of this study to compare the abundance and composition of marine litter across geographical locations, some general conclusions can be drawn from the analysed data, with the caveat that these are generalisations and that marine litter abundance and composition are affected by a large number of geographical, temporal and socio-economic factors at macro and micro scales. In the coastal areas of the Mediterranean Sea, tourist and urbanised beaches are characterised by high proportions of cigarette butts, food wrappers, plastic bottles and caps. Consumer and tourism-related plastics are the most abundant marine litter items (e.g. Orthodoxou et al., 2022). Fishing gear is present but generally less dominant than in other areas. The enclosed nature of the Mediterranean seems to favour the retention of fragmented plastics. In the Atlantic Ocean, studies often report high proportions of plastic fragments, and there is evidence of long-distance transported litter on remote islands. The reviewed studies also report significant quantities of fishing gear on exposed coastlines and islands (e.g. Herrera et al., 2022). Consumer items remain important near urban centres. Asian studies reported some of the highest litter densities in the dataset, particularly in densely populated coastal regions, estuaries, tourist destinations and mangrove systems. Asian coastlines show a more mixed composition reflecting both population pressure and coastal activities, including fishing and port activities (e.g. Sundaram et al., 2026). High proportions of fishing gear (nets, ropes, floats and lines) have been reported, particularly in Bangladesh, Pakistan and Taiwan. Expanded polystyrene appears more frequently than in many European studies. Single-use, consumer plastics are prominent on Asian coasts as well. The relatively small number of studies from other areas does not allow the deduction of meaningful conclusions. What is evident from the research, however, is that, while relatively recent data suggest that policies might be leading to a decrease in certain types of marine litter, such as plastic bags (e.g. Vlachogianni et al., 2020), there is no sign of an overall decreasing trend in the abundance of marine litter.

Across diverse geographical regions, land-based activities overwhelmingly dominate marine litter inputs to beaches, typically contributing between 70% and 90% of total litter. Recreational activities and improper waste disposal are consistently identified as the primary sources (Andrades et al., 2016; Azman et al., 2021; Das et al., 2025; Hassan et al., 2024; Ilechukwu et al., 2024; Kesavan et al., 2024; Mghili et al., 2024; Rangel-Buitrago, 2025; Terzi & Seyhan, 2017). Cigarette butts and other smoking-related debris represent a major and widespread fraction of beach litter, particularly on recreational beaches, highlighting smoking behaviour as a significant and often underestimated source of coastal pollution (Araújo et al., 2018; Bettencourt et al., 2023; Mghili et al., 2020; Mokos et al., 2019; Munari et al., 2016).

Although land-based sources dominate overall, fisheries and aquaculture are important contributors in regions with intensive maritime activities. Fisheries-related debris often contributes a relatively small proportion of item counts but a disproportionately large share of litter mass due to the size and weight of fishing gear (Das et al., 2025; Fruergaard et al., 2022; Lee et al., 2025; Otley & Ingham, 2003; Ponmani et al., 2024; Raharinaivo et al., 2025; Rangel-Buitrago, 2025; Selvakumar et al., 2024; Van Hoytema et al., 2020).

A study in Kerala, India found that fishing-related litter was four times more abundant on beaches with higher fishing intensity compared to beaches with lower fishing intensity (Daniel et al., 2019). Similarly, an analysis of citizen science data from the United Kingdom, looking at over 1000 beaches, found that fishing-related items make a large proportion of marine litter, particularly in areas adjacent to fishing grounds (Unger & Harrison, 2016). Such items included plastic boxes and crates used for packaging, plastic nets and ropes, and plastic floats.

Some very interesting results emerge from the studies exploring litter accumulation and composition in mangroves. Mangroves function as highly effective litter traps. Some of the highest litter densities in the dataset were recorded in mangrove systems, particularly in Southeast and South Asia. The combination of tidal transport and complex mangrove root structures means that any waste that is transported through tides and storms on mangrove beaches remains trapped there for long periods (Figure 18), making mangroves important hotspots for litter accumulation (Rupasinghe et al., 2025). This is also why litter surveys on mangroves identify larger plastic objects than surveys on beaches (Martin et al., 2019). Mangrove litter composition often reflects the surrounding land use. Mangroves near settlements and urban areas typically contain larger proportions of food packaging, bottles, wrappers and household waste, whereas mangroves associated with fishing communities often contain relatively higher proportions of fishing gear. In fact, fishing-related waste is especially common in mangroves, and includes nets, ropes, buoys, and fishing lines,

reflecting local fisheries activities. The effects of urbanisation are also evident in mangrove ecosystems, with urban mangroves generally accumulating more litter than rural mangroves, as they receive inputs from both terrestrial sources and marine transport pathways (e.g. Ponmani et al., 2024). When studying mangroves in the Red Sea, Martin et al. (2019) found that maritime traffic was a direct source of litter. The abundance and permanence of marine litter in mangrove forests contributes to the degradation of these very important ecosystems, whose ecosystemic services include erosion protection and mitigating against extreme events and sea level rise (Manullang, 2020; Neelavannan, et al., 2025).

Proximity to river estuaries was found to be an important driver of litter accumulation on beaches by several studies (e.g. Andrades et al., 2020; Terzi et al., 2025). In Cambodia, rivers have been found to be significant litter sources (Roman et al., 2024), in India increase in plastic items on a monitored beach coincided with the maximum river discharge (Sulochanan et al., 2019), and illegal dumping in riverine ecosystems, as a result of inadequate waste management services, was also identified as a source of marine litter in Costa Rica (Damian et al., 2022). On the Turkish Black Sea Coast, river runoff contributed over 20% of the identified litter (Bat et al., 2022). In China, during a study looking at 24 sites in 16 coastal cities, the litter density near the Yangtze Estuary was four times greater than the mean density across sites (Chen et al., 2020).

Importantly, several studies revealed the impact of waste management practices, whether formal or informal, on coastal marine litter. For example, Pama et al. (2026) showed that the density of macroplastics along mangrove areas in the Philippines was lower in tourist areas than in community (urbanised) areas, and this difference was due to the waste management practices implemented in tourist sites. De Veer et al. (2023), who analysed citizen science data from cleanups along 12,000 km of the East Pacific coast, covering several countries, noted that while GDP per capita did not influence total marine litter densities, plastic densities were significantly greater on beaches in countries with low GDP per capita. This difference was attributed to inefficient waste management and lack of enforcement of relevant regulations. In Europe, particularly in Portugal, low municipality expenditure in waste treatment was significantly related to high quantity and large variety of beach litter (Iglesias et al., 2023). However, even in areas where waste management services are available, the high influx and concentration of tourists can overwhelm the waste management system and result in littering (Akarsu et al., 2022).

Seasonal variability is a consistent feature of beach litter accumulation, but the timing of peak accumulation depends on local drivers such as tourism intensity, rainfall patterns, hydrodynamic conditions, and beach characteristics rather than season alone (Bouzekry et al., 2022; Mghili et al., 2024; Ribeiro et al., 2025; Silva

et al., 2018; Yang et al., 2023; Yenici & Turkoglu, 2023). Rainfall-driven transport is one of the most consistent global drivers of beach litter accumulation. Increased runoff, river discharge, and flooding transport land-based waste to coastal environments, often producing higher litter densities during wet seasons (Cordova et al., 2022; Duong et al., 2025; Fadare et al., 2022; Hassan et al., 2024; Salazar et al., 2022; Suteja et al., 2021; Weideman et al., 2020). Tourism is a major seasonal driver of beach litter accumulation and can amplify seasonal patterns independently of environmental factors (Bouzekry et al., 2022; Kasa et al., 2025; Silva et al., 2018; Yenici & Turkoglu, 2023).

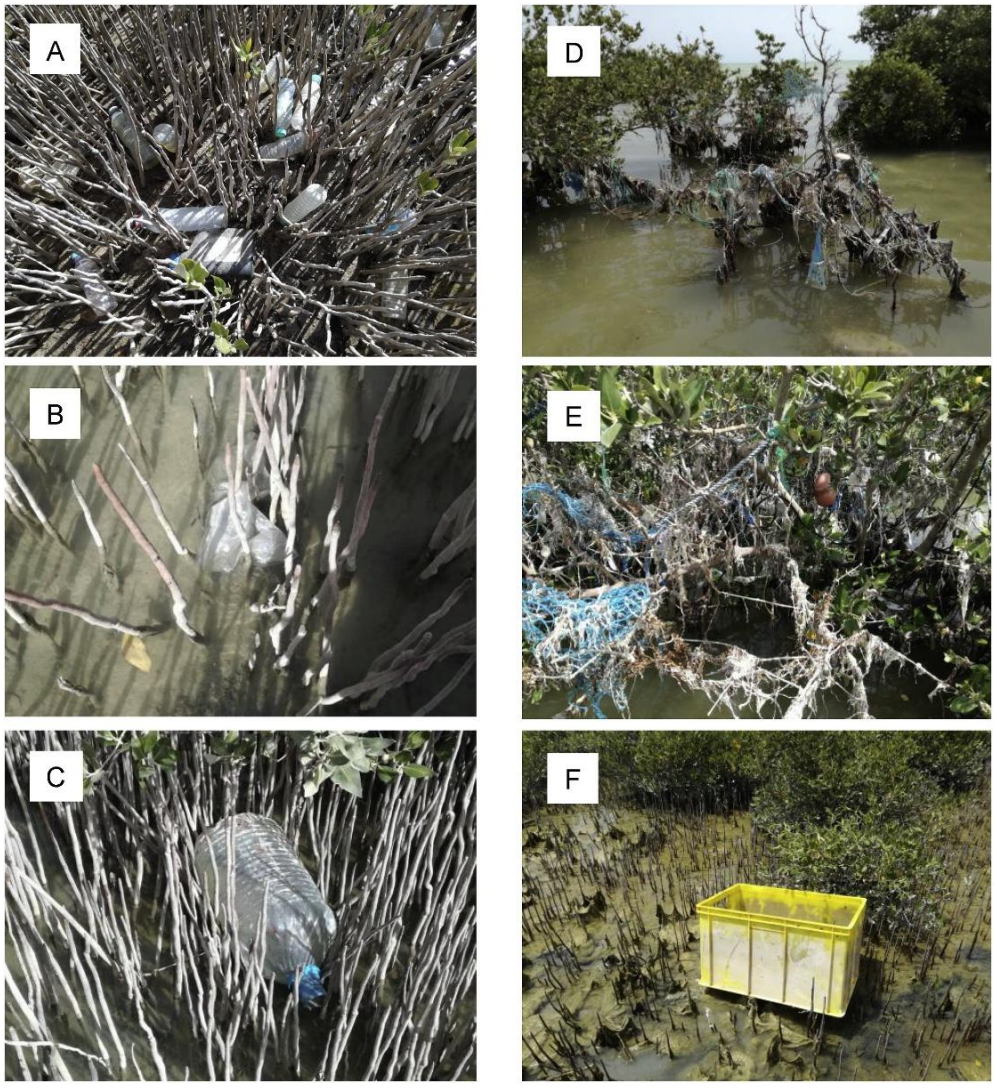


Figure 18. Photographs showing litter trapped in the aerial roots of mangroves (from Martin et al., 2019).

A closer examination of the table reveals that the methods used to assess marine litter are not directly comparable. Some studies present the results from standing stock surveys, while others examined accumulation rates. In general, standing stock surveys report higher litter densities because they measure all accumulated litter present at the time of sampling. In some cases, this is from very remote sites that might not have been sampled before. Accumulation surveys, used to estimate litter inputs over a predefined period, generally show lower densities. However, even within studies that had the same aim the monitoring protocols used varied widely. For example, some implemented standardised protocols looking at specific stretches of beach; others used protocols available in previous research; others still used data from citizen scientists and volunteers, where the exact protocols were either not known or not controlled. Furthermore, while most studies focused on surface litter, some studies included buried litter as well, which substantially increases the litter abundance, even up to 25 or 26 times (Lavers et al., 2019; Tavares et al., 2020). In conclusion, differences in reporting units and survey protocols can complicate direct comparisons among studies. Nonetheless, the dominant litter categories identified are generally consistent, regardless of the methodologies employed. What significantly alters the abundance of litter is whether this is collected from the surface only, or whether buried litter is also collected.

Within Table 1, reference is made to several protocols that have been used for marine litter monitoring. For clarity, these are summarised here:

- OSPAR refers to the guidelines developed by the OSPAR (Oslo and Paris Conventions) Commission. Details can be found in OSPAR Commission, 2010.
- MSFD refers to the guidance developed by the Marine Strategy Framework Directive (MSFD) Technical Group on Marine Litter. Details can be found in Galgani et al., 2010.
- NOAA refers to the guidelines for the monitoring and assessment of marine litter developed by the National Oceanic and Atmospheric Administration (NOAA). Details are available in Burgess et al., 2021.
- GESAMP refers to the guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean developed by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), established by the United Nations. Details in GESAMP, 2019.
- UNEP/IOC refers to the guidelines on survey and monitoring of marine litter developed by the United Nations Environment Programme (UNEP) and the Intergovernmental Oceanographic Commission

(IOC) of United Nations Educational, Scientific and Cultural Organisation (UNESCO). Details are available in Cheshire et al., 2009.

- Ocean Conservancy refers to the guidelines protocol developed by this organisation, and which are available here https://oceanconservancy.org/wp-content/uploads/2025/04/Beach-Cleanup-Guidelines_SDG14.pdf
- CSIRO refers to the guidelines developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia. Details can be found in Hardesty et al., 2026.
- CCAMLR refers to the guidelines developed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Details can be found here https://www.ccamlr.org/en/node/75828.
- SEACleaner protocol refers to the guidelines developed by the SEACleaner educational and citizen science project. Details are available in Locritani et al., 2019.
- Litter Scientists refers to the citizen science project Cientificos de la Basura. Details are available here: https://cientificosdelabasura.ucn.cl/.

Table 1. Abundance and composition of marine litter on beaches and mangroves as reported in literature from 2000 to 2026.

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Acksen et al., 2026	2023 (May-July)	São Vicente, Cabo Verde, Africa	Short-term (every 4 days, May-July)	6 beaches	OSPAR	0.05 ± 0.06 items/m^2/d	Plastic (83%), wood (5%), glass (4%)
Sundaram et al., 2026	2025	Southern Tamil Nadu coast, India	Standing stock	40 beaches	Manual collection of items> 2.5 cm from areas of 100m^2	3.41 ± 0.24 items/m^2	Plastics 19.44 ± 0.69 items/m^2, wood (15.64 ± 1.74 items/m^2), textile (15.85 ± 1.52 items/m^2)
Pama et al., 2026	2023	Suyac Island, Negros Occidental, Philippines	Standing stock	4 mangrove sites (tourist, pristine, community, channel)	Transects 10×10m quadrats	0.02-0.22 items/m^2 Tourist: 0.02±0.02; Community: 0.22±0.01; Pristine: 0.15±0.03; Channel: 0.11±0.03	Rope/nylon/wires (24%), fishing nets (24%), food packaging and wrappers (17%), cellophane (10%), plastic fragments (10%), plastic bottles (8%), other macroplastics (7%)
Lozoya et al., 2026	2023	Bahía Esperanza/Hope Bay, Trinidad/Trinity Peninsula, Antarctica	Standing stock	3 locations, 85 sampling points	Transect sampling	0.29 items/m^2	'Other plastics' (43.2%), primarily composed of plastic fragments, other rubber (23.1%), wire (10.3%), plastic utensils (6.5%), Styrofoam (4.3%), cups, lids, straws (3.4%), bags, pieces of bag (2.3%), others remaining %.
Savva et al., 2026	2020-2021	Cyprus, eastern Mediterranean	Standing stock	23 caves	MSFD and UNEP classification	0.044 items/ m^2 - 96.839 items/m^2. Mean: 12.894 items/m^2	Polystyrene pieces (30%), Plastic pieces (27%), Plastic film (9%)
Brabo et al., 2026	2022-2023	Jericoacoara National Park, northeast Brazil	Daily accumulation rates	1 touristic beach	50 m transects,	1.77 items.m^{-1}.day^{-1}	Cigarette butts (0.95 items.m^{-1}.day^{-1}), metals (0.24 items.m^{-1}.day^{-1}), paper (0.20 items.m^{-1}.day^{-1}), hard plastics (0.16

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					3 zones on beach		items.m^{-1}.day^{-1}), flexible plastics (0.13 items.m^{-1}.day^{-1}).
Ribeiro et al., 2025	2023-2024	Gravatá Beach, Santa Catarina state, Brazil	Seasonal	Non-urbanised and isolated beach	3 areas, 3 transects per area	0.14 items/m^2	Plastic fragments (dominant), fishing gear, pellets and packaging (significant)
Rupasinghe et al., 2025	2024	Sri Lanka	Monthly from March to June	4 mangrove sites around Sri Lanka	3 transects (50m x 2m)	0.47–0.87 items/m^2 (average: 0.66 items/m^2)	Plastics (60%), unclassified (19%), pharmaceuticals (8%), glass (4%), paper (3%), rubber (2%), cloth (3%), metal (1%)
Rangel-Buitrago, 2025	n.a.	Central Caribbean coast of Colombia	Standing stock	8 remote coastal sites, 76km stretch	Five fixed quadrants (2x2m) per site, OSPAR classification	60.34 items/m^2	90% land-based: Shoreline and recreational, including plastic bottles, footwear, food wrappers, caps, cigarette lighters (66%), waste and dumping including bottle caps, plastic bag fragments, cleaning product containers (17%), dumping related materials (2%). 10% ocean-based of which mostly fishing-related and ALDFG.
Neelavannan et al., 2025	2023	Saudi Arabian coast, western Gulf	Standing stock	6 mangrove forests	20 x 20m	1.4 ± 0.61 items/m^2	Plastics (80.05%), timber/processed woods (5.37%), tetra pack (3.05%), rubber (2.12%), glass/ceramics (2.05%), metal (1.92%), textile/fabrics (1.66%), footwear (1.39%), leather (1.06%), sanitary (0.66%) and medical items (0.66%). Most abundant plastics: lightweight single-use bags, drink bottles, bottle caps, fragments, Styrofoam, rope/line, tetra pak, fishing net.
Bastami et al., 2025	2023	South Caspian Sea, Iran	Summer and winter sampling	10 beaches	3 transects per beach, 50 x 10 m	Summer: 0.18 to 0.84 items/m^2	Summer: plastics (60.35%), paper (18.19%), metal (2.51%).

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						Winter: 0.17 to 1.04 items/m^2	Winter: plastic (60.82%), paper (17.56%), metal (2.91%)
Nisanth et al., 2025	2023	Lakshadweep islands, Indian Ocean	Standing stock	6 islands - inhabited and uninhabited	6 × 100 m (600 m^2) transects, NOAA	0.90 ± 0.44 items/m^2	82.9% plastics, with plastic beverage bottles (24%), food wrappers (13.2%), caps (9.5%) being most common
Terzi et al., 2025	2024	Turkish Black Sea	Standing stock	37 stations (urban, semi-urban, rural)	10 x 100 m	0.80 ± 0.07 items/m^2	Plastics (88.2%), mostly single-use plastics, including cigarette butts, food wrappers and bottle caps
Duong et al., 2025	2022-2023	Central Vietnam	Seasonal	9 beaches, 21 sampling sits	OSPAR	0.086 ± 0.056 items/m^2	Plastics dominated at 96.48%, followed by rubber (2.02%) and paper (1.10%)
Savva et al., 2025	2014-2018	Cyprus	Repeated (not regular) in summer	5 sites, several cleanups per site	Ocean Conservancy	0.37 items/m^2	Cigarette butts (24%), plastic pieces (22%), plastic bottle caps (8%), plastic bottles (7%), glass pieces (3.6%), cans (3.2%), confetti (2.7%), wet wipes (2.1%), food wrappers (1.9%), foam pieces (1.8%)
Monràs-Riera et al., 2025	n.a.	West Antarctic Peninsula	Standing stock	8 beaches along West Antarctic Peninsula, 13 beaches on Livingston Island, 10 beaches on Deception Island	3 transects per beach	WAP total: 9.94×10^{-1} items m^{-2} Livingston Island: 1.23×10^{-2} items m^{-2} Deception Island: 1.08×10^{-2} items m^{-2}	68.4% plastics, plus wood, metal, glass, paper, and ceramics
Cerqueira, 2025	2022-2024	Gafanha da Boa Hora Beach, Portugal	Seasonal (4x/year)	Rural sandy beach - located outside	OSPAR	777 items/ 100m	83.6% plastic & polystyrene, 9.2% ceramic, 2.8% sanitary waste, 1.5% wood, 0.7% glass. Top items were plastic fragments (0-2.5cm and

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				urban/village environment			2.5-50cm), string/cord from fishing, and expanded clay pebbles
Lumilan et al., 2025	2024	Isabel and Merida, Leyte, Philippines	Standing stock	11 residential sites, 5 non-residential sites	4 quadrants in 100m transects	Macroplastics: 0.37 items/m^2 (residential), 0.30 items/m^2 (non-residential) Mesoplastics: 3.52 items/m^2 (residential), 2 items/m^2 (non-residential)	Macroplastics: sando bags (26.69%), food packaging, ropes and nylon (67% combined) Mesoplastics: Fragments (50%), films, fibres; white (29%), green (29%), blue (18%); polypropylene (34%)
Das et al., 2025	2024	Goa coast, Eastern Arabian Sea, India	Standing stock	7 sites – urban settlements, islands, and estuarine locations. Mangroves	Belt transects: 20m × 1m	5.14 ± 0.55 items/m^2	Plastic (66.26%), Tetra packs (9.12%), glass (6.33%), Footwear (3.44%)
Edward et al., 2025	n.a.	Tamil Nadu, India	Standing stock	52 fishing-dominant villages across 13 districts	NOAA standing stock survey	1.14 items/m^2	ALDFG (47.46%: fishing ropes (65.85%), floats (21.45%), nets (9.84%)), plastic (39.64%), non-plastic (12.9%). Of plastics: food wrappers (18.25%), beverage bottles (9.94%), plastic containers (7.81%), bottle caps (25.1%), plastic fragments (6.5%), plastic bags (12.13%), plastic cups (11.82%), straws (1.14%), syringes (3.11%), napkins/masks (1%). Non-plastics: paper and cardboard (29.3%), glass beverage bottles (28.6%), clothing and shoes (23.03%), glass fragments (14.56%)
Raharinaivo et al., 2025	2021-2022	Southwestern Madagascar	Seasonal (wet/dry)	3 sites (1 urban, 2 rural, incl. mangroves)	Standing-stock survey (initial	Beaches: 0.17 items/m^2	Beaches: 54.08% plastics, 21.68% processed woods, 13.84% clothes, and 8.69% rubbers

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					collection) and accumulation survey (10 consecutive days)	Mangroves: 0.04 items/m^2	Mangroves: 87.30%, clothes 7.89%, with processed wood and rubber each under 3%
Kiruba-Sankar et al., 2025	2024	South Andaman mangroves, Andaman and Nicobar Islands, Bay of Bengal	Standing stock	20 mangrove sites	50 quadrats per site (1x1m)	23.4 items/m^2	PET bottles (18.2%), tetra pack (18.1%), polythene bag (9.0%), disposable plate (7.7%), disposable cup (8.4%), glass bottle (8.4%), plastic cap (6.9%), cigarette lighter (5.0%), beverage can (4.7%), floaters (3%), fishing net (2.8%), plastic rope (2.7%), plastic buoy (1.5%), jerry can (1.5%), other.
Lee et al., 2025	2009-2018	Taiwan	Monitoring	20 counties	n.a.	n.a.	Plastic products (44%). Specifically, caps/lids (12.3%), PET bottles (11.04%), plastic bags (11.82%), other beverage bottles and food containers (4.56%), non-food bottles and containers (2.14%), and food wrappers/containers (2,41%). Disposable items (22%). Specifically, straws (8.63%), takeaway cups (4.77%), disposable tableware (4.77%). ALDFG (14%). Specifically, fishing buoys (8.49%), fishing nets and ropes (3.59%), gears (2.32%). Glass (6.90%), tetra pak (1.29%), tin and aluminium cans (1.48%), cigarettes (7.02%), cigarette lighters (1.99%), other.
Kasa et al., 2025	2023 - 2024	Visakhapatnam city, Bay of Bengal coast, Andhra Pradesh, India	Seasonal (before/after monsoon)	12 sites, tourist and non-tourist	NOAA	2.66 ± 0.31 items m^{-2} before monsoon, 2.03 ± 0.29 items m^{-2} after monsoon	Before monsoon: plastic items (81.74%), “others” (6.41%), fishing gear (3.97%), paper and lumber (2.63 %). Among plastic items, plastic film (28.14%), plastic hard fragments (16.40%) and foam fragments

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							(14.56 %) items, followed by plastic food wraps (9.44%). After monsoon: plastic items (86.35%), paper and lumber items (7.83%), "others" (2.25 %), metal (1.11 %). Among plastic items, plastic food wraps (28.41 %), plastic film (19.24 %), foam fragments (13.37 %), and plastic bottle caps (11.26 %).
Kausar et al., 2025	2024	Karachi, Pakistan	Standing stock	2 beaches, Sandpit beach and Clifton beach	20 sampling sites. Quadrats of 150 x 10 m at 300m intervals	n.a.	Sandpit beach: entangled debris (51%), plastic (21%), wood (11.5%), packaging waste (9%), sponges (4%), glass (1.5%), others (2%). Clifton Beach: plastic waste (47.33%), styrofoam (19.86%), wood (13.74%), hospital waste (9.16%), glass (3.85%), others (6.06%).
Syamsuddin et al., 2025	2024	Prigi Bay, Trenggalek, Indonesia	3 repetitions to assess differences between weekdays and weekends	4 recreational beaches	5×5 m quadrat transect method placed at 20 m intervals	1.57±0.29 items/m^2 on weekdays and 1.93±0.38 items/m^2 on weekends	Weekdays: plastic (88%), paper (4%), other materials (3%), rubber (2%), and hazardous waste (2%). Weekends: plastic (81%), paper (7%), other materials (4%), wood (3%), rubber (2%), and hazardous waste (2%). Plastics included ropes, cutlery, straws, cigarette butts, styrofoam, packaging, and other miscellaneous items.
Andreussi et al., 2025	2018-2020	Joaquina Beach, Santa Catarina Island, southern Brazil	Monthly (18 months)	Touristic	GESAMP	Macroplastics: 0.32 items m^{-2} Mesoplastics: 2.18 items m^{-2}	Macroplastics: cigarette butts (27%), fragments (18%), packaging (18%), bottle caps (6%), fishing ropes (5%), plastic foam (6%), lollipop sticks (5%), straws (3%) and others (16%) Mesoplastics: fragments (70%), plastic foam (24%), fishing lines (2%), straws (1%), packaging (1%) and others (2%)

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Suteja et al., 2024	2022	Padang City, West Sumatera Province, Indonesia	Field sampling conducted at least twice at each beach with one to three-day intervals	5 tourist beaches	three duplicated 25 m x 2 m (50 m^2) transects	3.37 ± 2.52 items/m^2	Plastic/rubber (66.88%), metal (0.16%), Glass (0.30%), Fabric (0.32%), Other categories (0.75%). Lumber/paper dominated by weight (no info on density). Within plastics: food/beverage related items (e.g. straws, plastic bags, plastic lids, cups, food containers/utensils) (66.61%), fishing-related items (0.24%)
Pasternak, 2024	2020-2023	Eilat (Israel) in the Gulf of Aqaba, Red Sea	Seasonal	2 beaches, mild tourism	MSFD	6.37 ± 1.5 items/100m^2	Plastics (83%), metal (9%), paper & cardboard (3%), wood (2%), cloth (1%), glass & ceramic (1%), rubber (1%). Top items: cigarette butts (54%), tent-related (12%), bottle caps (11%), single-use plastic tableware (4%), food packaging (2.5%), other (16%)
Ponmani et al., 2024	2023-2024	Tuticorin coast, Gulf of Mannar, Southeast Coast of India	Standing stock	7 mangrove patches	20x2m transects, 5 transects per patch	1.3-23.2 items/m^2 (mean: 6.3 ± 1.9 items/m^2)	81.3% plastics, 8.97% cloth/fabric, 2.5% wood, 2.2% glass, 1.9% metals
Ribeiro et al., 2024	2022-2023	Perequê beach, Guarujá, southeastern Brazil	Seasonal	10 locations	10x10m	0.64 ± 0.72 items.m^{-2}	Plastic: 44.6-50.9%; Cigarette butts: 20.6-28.4%; Concrete: 3.4-10.5%; paper/cardboard (5.7–5.9 %), others (2.8–3.0 %), metal (2.1–2.9 %), glass (1.3–1.5 %), processed wood (0.8–3.7 %), and cloth/textile (0.4–1.0 %)
Gacutan et al., 2024	2014-2019	Australia (including the island of Tazmania)	n.a.	3144 events across 538 sites	n.a.	0.155-0.279 items/m^2	n.a.

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Roman et al., 2024	2022-2023	Cambodia	n.a.	243 coastal, river and inland sites	3-6 transects per site	6.8 ± 0.7 items/m^2	Whole items: water bottles (16.0 %), other bottles (10.8 %), thin film carry bags (8.9 %). Fragment items: polystyrene (17.9 %), food containers (12.2 %), thin film carry bags (9.8 %)
Fetisov et al., 2024	2019-2023	Southeastern Baltic Sea, Sambian Peninsula shores	OSPAR monthly. Observations after storms.	8 sampling locations	OSPAR method (fine-weather conditions) Modified frame method (post-storm conditions)	Fine weather: 0.15 ± 0.01 items/m^2 Post-storm: 2.48 ± 1.61 items/m^2	77% plastic debris of total anthropogenic items, 97% plastic in post-storm samples
Selvakumar et al., 2024	2022	Northern coast of Jaffna, Sri Lanka	Twice a month between May and July	4 sites close to tourism-based beaches and fishing ports	OSPAR & NOAA	1.71 ± 0.42 items/m^2	Main plastics: plastic bottles (16.19%), food wrappers (2.49%), plastic ropes and net pieces (23.19%), Styrofoam (14.19%), personal care products (4.70%) bottle caps (12.96%), cups (1.54%) plastic fragments (16.68%), buoys (1.41%), cigarette lighters (1.52%) bags (3.01%) Cigarette butts (0.36%), straws (0.67%), plastic utensils (0.75%), jugs (0.33%)
Robbe et al., 2024	2021-2023	Morocco, Tunisia, Egypt	n.a.	16 cleanups	UNEP/IOC (but 60m instead of 100m)	Tunisia: 0.69 items/m^2 Morocco: 0.82 items/m^2 Egypt: 2.70 items/m^2	Morocco: 27.7% SUPs, 72.3% other litter. Of SUPs: crisp packets/wrappers (8.0%), cigarette butts/filters (5.3%), plastic caps/lids (3.2%), lolly sticks (2.0%), cotton bud sticks (1.9%). Tunisia: 32,4% SUPs, 67.6% others. Of SUPs: plastic bags (11.5%), cigarette butts/filters

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							(7.8%), crisp packets/wrappers (4.1%), drink bottles (2.3%), plastic caps/lids (2.2%). Egypt: 48.1% SUPs, 51.9% others. Of SUPs: cigarette butts/filters (18.2%), plastic bags (9.0%), crisp packets/wrappers (8.6%), straws/stirrers (3.1%), plastic caps/lids (2.9%).
Monchanin et al., 2024	2022-2023	Koh Mun Nai island, eastern Gulf of Thailand, Rayong province	Weekly surveys	5 sandy beaches	7x3m quadrats, 3 quadrats/site	3.18 ± 11.39 items/m^2	Plastic (48%), foam/polystyrene (31%), fishing gear (11%), glass (6%), rubber/latex (2%), medical (1%), metal (1%), others (0.3%)
Jokar et al., 2024	2022-2023	Northern coasts of Persian Gulf, Bushehr province, Iran	Seasonal (fall/winter)	19 stations (30 m x 3 m)	n.a.	1.75 items/m^2	Macroplastics only. Mugs (18%), bags (16%), bottle caps (13%), others (13%), ropes (7%), tissues (6%), cutlery (5%), straws (5%), bottles (5%), nets (2%), gloves (1%), pampers (1%).
Salinas et al., 2024	2021	Punta Arenas, Strait of Magellan, Chile	Standing stock	Urban sandy beach	OSPAR 24 transects, 3x3m quadrats each	0.1-1.3 items/m^2 (average 0.50 ± 0.37	Plastic/Polystyrene (37.5%), Glass (25.9%), Metal (9.6%), Cloth (8.2%), smoking related (7.1%), pottery/ceramics (4.2%), faeces (2.7%), wood (2.2%), rubber (1.7%), sanitary waste (0.6%), other (0.5%)
Kesavan et al., 2024	2022-2023	Point Calimere Wetland, southeastern coast of India, adjacent to Bay of Bengal	Standing stock	Rural wetland area including sandy shores, mud flats, and islands with low tourism activity	15 line transects (50m × 5m each)	1.23 ± 1.17 items/m^2	Plastic: 62.73%. Specifically: rope/small net pieces (24.18%), carry bags (22.19%), food wrappers (18.93%), cups (8.79%), buoys/floats (6.07&), bottle/container caps (4.26%), beverage bottles (4.08%), plastic utensils (3.17%), personal care products (2.54%), other jugs/containers (2.26%). Cloth/fabric: 12.33%. Other materials: Metal, glass, rubber, lumber in smaller proportions

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Soliveres et al., 2024	2011-2020	Spain	Systematic collection	881 beaches (urban, semi-urban or isolated)	OSPAR or Spanish Ministry standard	803 items/100 m	Cigarette butts, plastics <2.5cm, caps and wrappers (>50%), bottles, ropes, glass pieces, straws, plastic bags, swabs, cans, nets, building materials, glass bottles, wet wipes, cosmetics (remaining)
Mghili et al., 2024	2023	Morocco	2 surveys (spring/summer)	29 Moroccan beaches (17 Mediterranean, 12 Atlantic)	MSFD	0.31 items/m^2	78.70% artificial polymer materials, 7.88% processed/worked wood, 6.22% paper/cardboard, 2.66% metal, 1.37% cloth/textile, 0.34% rubber. Top 10 items in Mediterranean sites: crisps packets/sweets wrappers, other wood >50cm, plastic caps/lids, cigarette butts, plastic/polystyrene pieces, and small plastic bags. Top10 items in Atlantic: cigarette butts, plastic caps/lids, crisps packets/sweets, other wood<50cm, drink bottles <0.5l.
Ilechukwu et al., 2024	2023	Okinawa Island, Japan	Standing stock	30 beaches (urban, semi-urban, rural)	OSPAR and NOAA	0.005-0.38 items/m2 (average: 0.13 ± 0.10 items/m2)	Plastics: 81.72%. Glass/ceramics: 8.38%, Cigarette butts: 7.44%, metal (1.11%), wood (0.65%)
Hassan et al., 2024	2021-2022	Liido Beach, Mogadishu coastal area, Somalia	Monthly	1 beach	OSPAR	2.19- 14.18 items/m2 (mean: 6.25 items/m2)	Plastics (89.47%), clothing items (7.53%), and others (3.00%). Most frequent plastics: plastic bottles and containers (13.90%), shopping bags (11.70%), shoes/sandals (8.50%), crisp/sweet packets and lolly sticks (8.30%), and caps and lids (7.70%), plastic/polystyrene pieces of 0–2.5 cm (5.30%), plastic bag ends (5.10%), foam sponges (4.60%), food containers including fast food containers (4.60%), cutlery/trays/straws

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							(4.50%), toys and party poppers (4.00%), plastic cleaner bottles and containers (3.70%).
Pradhan et al., 2024	n.a.	Rushikulya River mouth beaches, Odisha coast, east coast of India	Standing stock	400km stretch of beach	UNEP/IOC	11-270 items/400m^2	63.5% plastic items, followed by thermocol, and food wrappers/containers. Dominant items: plastic bags, bottles, thermocol, and bottle caps
Suhail et al., 2024	n.a.	Manora and Sandpit beaches, Karachi, Pakistan	2 x per month for 6 months	2 touristic beaches. 24 transects, 100 x 25m	OSPAR	57.5 ± 44.17 plastic items 100 m^{-1}	Only assessed plastics. Branded plastic (36%), unbranded plastic (31%), Styrofoam (10.7%), unrecognisable plastic (6.88%), plastic cups (4.8%), plastic ropes (4.71%), plastic caps (1.88%) > plastic straw (1.81%) > plastic bottles (1.3%) > plastic fishing nets (0.43%)
Jaquemet, 2024	2007	Juan de Nova island, central Mozambique Channel	Standing stock and daily accumulation rates (12 consecutive days)	1 beach on an isolated and uninhabited island	200 x 25m	Standing stock: 7 items/100m Accumulation rate: 0.5-42.5 items/100m/day	99.8% plastics, remaining aluminium. Main plastic litter items: plastic fragments (up to 10cm) (78.6%), plastic fishing nets and ropes (5%), plastic caps (4.8%), plastic strapping bands (2.8%), plastic containers (1/6%), plastic flip-flops (1.6%).
Kannan et al., 2023	2021-2022	Cuddalore coast, Southeast coast of India	Seasonal plastic litter survey during summer 2021 (lockdown period) and post-monsoon 2022 (post-lockdown period)	4 sandy beaches (fishing, tourism, recreational and industrial activities)	NOAA	Summer 2021: 0.65 items/m^2 Post-monsoon 2022: 2.04 items/m^2	21 different types of plastic debris: straws, cutlery, polybags, food & snacks pouches, plastic cups, water bottles, bottle caps & corks, HDPE bottles, personal care waste, nylon ropes, fishing nets & ropes, buoys & floaters, foam floaters, thermocol, plastic plates, foam plates, cement bags, milk pockets, shampoo pockets, food wares, and fragments
Currie et al., 2023	2017, 2020-2021	Maui, Hawai'i	Daily accumulation	2 beaches	NOAA	2020: 2.5 and 15.2 items/100 m/day	Main litter categories in decreasing abundance: plastic fragments, Styrofoam, paper, cigarette

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			surveys, conducted once a week			2021: 60.2 and 16.5 items/100 m/day	butts, glass fragments, bottle caps, food wrappers, clothing or shoes, fishing gear, others
De et al., 2023	2022	Central West coast of India, Eastern Arabian Sea	Standing stock	7 mangrove stands: 3 near megacity Mumbai, 2 peri-urban, 2 rural	20m × 2m belt transects (n=3 per site)	Mean 8.5 ± 1.9 items/m^2 (range: 1.4-26.9 items/m^2)	Plastics (83.02%), fabrics (6.87 %), glass (2.58 %), footwear (2.17 %), metal (1.97 %), tetra pack (1.13 %), processed woods (0.81 %), rubbers (0.32 %), and leather items (0.2 %).
De Veer et al., 2023	2021	East Pacific Coast: Mexico, Guatemala, El Salvador, Costa Rica, Panama, Colombia, Ecuador, Peru, and Chile	Standing stock	130 sandy beaches with varying urbanisation levels	Citizen science. 6 quadrat stations, 3x3m	Mean: 0.46-2.26 items/m^2 Mexico: 0.95 ± 0.59 items/m^2 Guatemala: 1.6 ± 2.70 items/m^2 El Salvador: 1.65 items/m^2 Costa Rica: 2.0 ± 3.27 items/m^2 Panama: 0.46 ± 0.28 items/m^2 Colombia: 2.26 ± 2.30 items/m^2 Ecuador: 1.1 ± 1.74 items/m^2 Peru: 1.14 ± 0.86 items/m^2 Chile: 1.27 ± 1.31 items/m^2	62.9 % plastic, 9.9 % cigarette butts, 9.2 % processed wood, 4.4 % paper, 3.9 % metal, 2.7 % glass, 0.5 % face masks, 6.5 % other items

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Inteca et al., 2023	2019-2020	North and South Mozambique	Daily accumulation rates, seasonal	6 beaches	500m transects	0.067 to 1.85 items/m/day	Plastics (60.1%), clothing (20.4%), foam objects (15.7%), glass (4.3%), rubber (1.7%), wood (1.6%), metal (1.3%), paper and cardboard (1.1%), hygiene items (1.1%), construction material and ceramics (0.6%).
Bettencourt et al., 2023	2020-2022	Funchal, Madeira Island, Portugal	Seasonal (4 annual surveys) for 2 years	2 beaches (one urban, one near port)	OSPAR	0.29 items/m^2	cigarette butts (30.9%), plastic objects (30.7%), paper/cardboard (e.g., chewing gum wrappers, cigarette packs, labels (especially from beer), invoices/receipts, straws, and scratch cards) (9.2%), metal items (8.3%).
Aranoco et al., 2023	2023	Mabini Protected Landscape and Seascape, Davao de Oro, Philippines	non-consecutively for six days	4 beaches (2 rocky, 2 sandy)	30x4m transects	0.91 ± 0.51 items/m^2 Rocky beaches: 1.38 ± 0.52 items/m^2, Sandy beaches: 0.45 ± 0.11 items/m^2	Plastics (82.22%), glass (7.07%), wood (3.42%), rubber (3.30%), metal (2.39%), cloth (1.44%). Predominant plastic litter: plastic fragments (37.32%), food packaging (18.24%), foamed fragments (11.22%), ropes and nylons (9.98%), cigarette butts (6.70%), bottles (4.57%), food containers (4.20%), caps (3.23%), disposable utensils (1.94%).
Ramilo-Henry et al., 2023	2022-2023	Príncipe Island, Gulf of Guinea, São Tomé and Príncipe	Monthly	11 beaches (turtle nesting vs non-turtle-nesting, with/without human communities)	100m transects	Mean plastic density: 1.62 ± 6.75 items/m^2	Plastics (64.5%), metal (11.4%), cloth (10.4%), glass (5.10%), pottery (2.18%), wood (1.68%), paper (1.52%), sanitary waste (1.38%), rubber (1.15%), medical waste (0.74%). Most common plastics: 2.5- 50 cm pieces (20.8%), plastic bags (13.3%), fishing material (11.39%), plastic bottles (9.32%), plastic caps/lids (8.21%), shoes/sandals (5.58%).
Gacutan et al., 2023	2019-2021	Queensland, Australia	Quarterly	17 sandy beaches (remote and	Four 25m transects per site	0.078 items/m^2 Range: 0.010-0.406 items/m^2	87% plastics (74% hard, 11% soft, 2% expanded), with hard plastic remnants most common (59%).

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
				near population centres)			
Kiruba-Sankar et al., 2023	2022	Car Nicobar Island, Nicobar archipelago, Bay of Bengal	Standing stock	10 locations, various urbanisation levels	Five transects per location, 100m^2 per transect	1.28-7.2 items/m^2	Plastic (83.72%), glass bottles (27.35%), rubber (25.64%), metal (14.54%), aluminium tins (24.78%), clothes (7.69%). Among plastics: Nets/ropes (39%), plastic bottles (17%), plastic cups (15%), wrappers (9%), plastic bags (9%), plastic cans (5%), polypropylene woven bags (3%), floaters (3%).
Krelling et al., 2023	2019	Paraná state, southern Brazil	2 samplings 30 days apart	4 locations in areas with main artisanal fishing municipalities	200m of beach at each location, five quadrats (2x2m)	3.43 items/m^2	Plastics (77%), Polystyrene/foam (20%), Other materials (remaining 3%)
Yang et al., 2023	2018-2019	Southern Taiwan	Seasonal	6 sites (2 rocky, 2 sandy, 2 fishing ports)	Strip Transect Method (100x5m strip)	0.022-0.615 items/m^2	Plastic (71.84%), polystyrene (8.17%), nylon (5.44%), paper (5.37%), rubber (5.06%), metal (1.55%), glass (1.22%), fabric (0.41%), other (0.94%).
Yona et al., 2023	2022	South Java Region, Indonesia	Standing stock	5 beaches, tourist	OSPAR and other protocols. 5 square transects	0.4-6.1 items/m^2 Mean: 2.0 ± 1.5 items/m^2	>60% plastics, of which 80% were single-use plastics
Vorsatz et al., 2023	2021-2022	Hong Kong	Seasonal surveys	8 mangrove forests	Transects 2x25m	0.04-5.2 items/m^2	~76% plastic items

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Iglesias et al., 2023	2002-2021	Continental Portugal and Azores Island	n.a.	454 surveys	OSPAR	n.a.	Plastic (92.9%), paper (2.2%), wood (1.5%), metal (1.3%). Top items: plastic/polystyrene pieces 0-2.5 cm, cigarette butts, and plastic/polystyrene pieces 2.5-50 cm
Anastácio et al., 2022	2014-2015	Northeast Atlantic, Portugal	Quarterly beach surveys	4 urban beaches, 7 non-urban beaches	OSPAR	0.06-1.93 items/m^2 Mean: 0.39 items/m^2	Plastic (71.2%), paper (16.3%), and sanitary waste (9.1%), other categories less than 1% each.
Yenici & Turkoglu, 2022	2017-2018	Coasts of Çanakkale Strait, Turkey	Seasonal	7 sampling stations, 100 m transects		0.050-1.182 items/m^2 Mean: 0.378 ± 0.184 items/m^2	Plastic (90.95%), composites (1.81%), metal (1.71%), paper (1.63%), foam (1.5%), glass (0.97%), rubber, cloth and unknown all less than 1%.
Fruergaard et al., 2022	2019	Nha Trang, Vietnam	Standing stock	7 beaches (4 rural, 2 informal housing, 1 formal housing)	100m transects. Plastic collection only	19.8 ± 19.5 items/m^2	Food containers (35.8%), PS thermal boxes (29.6%), plastic bags (11.1%), cup/lid/bowl/cutlery (8.1%), ropes (6.1%), fishing nets (2.3%). Bottles (0.5%), other (6.5%)
Islam et al., 2022	2017-2018	Cox's Bazar Beach, Bay of Bengal Coast, Bangladesh	Standing stock	1 beach	10 sampling points, 100m transects	0.14-0.58 items/m^2 Mean: 0.26 items/m^2	Aluminium cans, plastic bottles, syringes, food containers, baskets, drink package rings, plastic buoys, fishing nets, fishing gear, footwear, clothing
Ouyang & Yang, 2022	2012-2021	Bohai sea, Yellow sea, East China Sea, South China Sea	Seasonal, time-series	Various	At least 2 quadrats (10x10m) per transect	50,142-280,043 items km^{-2}	n.a.

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Bouzekry et al., 2022	2018-2019	Morocco	Seasonal	1 urban, 1 semi-urban, 1 village beach	MSFD	0.58 items/m^2	74% artificial polymer materials (plastics), 5.51% glass/ceramics, 5.14% processed wood, 4.94% paper/cardboard, 4.62% cloth/textile, 3.37% metal, 1.18% other, 0.59% rubber. Of the collected plastics: plastic caps/lids drinks, plastic polystyrene pieces, cigarette butts/filters, crisps packets/sweet wrappers
Lima et al., 2022	2021	São Marcos Estuary Complex (SMEC), Maranhão Island, Brazil	Standing stock	21 beaches: 9 urban, 12 non-urban	OSPAR	0.01-0.62 items/m^2 Average: 0.19 items/m^2	Plastic: 84.5%, Paper: 4.8%
Fadare et al., 2022	2021	Araromi seaside, Gulf of Guinea coastline, Nigeria	Seasonal (dry/wet seasons)	20 sampling sites	NOAA	Dry season: 0.61 ± 0.19 items/m^2 Rainy season: 1.80 ± 0.35 items/m^2	Dry season: plastic (86%), metals (3.9%), rubber (3.2%), wood (2.6%), cloth/fabric (1.3%), glass (0.9%), unclassified (2.2%). Wet season: plastic (91.8%), metals (2%), wood (1.3%), cloth/fabric (1.3%), glass (1.3%), rubber (1.2%), unclassified (1.1%). Single-use plastics dominated plastic components.
Salazar et al., 2022	2018-2020	Data de Posorja coastal zone, Guayas Province, Ecuador	Monthly	3 sampling sites (2 village beaches, 1 remote beach)	Litter Scientists method	0 to 11.07 items/m^2 Average: 1.95 items/m^2	Plastics (91.8%), paper (1.9%), metal (1.4%), glass (0.5%), cigarettes (0.2%), other (1.9%)
Poeta et al., 2022	2019-2020	Tyrrhenian coast, Central Italy	Monthly, 13 sampling events	8 sites	4 quadrats per site per sampling, 4 × 4 m quadrats		Plastic (97.6%), glass (0.8%), cloth (0.6%), other/unidentified (0.4%), metal (0.3%), rubber (0.2%), paper (0.1%), wood (0.1%). Most abundant plastics: cotton buds (42.3%), plastic fragments (28.5%) and polystyrene fragments (5.43%)

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Khadanga et al., 2022	2021	Gopalpur coastline, Bay of Bengal, India	During (LD) and post COVID-19 lockdown (PLD)	Touristic	10 zones, 20 m × 150 m each	DL: 0.343 items/m^2 PDL: 0.989 items/m^2	Top items DL: bottle/barrel/container caps (10%), medical/ personal care litter (10%), plastic fragments (9 %), poly bag (6%), food wrappers (6 %), plastic cups (5%), glass (5 %). Top items PDL: polybag was (15 %), food wrappers (10 %), gutkha packets (9 %), bottle/ barrel/container caps (6%), plastic fragments (6 %), plastic cups (5%), glass (5 %)
Cordova et al., 2022	2018-2019	Indonesia	Monthly	18 beaches, all with local tourism. 1 in port area, 1 in national park, 1in popular with international tourists	3 replicate transects per area	2.69 ± 1.31 items/m^2	Plastics (46.38%), followed by processed wood, cloth, metal, glass and other. Most abundant plastics: plastic sachets/multilayers (12.15 %), thin plastic wrap/bags (11.96 %), plastic bottles (11.42 %), straw, cotton buds, pieces (8.05 %), plastic cup (7.64 %), styrofoam packaging (6.99 %), thick plastic wrap, sack (6.81 %), cigarettes filter butts (6.47 %), rope, fishing line, fishing rod, plastic rope/small net pieces (4.78 %), Shoes, sandals, gloves (3.15 %).
Yen et al., 2022	2018-2019	Taiwan	Seasonal	121 locations	100m transects	406.64 kg/km	Plastic bottles (30.0%), foamed plastics (20.8%), nets and ropes (17.2%), fishery buoys (8.2%), single-use plastics (6.2%), glass bottles (4.1%), plastic bags (3.5%), cans (1.2%), paper (0.7%), fishing gear (0.4%), cigarette waste (0.1%), other items (7.4%). By Volume.
Baak et al., 2022	2019-2020	Nova Scotia, Canada	Standing stock/ annual	46 beaches, 24 in provincial parks, 22 not	100 m transects, 1x1m quadrat every 10 m, photos	0.2 ± 0.6 items/m^2	Plastic (56%), wood (5%), paper (2%). Other/unknown was the second most important category of which cigarette butts (45%) and rubber (15%). Of the plastic debris: fragments (63%), thread (27%), sheets (8%) and foam (2%).

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Herrera et al., 2022	2020	Alegranza, Canary Islands archipelago, Northeast Atlantic	1 site (Caleta del Trillo), 5 expeditions to determine baseline	Uninhabited island	OSPAR		97.7% plastic, 1.9% textile, 0.4% metal. Of plastics: mostly drink bottles, caps, string and cord, foam sponges, buoys, shoes.
Orthodoxou et al., 2022	2021	Cyprus	Seasonal	20 beaches (urban, semi-urban, rural; touristic, non-touristic)	MSFD	0.19 items/m^2	Plastic (86.3%), metal (3.4%), paper (3.8%), glass (1.9%), hygienic (1.0%), wood (1.0%), medical (0.5%), PPE (0.1%), other (2.0%). Of plastics: 23.0% bottles and caps, 22.1% plastic fragments, 17.0% cigarette butts, plastic bags (10.1%), 5.4% food containers, straws 3.4%, ropes, cords and string (2.9%), cutlery and crockery 2.7%, industrial objects (1.0%), fishing equipment (0.9%).
Damian et al., 2022	2016-2018	Playa Norte, northeastern Costa Rica	Accumulation rate surveys, monthly	Turtle nesting beach	NOAA	1.32 items/m/month ±2.001	Plastics (96.21%), metal (0.19%), glass (0.18%), rubber (0.38%), processed lumber (2.53%), clothing/fabric (0.48%), unclassifiable items (0.03%)
Portz et al., 2022	2019	Islands of Providencia and Santa Catalina, SEAFLOWER Biosphere Reserve, Colombia	Standing stock	39 collection points. Beach, mangrove, reef	UNEP	0.01-16.17 items/m^2 Average: 3.40 items/m^2 Mangroves: 9.07 items/m^2	Plastic/expanded polystyrene waste (83.77%), metal parts (6.21%), glass (4.02%), clothes (2.57%), and other materials (3.43%), including rubber, paper, wood (processed), O.M., ceramics, and others. Of plastics: (42.5%) plastic fragments from 2.5 to 50 cm, expanded polystyrene (22%), (16.35%) larger plastic pieces (>50 cm), bottle caps (7%), bottles (6.41%), candy and snack wrappers (4.09%).

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Akarsu et al., 2022	2017-2018	Istanbul, Turkey (northeastern coast of Marmara Sea)	Seasonal	4 urban beaches	13 sampling areas per beach	5.50 ± 4.46 items/m^2	Plastic (57%), non-plastic (43.0%)
Bat et al., 2022	2019	Sinop, Turkish middle Black Sea coast	Seasonal	9 beaches, remote, semi-remote, populated	MSFD	0.29–7.67 items/m^2 Mean: 2.46 ± 3.23 items/m^2	Plastic (96.09%), metal (1.12%), paper/cardboard (0.94%), glass/ceramic (0.8%). Top items: plastic pieces 2.5-50 cm (28.25%), plastic caps/lids drinks (8.37%), cover/packaging (8.34%), polystyrene pieces 2.5 cm> <50 cm (7.95%), cigarette butts and filters (6.26%).
Schneider et al., 2022	2020	Taiwan's main island, Penghu, Kinmen, and Matsu	2-4 samplings per site	mixed	168 sampling points. Volume-based assessment	12.7 m^3/km	69% fishing-related waste (42% foamed buoys, 19% fishing nets/ropes, 8% hard plastic buoys), 20% plastic bottles, 8% other items, 3% remaining categories
Hassan et al., 2022	2020	Alexandria, Egypt Hurghada, Egypt Jeddah, Saudi Arabia	Daily (June-August 2020)	High human activity coastal areas with intensive fishing, sightseeing, swimming, and tourism	Collection of all litter from ~500 m^2	Alexandria: 7.20 items/m^2 Hurghada: 0.51 items/m^2 Jeddah: 1.77 items/m^2	PPE (gloves and masks) represented 38.1%, 57.3%, and 48.8% of total litter in Alexandria, Hurghada, and Jeddah, respectively. Plastic bags represent 18.3%, 7.0%, and 8% of the total litter collected from Alexandria, Hurghada, and Jeddah, respectively.
Owens et al., 2022	2019-2020	India	Once-off	9 sites	NOAA	0.38–3.86 items/m^2	Plastic (83.0%), cloth/fabric/shows (4.06%), processed wood (4.04%), natural materials left by humans (3.30%), metal (2.49%), glass

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							(1.40%), rubber (0.46%), mixed and other (1.29%)
Corbau et al., 2021	2017-2019	Sardinia, Italy	Seasonal	5 pocket beaches (protected areas, urban, natural)	UNEP	0.05 to 2.82 items/m^2	Plastic: ~90% overall (60-97% range); Construction materials: 5-15%; Metal: up to 12%; Paper, rubber, wood: <5% each. Top items: shopping bags, plastic rings from bottles, plastic caps, food containers, drink bottles, cigarettes butts, lolly sticks, cotton bud sticks, ropes.
Ertaş, 2021	2019-2020	Adana Akyatan Lagoon Coast, southeastern Mediterranean Sea Region, Turkey	Seasonal	Wetland	MSFD	2.679 ± 0.418 items/m^2	plastic and cloth/textile, followed by paper/cardboard, and unidentifiable.
Perumal et al., 2021	2021	Thondi coast, Palk Bay, Southeast coast of India	Standing stock	Agriculture and aquaculture activities	NOAA	4.09 items/m^2	Plastic bottles (22%), plastic cups (14%), straws (12%), cotton swabs (9%), cigarette butts (9%), plastic resealable bags (10%), plastic cling wrap (11%), plastic silverware (6%), plastic stirrers (4%), and food containers (4%)
Suteja et al., 2021	2020-2021	Southern coast of Bali Island, Indonesia	Rainy/dry season, twice per season	14 touristic beaches	Adapted NOAA	0.356 ± 0.366 items/m^2	Plastic (86.9%) > wood or paper (7.8%) > glass (2.3%) > fabric or cloth (1.2%) > metal (1.0%) > others (0.7%). Plastic bags, straws, and plastic cups were the most common among plastic items found on all beaches, with percentages of 21.0%, 16.2%, and 11.5%, respectively
Rizzo et al., 2021	2021	Torre Guaceto Marine Protected Area, Brindisi, Italy	Standing stock	Protected beach within Zone A of MPA (highest	MSFD	0.47 items/m^2	Artificial polymer materials (plastics): 74.5%; Metal: 14.9%; Processed/worked wood: 6.4%;

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		(Adriatic coast of Apulia Region)		protection level, no-take area with restricted human activities)			Cloth/textile: 4.3%. Top plastic items: plastic caps/lids from drink containers (29.8% - 14 items), drink bottles ≤0.5 l (10.6% - 5 items), and buckets (8.5% - 4 items).
Blanke et al., 2021	2019	Belize	Standing stock	7 southern Belizean islands with varying populations and economic use	20x5m transects	0.79 - 4.09 items/m^2	68.1% plastics, 9.46% styrofoam, 8.04% foam/rubber, glass (3.82%), metal (2.57%), and aluminium (1.94%), paper, rope and other (~1% each)
Barnardo et al., 2021	2019-2020	Port Elizabeth (now Gqeberha), Eastern Cape, South Africa	Daily accumulation surveys over 10 consecutive days per survey period	Cape Recife: Rural (nature reserve) Bluewater Bay: Urban	600m initial cleanup followed by 500m transect monitoring	24.58-86.54 items·100 m^{-1}·day^{-1}	Plastics (51.8%), foam (22.4%). The ten most common plastic items were, by order of frequency, food packaging (*n* = 2467), bottle caps (*n* = 1285), small fragments (<5 cm) of hard plastic (*n* = 1181), cigarette butts (*n* = 784), small and medium-sized fragments (<5 cm, and 5–10 cm) of plastic film (*n* = 649 and 588 respectively), medium-sized fragments (5–10 cm) of hard plastic (*n* = 542), large fragments (10–25 cm) of plastic film (*n* = 539), straws (*n* = 367) and transparent bags (*n* = 352).
Roman et al., 2021	2011-2020	Queensland, Australia	Standing stock	441 sites on 81 mainland beaches, 4 coastal islands, and 13 uninhabited	CSIRO, Australia	Coastal islands: 16.49 ± 2.20 items per transect Mainland: 15.64 ± 2.34 items per transect	Hard plastic dominated (61.6% coastal islands, 69.7% offshore islands, 27.7% mainland).

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				offshore islands		Offshore islands: 2.21 ± 0.22 items per transect	
Finger et al., 2021	2019-2020	ASPA No. 133 Harmony Point, Nelson Island, South Shetland Islands, maritime Antarctic	Standing stock	Remote Antarctic protected area with minimal human infrastructure (refuge and storage building)	Visual surveys on foot, detailed quadrat surveys near refuge, and random searches	Refuge area: 33 items/m^2 Coastal/plateau domains: 26 items/ha (0.00026 m^{-2})	Refuge vicinity: Charcoal (28%), rubber (18%), wood (13%), glass (11%), paint chips (11%), metal (11%), rope (4%), plastic (3%), foam (0.5%), textile (0.3%). Coastal/plateaus: Plastic 57%, metal (12%), rope/thread (7%), foam (7%), polystyrene (5%), wood (4%), rubber (3%), textile (2%), glass (1%).
Asensio-Montesinos et al., 2021	2019	Ceuta Province, easternmost Gibraltar Strait	Monthly (February – April)	12 beaches: 7 urban, 2 rural, 3 remote	UNEP/MAP	0.063 - 1.96 items/m^2 Rural: 3.29 items/m^{-2} Urban: 0.48 items/m^{-2}	Plastic (35.2%), glass (18.2%), pottery/ceramics (14.6%), wood (11.4%), metal (11.4%), paper/cardboard (4.8%), cloth (3.5%), rubber (0.7%), organic (0.3%), other materials (0.1%). Among plastics: bottle caps (17%), cigarette butts and filters (15%), crisp/sweet packets and lolly sticks (10%)
Azman et al., 2021	2019-2020	Pahang coastline, Malaysia	Monthly (12 months)	4 sites: 2 near industrial areas with high population density, 2 near river runoff	NOAA	Air Leleh: 12.3 items/m Cherok Paloh: 11.1 items/m Batu Hitam: 6.9 items/m Gebeng: 2.6 items/m	Plastic (86.1%), cloth/fabric (6.0%), processed lumber (3.3%), rubber (2.7%), glass (1.5%), metal (0.4%)
van Gool et al., 2021	2017	New Zealand North and South Islands	Standing stock	41 beaches	Triplicate belt transects	0-0.82 items/m^2	Plastic (*n* = 261 items), foamed plastic (*n* = 44 items), metal (*n* = 41 items), wood (*n* = 19 items), glass and ceramic (*n* = 9 items), cloth (*n* = 7

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					(10 m long by 2 m wide)	Mean: 0.16 ± 0.02 items/m^2	items), rubber (*n* = 6 items), other (*n* = 2 items), and paper and cardboard (*n* = 1 item).
Özden et al., 2021	2017-2019	Northern Cyprus, Eastern Mediterranean Sea	Monthly	8 beaches: 6 in Special Environmental Protection Areas, 4 touristic, 6 turtle nesting	MSFD	1.19 items/m^2	96% plastic/polystyrene. Top items: unidentifiable plastic pieces (17.3%), drinks containers (11.0%), shopping bags (8.1%), caps/lids (7.6%)
Mghili et al., 2020	2019	Moroccan Mediterranean coastline	Seasonal	5 beaches: 3 urban, 2 village	100 m × 20 m	0.20 ± 0.098 items/m^2	Polymers (71.36%), paper/cardboard (11.50%), metal (5.77%), processed wood (5.34%), cloth/textile (2.51%), glass/ceramics (1.76%), rubber (0.35%), other (0.53%). Top 10 items: Crisps packets/sweets wrappers (13.19%), cigarette butts (11.92%), plastic pieces 2.5 cm > < 50 cm (11.50%), plastic caps/lids drinks (8.06%), other wood <50 cm (3.72%), drink bottles ≤0.5 l (3.59%), paper fragments (3.53%), food containers (3.08%), shopping bags (2.65%), cans (beverage, 2.52%).
Weideman et al., 2020	2015-2019	Muizenberg, False Bay, South Africa	Monthly	Rocky intertidal shore and adjacent sandy beaches. Highly urbanized	All litter collection	Rocky shore: 2.4 ± 1.7 items/m/month Sandy beach: 2.3 ± 0.3 items/m/month	74% plastic on rocky shore, 96% plastic on sandy beach; packaging dominated both sites
Anfuso et al., 2020	2020	Admiralty Bay, King George Island, Antarctica	Standing stock	17 remote pocket beaches	All litter collection	0 -1.03 items/m Mean: 0.16 items/m	Wood fragments (47.4%), plastic (41%), metal (5%), rubber (3%), paper and cardboard (3%), paint fragments (0.8%), cloth (0.4%).

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Manullang, 2020	2019	Ambon Island, Maluku Province, Indonesia	Standing stock	2 urban mangrove areas, 1 rural area	Line transects. Plastics only	10-230 items/m^2 Mean: 92 ± 28 items/m^2	Film: 63%, Fiber: 31%, Fragment: 6%, Foam: <1%
Fortibuoni et al., 2020	2015-2018	Italy	Twice yearly	54 beaches	MSFD	477 items/100m Adriatic Sea: 590 items/100m (highest) Western Mediterranean Sea: 491 items/100m Ionian Sea and Central Mediterranean Sea: 274 items/100m (lowest)	Plastic/polystyrene (74%), paper/cardboard, incl. cigarette butts (9%), sanitary waste (6%), glass/ceramic (4%), metal (3%)
Chen et al., 2020	2018	China	Every 2 months	24 sites in 16 coastal cities, mixed	105 m shoreline, 5 transects. Ocean Conservancy data card	Mean: 3.85 ± 5.39 items/m^2 High pollution (Yangtze Estuary: 16.08 ± 9.23 items/m^2) Low pollution (Northern China Sea Area: 0.51 ± 0.39 items/m^2)	71.8% ± 13.7% plastics, 11.3% ± 7.0% mixture, 5.8% ± 8.3% glass/ceramics. Top items: polystyrene foams (packaging; 16.6% ± 18.0%), plastic food wrappers (9.3% ± 6.3%), cigarette butts (8.3% ± 6.6%), other plastic bags (8.0% ± 4.6%), plastic bottle caps (7.7% ± 4.5%), plastic grocery bags (5.3% ± 4.5%), and plastic beverage bottles (5.0% ± 4.2%).
Veerasingam et al., 2020	2019	West coast of Qatar	Standing stock	12 beaches: 2 urban, 2 semi-urban, 5 semi-	Three transects per beach	1.98 items/m^2	Plastics (71.4%), metal (9.3%), glass (5.1%), paper (4.4%), fabric (4.0%), rubber (3.9%), processed wood (2.0%)

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				rural, 3 remote/natural	(100m x 1m)		
Tavares et al., 2020	2019	Senegal, West Africa	Standing stock	2 beaches: 1 urbanised, 1 not urbanised	Surface: 200 × 2 m^2 transects Buried: 40 × 40 cm^2 quadrats, 10 cm depth	Surface: 3.63 items/m^2 (urbanised), 0.20 items/m^2 (non-urbanised) Buried: 207.29 items/m^2 (urbanised), 36.46 items/m^2 (non-urbanised)	97.62% plastics, mainly plastic bags (29.28%), clothing (15.01%), drink bottles (6.51%), small plastic bags (6.23%).
van Hoytema et al., 2020	2020	Wetlands Reserve in Al Wusta Governorate, Barr Al Hikman Peninsula, Omani Coast of the Arabian Sea	Standing stock	7 sites in a wetlands reserve	OSPAR	0.11-1.44 items/m^2	Plastic dominated (84.4-97.7%). Fisheries-related items (19.6-36.7% abundance, 41.4-94.4% weight). Most abundant items: string and cord (12.6%), plastic water bottles (9.3%), polystyrene pieces <2.5cm (7.7%), caps/lids (6.0%), plastic pieces <2.5cm (5.9%), food packets (5.7%), industrial packaging (4.1%).
Gaibor et al., 2020	2018	Ecuador	Standing stock	26 beaches: 25 continental, 1 in Galapagos. Various urbanisation levels	Litter Scientists Protocol	1.31 ± 1.03 items/m^2 for continental beaches	Plastics (>65%), followed by cigarette butts, metals, papers, glass and other.
Cavalcante et al., 2020	2009	Fortaleza, Ceará, northeastern Brazil	Standing stock	1 beach, non-urbanised, not accessible, near port	10 sectors, 30x 35m	0.21 - 1.15 items/m^2	Small debris (119.9%): lollipop holder (7.3%), cigarette butt (6.2%), cotton swab (5.9%), virgin plastic pellets (0.5%). Medo-debris (55.0%): plastic material (27.4%), polystyrene foam (18.7%), others (7.8%), nylon (0.6%), glass (0.2%), aluminium (0.1%).

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
							Macro-debris (25.1%): polystyrene foam (8.9%), plastic material (8.4%), others (2.6%), fishing material (2.0%), rubber and leather (1.8%), paper (0.5%), polyurethane (0.4%), glass (0.3%), metals (0.2%).
Vlachogianni et al., 2020	2018	Croatia, Cyprus, France, Greece, Italy	Seasonal (autumn, winter)	23 sites, various categories	MSFD	53-6,660 items/100 m Mean: 714 items/100 m 0.61 items/m^2	Artificial polymers (90%), glass/ceramics (3%), paper/cardboard (2%), metal (2%), cloth/textile (1%), rubber (1%), processed/worked wood (1%). The top 10 items: plastic pieces 2.5 cm > < 50 cm (26%), cigarette butts and filters (12%), plastic caps/lids (8.1%), cotton bud sticks (6.3%), polystyrene pieces 2.5 cm > < 50 cm (5.8%), straws and stirrers (3%), plastic pieces > 50cm (2.2%), polystyrene pieces >50 cm (2.0%)), glass bottles (1.8%), crisps packets/sweets wrappers (1.7%).
Waluda et al., 2020	1989-2019	Bird Island and Signy Island, Scotia Sea, Southwest Atlantic sector of the Southern Ocean	Monthly	Remote Antarctic and sub-Antarctic island beaches with no urbanisation	CCAMLR protocol	100 items km^{-1} $month^{-1}$ Bird Island: 99.9 items km^{-1} $month^{-1}$ Signy Island: 3.1 items km^{-1} $month^{-1}$	Bird Island: 97.6% plastic, 0.8% rubber, 0.6% fabric, 0.5% metal, 0.4% glass, 0.1% paper. Signy Island: 85.3% plastic, 6.2% metal, 3.6% rubber, 1.8% paper, 1.7% fabric, 1.4% glass.
Andrades et al., 2020	2018	Brazil	Standing stock	44 beaches, estuarine, urban and non-urban	8 random transects, 4m each	0.42 (±0.53) items/m^2	Plastics (food related > fragment > fishery > packaging > general use > plastic bag > other), > cigarette butts > charcoal > paper > metal > glass > wood > cloth.
Dunlop et al., 2020	2003-2019	Cousine Island, Seychelles	Daily accumulation	1 beach, privately owned	2-6 surveys per year for 30 days per	0.0082 items·m^{-1}·d^{-1}	Polystyrene fragments/pieces (0.00249 items·m^{-1}·d^{-1}), plastic items (0.00135 items·m^{-1}·d^{-1}) and plastic bottles (0.0011

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
				island, <100 visitors/yr	survey, entire beach		items·m^{-1}·d^{-1}) were the most common items of marine litter that were deposited.
Pervez et al., 2020	2018	Shilaoren Beach, Qingdao City, China	Twice-weekly over 3 months	Highly populated area, touristic	Collection of litter in 36 garbage tanks	720 items km^{-1}, 14 kg km^{-1}	Plastic (56.69%), paper (14.41%), food (7.40%), Styrofoam (5.51%), glass (5.32%), rubber (4.97%), metal (2.40%), wood (1.74%)
Daniel et al., 2019	2017-2018	Kerala Coast, India	Seasonal (pre-monsoon, monsoon, post-monsoon)	6 beaches (low and high fishing intensity)	NOAA	14.4 ± 12 fishing related items/100 m^2	Plastics (73.8%), wood (6.7%), paper and cardboard (6.4%), rubber (4.3%), metal (3.5%), glass (2.8%), clothes (2.1%), non-plastic fishing debris (0.3%). Plastics composition: fishing-related (48%), food packaging (13%), carry bags (8%), foamed plastics (8%), plastic bottle (7%), plastic chappals (3%), bottle caps (2%), food containers (1%), others (10%). Composition of fishing-related: rope (38%), netting (24%), float (17%), monofilament line (13%), buoys (8%)
Vesman et al., 2019	2018	Northern Island of the Novaya Zemlya archipelago, Russian Federation	Standing stock	4 beaches, Uninhabited island	MSFD	1.5 × 10^3 items/km^2	Plastics (87.77%), processed/worked wood (2.93%), metal (2.39%), glass/ceramics (1.86%), cloth/textile (1.86%), rubber (1.60%), unidentified (1.33%), paper/cardboard (0.27%)
Sulochanan et al., 2019	2011-2016	Mangaluru, India	Monthly	3 beaches: 1 urban and touristic, 1 fishing and near port, 1 residential and fishing	UNEP/IOC	n.a.	Fishing activities contributed the most to the total amount of litter (32.41–59.0%). Foam comprised 7.14–11.0% of total litter

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Mokos et al., 2019	2018	Croatian Adriatic	Standing stock	3 beaches: 1 semi-urban, 1 semi-rural, 1 remote/ natural	MSFD	3.35 items/m^2 Semi-urban: 1.11 items/m^2 (lowest) Semi-rural: 7.50 items/m^2 (highest) Remote/natural: 1.44 items/m^2	Artificial polymer materials (93.86%), metal (1.20%), glass/ ceramics (1.15%), processed wood (1.05%), cloth/textile (0.95%), paper/cardboard (0.9%), rubber (0.80%), unidentified items and/or chemicals (0.07%). Top items: plastic pieces 2.5-50 cm (63.5%), cigarette butts and filters (18.1%), plastic caps/lids from drinks (15.8%), cotton bud sticks (15.6%), string and cord (diameter less than 1 cm) (12.2%), plastic caps/lids from chemicals, detergents (non-food) (8.5%), plastic construction waste (8.5%), polystyrene pieces < 2.5 cm, < 50 cm (7.7%) and crisps packets/sweets wrappers (6.9%).
Lavers et al., 2019	2017	Cocos (Keeling) Islands, Australia	Standing stock	5 islands	10 x 2 m transects	Surface Debris: 4.72-55.67 items/m^2 Mean: 21.68 ± 19.01 items/m^2 Buried debris: 28.13-2,506.25 items m^{-2} Mean: 654.91 ± 869.97 items/m^2	Plastic (95.41%), foam (3.96%), all other (0.63%).
Araújo et al., 2018	2013	Pernambuco, Brazil	Standing stock	9 beaches: 3 low, 3 medium, and 3 high urbanization level	3 replicates, 100 × 1 m	Low urbanisation: 2.3 items/m^2 Medium urbanisation: 5.7 items/m^2 High urbanisation: 6.3 items/m^2	Plastic (57.3%), food/organic (31.4%), and wood (wooden skewers) (8.5%), other (<3%).

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Chitaka & von Blottnitz, 2018	2018	Cape Town, South Africa	1-week daily sampling	5 beaches, mixed use	Daily cleanups	36-2961 items/day/100 m	Plastic (94.5%–98.9%). Top 10 items: beverage bottle lids, snack packets, straws, single sweet wrappers, lollipop sticks, lollipop wrappers, cotton bud sticks, biscuit wrappers, polystyrene clamshells, polystyrene cups/
Walther et al., 2018	2004-2016	Taiwan	Standing stock	541 cleanup events	Volunteer cleanup event	2730 items/km	Plastic (63.6%), plastic mixed with other material (27.2%). Top 5 items: plastic shopping bags (15.3%), plastic bottle caps (11.6%), disposable tableware (10.6%), fishing equipment (14.8%), and plastic drinking straws (8.8%).
Loizidou et al., 2018	2016-2017	Cyprus	Standing stock	9 Blue Flag beaches	Ocean Conservancy protocol	0.37 items/m^2	Cigarette butts (59.4%), food wrappers (5.9%), straws (5.7%), plastic bottle caps (1.6%), other plastic or foam packaging (1.6%), beverage cans (1.0%), metal bottle caps (0.9%), plastic grocery bags (0.8%), balloons (0.8%), and plastic cups and plates (0.7%)
Vlachogianni et al., 2018	2014-2016	Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Montenegro and Slovenia, Adriatic and Ionian Seas	Seasonal	31 beaches (urban, semi-urban, semi-rural, remote/ natural)	MSFD	0.17-2.9 items/m^2 by country Regional average: 0.67 items/m^2	Artificial/anthropogenic polymer materials (91%), glass/ceramics (3.2%), metal (1.5%), paper (1.4%), cloth/textile (1.1%), rubber (0.6%), unidentified (0.1%). Top items: Plastic pieces 2.5 cm > <50 cm (19.89%), Polystyrene pieces 2.5 cm > < 50 cm (11.93%), cotton bud sticks (9.17%), plastic caps/lids (6.67%), cigarette butts and filters (6.60%).
Giovacchini et al., 2018	2014-2015	Pelagos Sanctuary macroarea, Italy	Seasonal	5 areas: Urban, near urban, natural	SEA Cleaner Protocol	1.06 items/m^2 Urban (0.64 items/m^2), Urbanized (0.87	Plastic (28.01-89.10%), polystyrene (6.27-55.04%), other (4.21-51.03%)

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
						items/m^2), Natural (1.50 items/m^2)	
Silva et al., 2018	2015, 2017	Arraial do Cabo, Rio de Janeiro, Brazil	Seasonal (winter, summer)	3 touristic beaches	UNEP	Prainha: 1.7 units/m^2 (winter), 1.6 units/m^2 (summer) Pontal: 0.43 units/m^2 (winter), 0.92 units/m^2 (summer) Grande: 0.31 units/m^2 (winter), 0.5 units/m^2 (summer)	Plastic (61.4% winter, 54.5% summer), cigarette butts (26.7% winter, 22% summer), straws (28%), bottle caps (15%), disposable cups (3%)
Jang et al., 2018	2016	Sri Lanka	Standing stock	22 beaches (urban, near river mouths, pocket, with barriers)	Large debris (>25 mm): Three 10×10 m quadrats per beach Small debris (5-25 mm): 50×50 cm quadrats, sieved through 5-mm mesh	Large debris: 4.1 ± 9.2 items/m^2 Small debris: 158 ± 170 items/m^2	Packaging material (55%), consumer products (25%), fishing gear (20%); 93% plastic
Šilc et al., 2018	2017	Velika plaža, Montenegro	Standing stock	1 beach, touristic	120 plots (20 per habitat type), 2×2m	n.a.	83.4% artificial polymer materials, 3.1% glass, 2.7% paper, remaining other.

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Rangel-Buitrago et al., 2019	n.a.	Las Salinas beach, Viña Del Mar, Chile	Standing stock	1 beach, urban and touristic	Collection of all debris from total beach	0.34 items/m^2	cigarette butts (38%), plastics (32%), paper-cardboard (15%), polystyrene (6%), machined wood (3%), metal (2%), glass, brick, organic items, cloth, sanitary waste, rubber, and other pollutants represent less than 4% combined.
Ramos & Pessoa, 2019	2014	Miramar beach, southern shores of Rio Paraiba estuary, northeast Brazil	Weekly collections during 2 months	1 beach, 2 distinct areas: low tourism and high tourism	Beach seine net (15m long, 5mm mesh-size) with three replicate hauls per week in each area	966.08 items/km^2	Hard plastic (68.75%), soft plastic (19.62%), metal (6.60%), cloth (2.26%). Other categories less than 1% each.
Ambrose et al., 2019	2013	South Eleuthera, The Bahamas	Seasonal (spring, fall)	16 beaches, remote	NOAA	n.a.	93% plastic, metal 1%, glass 2%, rubber 3%, paper/lumber 1%, cloth 0%. Of plastic: 69% plastic fragments, 8% plastic bags and films, 8% fishing, 4% plastic caps, 3% foam, 3% other, 2% plastic bottles and jugs, 2% foodware, 1% personal care.
Martin et al., 2019	2017	Saudi Arabian mangrove forests	Standing stock	16 sites on Red Sea Coast, 4 sites in Arabian Gulf	4-10 transects per station	Red Sea: 0.66 ± 0.18 items/m^2 (range: 0.02-3.7 items/m^2) Arabian Gulf: 1.21 ± 0.53 items/m^2 (range: 0.22-3.0 items/m^2)	Red Sea: 92.2% plastic (mainly drink bottles 23.5%, plastic bags 14.7%) Arabian Gulf: 95.5% plastic (mainly ropes 29.4%, plastic bags 15.0%)

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Alshawafi et al., 2017	2015	Martil beach, North-East of Tetouan, Morocco	Seasonal	Sea resort beach	100 m section	n.a.	Plastic (57%), lumber/paper (21.93%), cloth/fabric (7.8%), glass (5.42%), metal (4.40%), rubber (3.4%)
Polasek et al., 2017	2015	Five National Park Service units in Alaska	Standing stock	28 remote beaches in national parks	All litter collected	7.7 - 4195.6 kg/km	Hard plastic (60%), rope/netting (14.6%), foam (13.3%), metal (1.7%).
Hengstmann et al., 2017	2015	Isle of Rügen, Germany	Standing stock	4 beaches, 2 low tourism nature reserve, 1 high tourism, 1 medium tourism	OSPAR	Mean: 304±88.96 items/100m Range: 202-404 items/100m	Plastics (82.69%), glass and ceramics (3.7%), paper and cardboard (3.6%), all other material groups <4%. Top items: plastic pieces between 2.5 and 50 cm (17%), cigarette butts/filters (15%), foam (7%), crisp packets/sweet wrappers (6%).
Nelms et al., 2017	2005-2014	Great Britain	Standing stock	736 beaches across Britain	Volunteer cleanups	0.0085 items $m^{-1}min^{-1}person^{-1}$	Plastic (66%), polystyrene (10%), sanitary items (5%), metal (4%), paper (4%), glass (3%), cloth (3%), rubber (2%), wood (2%), faeces (1%), pottery (0.4%), medical (0.2%).
Pasternak et al., 2017	2012-2015	Mediterranean Coast of Israel	Seasonal	8 beaches, highly urbanised	UNEP/IOC	4.8 – 19.4 items/100m^2 Mean: 12.1 items/100m^2 (0.12 items/m^2)	90% plastic materials, cloth – 1%, glass/ceramic – 1%, metal – 2%, paper/cardboard – 3%, rubber and wood – 0.01%. Top categories: food wrappers/disposables (23.7%), plastic bags (23.1%), cigarette butts (11.6%), bottle caps (11.1%), cutlery (8.2%)
Terzi & Seyhan, 2017	2012-2013	South-eastern Black Sea coast, Turkey	Seasonal	9 beaches, urban	Collection of litter >2cm from 50m transects	0.16±0.02 items/m^2	Plastics (≥61.65%), Styrofoam and fabric. ≥45% from beverage and general packaging

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
Poeta et al., 2016	2014-2015	Tyrrhenian coast, Italy	Seasonal	1 beach, limited human activity	MSFD	105.8 items/m^1	94.4% artificial polymer material (79.4% plastic, 15% polystyrene), with cotton bud sticks representing >30% of total litter
Andrades et al., 2016	n.a.	Southeastern Brazil	Seasonal	3 beaches	Fixed-width transects of various lengths	High urbanised: 0.58 items/m^2 Low urbanised: 0.18 items/m^2 Non-urbanised estuary-associated: 0.24 items/m^2	Plastic dominated all sites (73.2-85.9%), with food-related items being most prevalent across all beaches
Arun Kumar et al., 2016	2015	Marina Beach, Chennai, India	Bimonthly surveys (4 surveys between March-April 2015)	1 urban beach	NOAA	171.8 items/100m 1.37 items/m^2	Plastic (44.89%), lumber/wood (28.94&), other (19.83%). Of plastics: plastic bags (32.26%), wrappers (17.50%), plastic cups (15.92%).
De Scisciolo et al., 2016	2015	Aruba, Southern Caribbean	Standing stock	10 beaches: 5 leeward coast, 5 windward coast	UNEP/IOC	Leeward: 0.20±0.07 items/m^2 Windward: 0.91±0.50 items/m^2	Leeward: 61% plastic, mainly smoking > drinking > eating items Windward: 98% plastic, mainly plastic fragments > bottle or container caps > straws > plastic rope/small net pieces > bags > plastic utensils.
Munari et al., 2016	2015	North-western Adriatic, Italy	Standing stock	5 beaches, included in the Po River Delta Parks and in the Natura 2000 Italian network	UNEP/IOC	0.2 items/m^2	Plastics (81.1%), paper and cardboard (7%), glass and ceramics (3.9%), foamed plastic (3.3%), rubber (1.4%) and wood (1.2%). Top items: cigarette butts (22.9%), unrecognisable plastic pieces (13.5%), bottle

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
							caps (9.2%), mesh bags (7.2%), plastic bottles (6.5%), and cutlery (6.4%).
Ali & Shams, 2015	2013	Clifton Beach, Karachi, Pakistan	Monthly (June – August)	1 urban beach	10 transects of various lengths	8865 ± 1483 items km^{-1}	Plastic (50.5%), food (7.5%), paper (6.6%), glass (5.9%), metal (5.9%), processed wood (5.9%), cloth (5.5%), Styrofoam (4.2%), masonry (4.2%), rubber (3.7%).
Duhec et al., 2015	2013	Alphonse Island, Seychelles (Western Indian Ocean)	Weekly over 6 weeks	Remote island coastline with two beach sections	10 x 500m	4.7 items/m	Plastic (96%), incl. small plastic fragments (26% of items), hard plastic (18%), plastic caps (13%), and foam sheets (11%).
Qari & Shaffat, 2015	2012	Karachi, Pakistan	Standing stock	4 beaches: 3 recreational, 1 mangrove	Chapman, 1964	n.a.	Plastic items (49.43 %), rubber (17.67%), pot pieces (10.74%) and glass (9.72%).
Rosevelt et al., 2013	2009-2010	Monterey Bay National Marine Sanctuary, California, USA	Monthly	12 survey sites	1 parallel, 50m transects	Range: 0.03 to 17.1 items/m^2 Mean: 1±2.1 items/m^2	Styrofoam (41% of total), fragmented plastics (68% of plastic subcategory), cigarette butts (6%), paper/wood (5%), food wrappers (5%), and fertiliser pellets (1%)
Debrot et al., 2013	2011	Bonaire, Southeastern Caribbean	Standing stock	21 natural beach sites, windward and leeward beaches	5m or 10m transect widths	Windward: 115±58 items/m Leeward: 1±0.4 items/m	Plastics (72%), Polystyrene foam (16%), Wood (7%), other materials (remaining)
Ribic et al., 2012	2008-2010	Sand Island, Midway Atoll, Papahānaumokuākea Marine National Monument	Monthly	Remote	Ribic et al., 2010	n.a.	72.2% pieces, of which 91% plastics, 7.2% foamed plastic, 1.6% rubber fragments from sandals. 27.8% identifiable, of which 88.4% fishing/aquaculture/shipping-related and beverage/household products-related.

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
							In the fishing/aquaculture/shipping-related category, 83.4% of the items were oyster spacer tubes, rope, and buoys/floats. In the beverage/household products-related category, 82.9% of the items were bottle caps, caps/lids, and plastic beverage bottles.
Ribic et al., 2012	1998-2007	Three regions - North Pacific Coast (Washington, Oregon, California north of Point Conception), Southern California Bight (California south of Point Conception), and Hawai'i (O'ahu)	Monthly	23 sites	Ribic et al., 2010	North Pacific Coast: 28.2 items/500m Southern California Bight: 69.5 items/500m Hawai'i: 133.8 items/500m	Land-based debris (highest in Southern California Bight at 60%), general-source debris (30-40% across regions), and ocean-based debris (highest proportion in Hawai'i at 38%)
Hong et al., 2014	2008-2009	Korea	Bimonthly	20 beaches along eastern, western, and southern coasts	100m survey line	480.9 (±267.7) items/100m	Plastics (49.8%), styrofoam (16.9%), processed wood (8.4%), glass (7.9%), foreign (4.3%), smoking/firework (4.0%), metal (2.6%), cloth (2.4%), paper (1.7%), rubber (0.6%), medical/personal hygiene (0.4%), miscellaneous (1.1%).
Kuo & Huang, 2014	2012-2013	Taiwan	Seasonal	6 sites: 2 sandy beaches, 2 rocky shores, 2 fishing ports	Strips transect method for beached marine debris	Highest: Jianzilu (rocky) (0.614±0.309 items/m^2) Lowest: Tamsui port (0.023±0.018 items/m^2)	Plastic fragments (33.58%), bottle caps (13.34%), fishery polystyrene (6.30%), cigarette butts (6.01%), rope (4.08%), plastic bags (3.82%), shoes (2.69%), fishing boat senders (2.40%), PET bottles (2.28%), plastic beverage bottles (2.13%), others (23.37%)

Article	Study Year	Location	Type of Monitoring	Beach Type	Method	Litter Density	Composition
						Rocky shores: 0.398±0.326 items/m^2	
Santos et al., 2009	2005	Costa do Dendê, Bahia, Brazil	Standing stock	Tourist beaches, river-dominated beaches, stable beaches, unstable beaches (erosion)	79 transects	9.1 items/m	Plastics (76%), Styrofoam (14%)
Bravo et al., 2009	2008	Chilean coast, SE Pacific	Standing stock	43 beaches, mixed	Trash Scientist Protocol	0.3-82.7 items/m^2 Mean: 1.8 items/m^2	Plastics, cigarette butts, and glass fragments
Liebezeit, 2008	2007	Kachelotplate, Lower Saxonian Wadden Sea, southern North Sea	Monthly (May to November)	Remote island	unknown	n.a.	Plastics (60.4%), wood (24.5%), glass (0.9%), metal (1.6%), other material (5.3%).
Edyvane et al., 2004	1991-2000	Anxious Bay, near Elliston, South Australia, western Eyre Peninsula	Annual	Remote beach	Systematic clearance of all litter	13.2 kg/km in 1991 and 9.7 kg/km in 2000	Hard plastic (35.5% in 1991, 39.5% in 2000), soft plastic (34.5% in 1991, 30.6% in 2000), glass (30% in 1991, 11% in 2000), and metal (19% in 2000) 6. Majority originated from commercial fishing activities.
Otley & Ingham, 2003	2001-2002	Volunteer Beach, East Falkland	Monthly accumulation rate (6 months)	Remote island, fishing activity	n.a.	77 ± 25 items/km/month	Plastics (74%), metal (3%), glass (11%), cotton (12%)

5. Composition and Abundance of Seabed Litter

Seabed litter is significantly less studied than beach litter, because the seabed, particularly in offshore or deep-sea environments, is much more difficult and much more expensive to explore. There are several ways in which benthic litter can be assessed, each with its own pros and cons. In coastal environments, seabed marine litter is recorded almost exclusively through visual surveys performed by divers. This is a relatively cost-effective option which allows the collection and removal of the identified litter. However, it can be time-consuming and relatively small areas of seabed can be studied each time. There are also limitations in the depth within which divers can safely operate. In deeper marine environments, fishing vessels using the bottom trawl fishing technique are used to collect and record seabed marine litter. Trawlers can cover wide and long distances but are not suitable for all types of seabed morphologies, as the nets can break if they get caught on rocky substrates. Results may also vary between bottom trawls depending on the type of specific trawling equipment used (e.g. net size and type). Bottom trawling also disrupts the seafloor, which makes it a less-than-ideal research method. With the wider availability and affordability of remotely operated vehicles (ROVs), such equipment is increasingly being used to monitor deep-sea environments through video and photographic imaging. However, the use of ROVs requires significant effort post-survey for the analysis and processing of the collected images, while sample collection is more difficult.

A search in Scopus for the term (seabed litter) OR (seabed debris) resulted in 412 documents between 2000 and 2026, with the majority of research being completed in the last decade, demonstrating that this is an issue of increasing concern (Figure 19). To investigate the most frequent types of litter on the seabed, the search in Scopus was refined using the following keywords: (seabed) AND (litter OR debris) AND (composition), to exclude any research papers that only included information on litter concentrations but not the types of litter. This resulted in a list of 68 documents, most of which originated in Europe (Figure 20). The titles and abstracts of these papers were reviewed, excluding those that were not relevant, not in English, not original research (i.e. were reviews), and focused on microlitter. This resulted in a refined list of 21 documents. As these documents were reviewed, additional papers referenced within them that were relevant to this work were identified and added to the list. Table 2 presents the 53 papers that were included in this literature review.

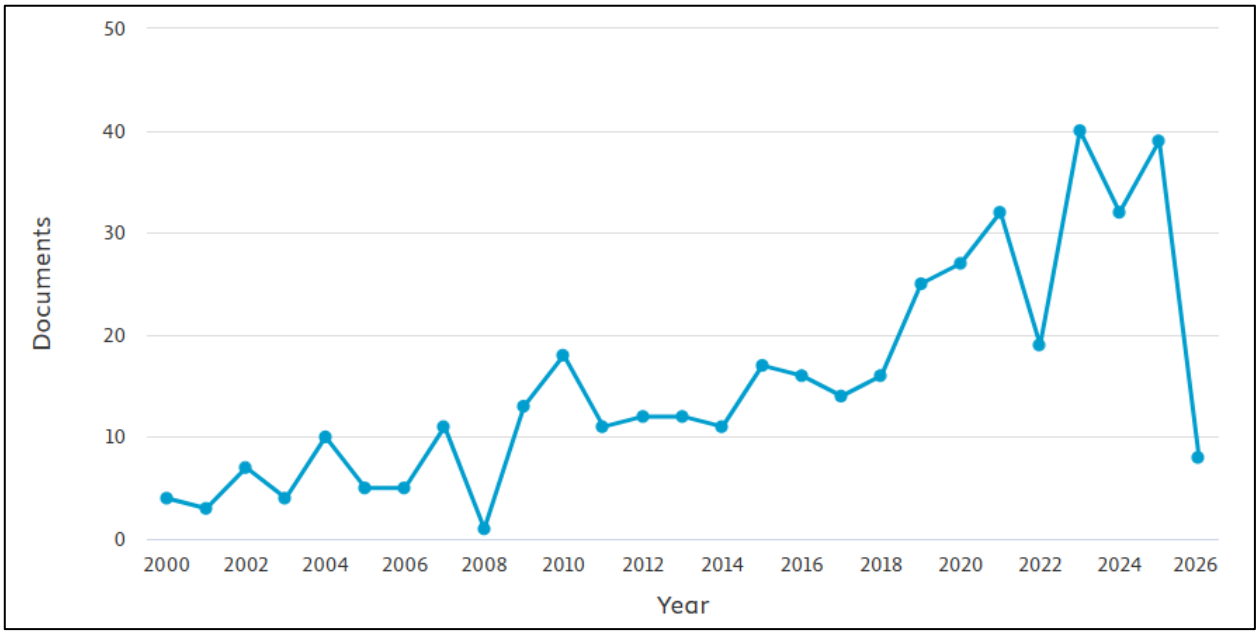


Figure 19. Research documents by year when searching for 'seabed litter' OR 'seabed debris' in Scopus.

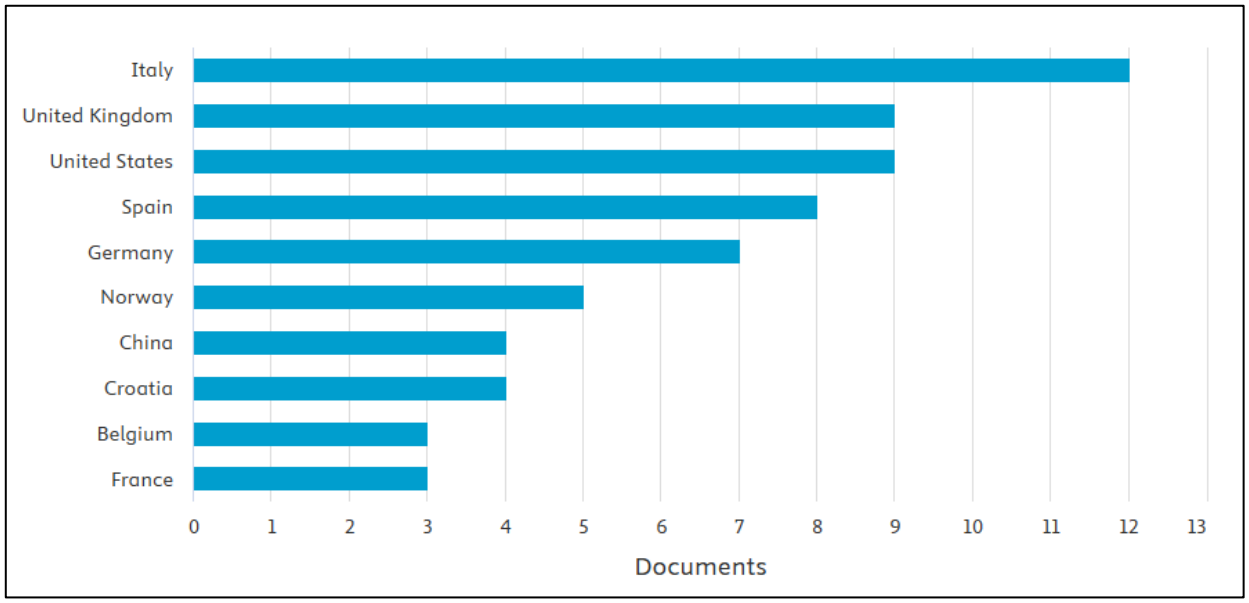


Figure 20. Documents by country/territory (top 10 countries only).

As can be seen in Table 2, there is a high variation in the mean densities of identified seabed marine litter. This is due to a multitude of factors, including the study areas, the anthropogenic pressures in these areas, the geomorphology of the areas, as well as the monitoring/collection method chosen for the study. Any comparisons between the data from the studies are further complicated by the way data are reported (e.g. items/km^2 or items/ha or event kg/units of distance). What is clear, however, is that none of the studies reported null seabed marine litter. Marine litter has been identified across all studied areas.

The geomorphology of the seabed highly affects the concentration of marine litter. Hotspots have been found in the upper parts of continental slopes in the Levantine basin, with litter concentrations reaching 2885 items/km^2 (Segal & Lubinevsky, 2023). Submarine canyons have been reported as pathways for litter into the deep sea (Angiolillo et al., 2021; Castella et al., 2025; Strafella et al., 2019). Even in the Calypso Deep in the Eastern Ionian Sea – the deepest point in the Mediterranean, at a depth of over 5100 metres – a litter concentration of 26,715 items/km^2 has been reported (Hanke et al., 2025). High concentrations of marine litter have also been reported in other areas of the world, including the South China Sea (Peng et al., 2019) and in the North Atlantic Ocean (Mordecai et al., 2011). Large concentrations of litter (6,566 items/km^2) were also recorded in the deep Arctic seafloor, in areas with very small population densities, demonstrating the distances that litter can travel on the seafloor as a result of currents (Tekman et al., 2017). Litter has also been observed in the Mariana Trench in the western North Pacific at a depth of 10,898 m (Chiba et al., 2018).

Plastics, which are generally lightweight and buoyant, can be transferred long distances. Predicting the trajectories and vertical movement of plastics in the marine environment is particularly difficult as there are a range of factors at play, including wind and current conditions, seabed geomorphology, and even water salinity changes. The buoyancy of plastics also affects trajectory and vertical movement. With increased biofouling, plastic buoyancy decreases, which increases their weight and eventually causes them to sink to the seafloor. This is why plastics are ubiquitous on the seabed.

Most of the identified and/or collected marine litter is consistently made up of plastics, sometimes close to or exceeding 90% (e.g. Angiolillo et al., 2023; Fortibuoni et al., 2019; Hanke et al., 2025; Li et al., 2025; Martínez-Dios et al., 2025; Meyerjürgens et al., 2022; Selvam et al., 2021). The composition of these plastic items varies depending on the location of the study, and it is generally, while not exclusively, influenced by the most prominent human activity in the vicinity of the study area. Nonetheless, single-use plastics are ubiquitous. For example, Read & Turner (2025) found that 40% of the plastics in the western English Channel was made up of packaging, mostly food containers and beverage bottles; Li et al. (2025) found that the identified plastics in their study included plastic bags and plastic packaging; Viejo et al. (2023) found wrappers and plastic bags among the top three items collected; drinks bottles, bags and plastic sheets were the most abundant plastic items in Ermoupoli Bay (Fakiris et al., 2022); whereas plastic bags, food wrappers and personal care products were the major contributors to plastic litter along the north-east Arabian coast (Selvam et al., 2021). Bags and packaging sheets were also important contributors to plastic litter identified by Pasquini et al (2016) and Fortibuoni et al. (2019) in the Adriatic-Ionian microregion.

The large distances that plastics can travel once in the marine environment can often make it difficult to assess their origin. However, the impact of land-based activities on the marine environment was evident in several research works. Li et al. (2025) found that plastic take-out containers were more common in shallower waters, closer to coastal areas with touristic activities. A study along the Algerian coast found that the Béjaia region, which is where the Soummam River flows into the sea, had the greatest concentrations of macrolitter (1800 items/km^2) as a result of landfills along the banks and mouth of the river (Inal et al., 2025). Pasquini et al. (2016) and Strafella et al. (2015; 2019) also noted higher quantities of litter in front of the mouth of the River Po. Some research also includes comparisons of seabed marine litter pre- and post-COVID lockdown. These show a decrease in seabed litter post-lockdown, demonstrating the impact of reduced human activities in the nearby coasts as well as reduced littering by maritime traffic (Segal et al., 2023; Viejo et al., 2023). Furthermore, a study implemented in the Adriatic-Ionian microregion demonstrates the impact of legislation on the composition of marine litter, as it found that plastic bags were abundant on the seabed of countries where their use is allowed, and reduced concentrations in countries where these are effectively banned, e.g. in Italy, which since 2011 has only allowed biodegradable plastic bags (Fortibuoni et al., 2019).

The impact of fishing and aquaculture activities on seabed marine litter was evident on sites that are used by this economic sector. For example, Strafella et al. (2019) found that lost fishing nets and mussel culture debris accounted for 50% of the seabed plastic litter identified in their study in the Northern and Central Adriatic Sea over a period of six years. Similarly, 80% of the 1700 litter items identified on the seamount El Seco de los Olivos (West Mediterranean Sea) comprised ALDFG, mainly longlines, but also trammel nets, bottom trawl nets, fishing traps, ropes, buoys, as well as batteries, anchors and metal bars (Martínez-Dios et al., 2025). This is attributed to the fact that this seamount has a long tradition of being used as a fishing ground. The impacts of fishing on seabed litter were also noted by Incera et al. (2024), who observed an increasing amount of ALDFG in areas with increasing fishing activity at the Concepción Seamount, Canary Islands. In fact, in areas of high fishing activity, fishing-related litter, mainly fishing lines and fishing ropes, makes up the majority of seabed marine litter, contributing nearly 72% if seabed litter in the Aeolian archipelago (Consoli et al., 2021), between 70% and 80% of seabed litter in shallow (<100m) and deeper (600-700m) Norwegian waters (Buhl-Mortensen & Buhl-Mortensen, 2018), and 84% of the litter identified in the Indian Oceans (Woodall et al., 2015). In the South-East German Bight, fishing accounted for approximately 61% of the identified litter, and this was attributed to the common practice of bottom trawling in the area (Meyerjürgens et al., 2022), whereas in a study completed in Korean waters, fishing operations accounted for over 98% of the seabed litter (Song et al., 2021).

Beyond plastics, including fishing gear, the reviewed studies also identified other types of litter on the seabed, albeit in smaller concentrations. These included metal, cloth/textiles, glass/ceramics, paper/cardboard, and timber. Heavy litter items such as metal cans, aluminium and glass bottles normally settle to the seabed near the point where they are released, as they tend to fill with water and sand quickly (e.g. Li et al., 2025; Segal & Lubinevsky, 2023; Viejo et al., 2023). Therefore, these are linked to sea-based littering, including recreational boating (e.g. Stagličić et al., 2021) and fishing activities (Viejo et al., 2023). Studies show that areas that are located in the vicinity of marinas and shipyards are littered with debris that stems directly from activities taking place in these areas, including tyres and cans (Fakiris et al., 2022). Similarly, investigated areas near aquaculture facilities demonstrated a high concentration of related litter. For example, Strafella et al. (2019) found a large amount of mussel culture debris, mainly tubular nets, near mussel farms. Pasquini et al (2016) and Passanini et al. (2023) also observed litter hotspots associated with congested shipping lanes in the Adriatic Sea.

Table 2. Abundance and composition of seabed marine litter as reported in literature from 2000 to 2026.

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Read & Turner, 2025	2024-2025	Western English Channel	Bottom Trawl	40-120	4.3 kg/km^2	40% packaging (food containers and beverage bottles), 33% fragments of larger objects, 13% plumbing and cooking articles, 7.8% military equipment (sonobuoys), 5.6% fragments of wires and ropes, floats and buoys.
Castellan et al., 2025	2023	Al Wajh, Saudi Arabian Northern Red Sea	ROV	92–1337	0.19 items/km	Plastic bags, a cup
Atmaja et al., 2025	n.a.	Bali, Indonesia	Manual collection	Shallow coastal seagrass habitats	High Tourism Impact Zone: 3.04 ± 2.6 items/m^2 Intermediate Tourism Impact Zone: 0.7 ± 0.9 items/m^2 Low Tourism Impact Zone: 0.3 ± 0.5 items/m^2	Predominance of single-use plastic waste: straws (101 items), plastic sheeting (76 items), food wrappers/labels (57 items), cup/plate/bowl (44 items), food containers (40 items), bottle caps (29 items), beverage bottles (26 items), cup/lid (22 items).
Dağtekin et al., 2025	2017-2018	Southeastern Black Sea coast of Türkiye, spanning from Çayağzı Cape to Ünye-Taşkana Cape	Bottom Trawl	0-100	48,744.69 ± 7,543.02 items/km^2	Plastic > 50%, Rubber, cloth/textile, and processed wood formed 9.46%-17.57%, glass/ceramic, paper/cardboard, and metal comprised minor portions, each <6%. Among plastic: plastic bags 36.4%, plastic bottles 18.97%.
Hanke et al., 2025	2020	Calypso Deep, Mediterranean Sea	Manned Deep Submergence Vehicle	5109	26,715 litter items/km^2	88% plastics. Remaining glass, metal and paper.
Li et al., 2025	2022	Offshore Israel, Southeast Mediterranean	Bottom Trawl	200–1300	251- 3515 items/km^2	~90% was plastic litter, which included plastic bags and packaging, plastic sheets, plastic bottles and cups, and plastic strings and nets

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Martínez-Dios et al., 2025	2010-2012	Chella Bank (Alboran Sea), part of the Sur de Almería – El Seco de los Olivos Site of Community Importance	ROV	76 - 700	0.014 items/m^2	90.5% plastic. ALDFG accounted for 80% of the observed litter
Inal et al., 2025	2016, 2019, 2021, 2022	Algeria	Trawl	22-600	373.04 items/km^2	76% was plastic. Mostly black bags and bottles. Cloth/fibre, metal, and other followed but at much lower rates
Kouvara et al., 2025	2020-2024	Thermaikos Gulf, Greece	ROV, visual survey by divers	ROV: 13-90; Divers: 0-5	ROV: 14,951 items/km^2 Divers: 429/100m	ROV: 80% plastics, 12.5% metal. 65% of identified litter attributed to fishing sources. Divers: 76.41% plastic, 14.11% metal, 3.39% rubber, 3.07% glass/ceramics, 1.56% cloth/textile, 1.02% processed wood, 0.43% paper. Approx. 46.16% were single-use plastics, 22.41% related to fishing.
Kokić et al., 2025	2019-2024	Montenegro, Southern Adriatic	Bottom trawl	35-120	260.89 items/km^2	81.95% plastic (of which 29.01% bags, 19.71% bottles), 6.98% metal, 6.42% textiles/natural fibres.
Incera et al., 2024	2018	Canary Islands, Spain	ROV	166-884	2122 items/km^2	83.1% plastics, mainly fishing lines
Martynova et al., 2024	2022	Eastern Red Sea	ROV	35–2415	4069 ± 1188 items km^{-2}	Plastic: 46%, Metal: 26%, Other materials: 28% (including 10% unidentified)
Santos et al., 2024	2013-2016 (Area A)	Bahia state, Northeast Brazil: Area A: Itaparica Island, Area B: Porto Seguro and Santa Cruz Cabrália municipalities	Beach seine net (trawl)	<2.0	Area A: 9.2 items/trawl/site/month Area B: 2.4 items/trawl/site/month	Plastic dominated (>90% of floating litter), with categories including (items/trawl/month): Soft plastics (39.00), single-use cups and plates (14.43), Fragments (11.46), Hard plastics (4.24).

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
	2015-2016 (Area B)					
Viejo et al., 2023	2019-2021	Gulf of Cadiz	Bottom trawl	10-14	24 items/km^2	73% was plastic, 14% metal, 6% textile, 4% glass and ceramics, 1% processed wood, 1% rubber.
Mghili et al., 2023	2022	Al Hoceima, North West Morocco	Bottom trawl	24-200	698 items/km^2	57.17% plastic (of which 40.31% single-use items), 37.65% metal, 2.77% processed/worked wood, 1.80% cloth/textile, 0.41% glass/ceramic, 0.22% rubber.
Pasanini et al., 2023	2020	Geographical subarea GSA 17 — Northern and Central Adriatic	Bottom Otter Trawl (OTB) and Bottom Beam Trawl (TBB)	20-100	Choggia OTB: 32.6 items/km^2; Chioggia TBB: 200 items/km^2; Civitanova Marche: 56.3 items/km^2.	74% plastics, 9.3% metal, 6.1% rubber, 4.8% cloth/textile, 4.7% glass/ceramic, 1.6% other
Sciutteri et al., 2023	2021	Southern Tyrrhenian Sea	Bottom Trawl	525- 576	128.1 items n/km^2	64 % plastic, 29% paper/cardboard, 4% cloth/textiles
Segal & Lubinevsky, 2023	2012-2021	Southeastern Levantine Basin (off Israel)	Bottom trawl	20-1600	115 items/km^2 in the shallow station and 2885 items/km^2 in the deep stations	86% plastic items (bags, cups, caps etc). 1-6% fabric products.
Cerrillo-Escoriza et al., 2023	2019	Motril, Carchuna, and Calahonda canyons,	ROV	Motril: 106-388 Carchuna: 107-740 Calahonda:127-324	Motril: 0.12 items/100 m Carchuna: 8.66 items/100 m Calahonda: 1.13 items/100 m	74.83% plastics (30% bottles, 21% fishing nets, 16% bags, 8% sheets, 2% seedbeds, 23% other), 7.13% metals, 2.0% building materials, 0.45% rubber, 15.59% unspecified.
Angiolillo et al., 2023	2015-2019	Italian coralligenous outcrops: Western Mediterranean Sea, MWE; Ionian and	ROV	14-199	2 items/100m^2	89.3% plastic, 5.5% undefined, 1.5% metal, 1.6% glass/ceramics. 86.04% was fishery-related litter (lines, ropes, nets)

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
		Central Mediterranean Sea, MIC; and Adriatic Sea, MAD				
Fakiris et al., 2022	2016-2019	Ermoupoli bay, Greece	Towed Underwater Camera	0-47	211 items/ha	Drink bottles were the most abundant litter, followed by bags and sheets. Other plastic/polystyrene pieces, cups and cup lids had relatively low densities.
Meyerjürgens et al., 2022	2017-2019	German Bight, North Sea	Bottom trawl	8.2-41.6	2473 items/km^2	97.7% plastics, mostly dolly ropes. 61% of litter associated with fishing and 26% of litter associated with shipping.
Song et al., 2021	2018	East, West and South Seas of Korea	Bottom trawl	79-152	N.A.	71.6% plastics, 25.3% plastics plus metals, minor fractions of rubber, metal, wood, glass, paper, and others. Fishing operations account for 98.4% of the seabed litter.
Stagličić et al., 2021	2018	Natura 2000 sites at Pakleni Islands and Vis Island, Croatia	Visual survey, divers	80-90	0.20 items/m^2	77.6% plastics near Vis Island, 48.0% glass near Pakleni Islands.
Consoli et al., 2021	2010-2015	Aeolian Archipelago, Western Mediterranean Sea	ROV	15 - 411	0.57 items/100 m^2	79.7% plastics and polymers, 9.1% metals, 6.6% glass/ceramics
Selvam et al., 2021	2017-2018	North-eastern part of Arabian Sea, along the northwest coast of India	Bottom trawl	6-21	134 items/km^2	87.1% plastics, mainly plastic bags, food wrappers, and personal care products.
Angiolillo et al., 2021	2018	Ligurian Sea	ROV	350-2200	N.A.	56.6% plastics, mainly fishing-related items (52.4%), plastic bags (8.5%), bottles (8.2%), fragments (2.7%), plastic glasses (2.7%), forks (1.0%), food sacks (0.7%), and unidentifiable pieces of plastic (17.3%). Glass/ceramics and metal contributed 11.3% and 6.8%, respectively.

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Büyükdeveci & Gündoğdu, 2021	2009-2010	Iskenderun Bay, northeastern Levantine coast of Turkey	Bottom trawl	<100	450.94 ± 306.24 items/km^2	Artificial polymer materials (plastics): 87.0% (mostly plastic bags, plastic containers, plastic bottles), Metal: 5.3%, Cloth/textile: 4.5%, Rubber: 3.2%, Processed/worked wood: 1.7%, Paper/cardboard: 1.5%, Glass/ceramics: 0.4%, Unidentified: 0.2%
Santodomingo et al., 2021	2019	Darvel Bay, East Sabah, Malaysia	Camera images	5-15	10.7 items/100 m^2	Plastics: 91%, Other materials: 9% (metal, glass, wood). Main plastic types: Other plastic items (24%), fishing nets/lines (21%), plastic bags (19%), plastic bottles (13%)
Garofalo et al., 2020	2015-2019	Strait of Sicily	Bottom trawl	10 – 800	79.6 items/km^2	58% plastics, 18% metal, 8% textile/natural fibres, 7% glass/ceramics.
Strafella et al., 2019	2011-2016	North-Central Adriatic Sea	"Rapido" trawl	8-100	102.66 kg/km^2	43% plastics, 24% metal, 20% other. Glass, wood and rubber made up very small percentages.
Fortibuoni et al., 2019	2014-2015	11 locations in 5 countries of the Adriatic-Ionian macroregion	Bottom trawl	10-281	10 - 2145 items/km^2 depending on location	
Peng et al., 2019	2018	Xisha Trough, South China Sea	Manned submersible	1729-3378	1-36,818 items/km^2	Plastics (plastic bags, plastic woven bags, capped plastic bottles, and plastic food wrappers) were the most prevalent, followed by derelict fishing gears such as ropes, fishing lines, and shrimp traps. Wood, glass, rubber, and paper were less abundant. Glass bottles or cardboard pieces were rare and mostly in isolation or semi-buried in sediments.
Loulad et al., 2019	2012-2015	Moroccan Mediterranean Sea	Bottom trawl	<50->500	26 ± 68 to 80 ± 133 kg/km^2	Plastic: 73%, Rubber: 12%, Textile: 8%, Metal: 3%, Glass: 0.32%, Unidentified materials: 2.70%
Chiba et al., 2018	1993-2014	Western north Pacific	Manned research submersibles	100 – over 6000	11 to 342 items km^{-2}	33% plastic (89% of which were single-use products), 26% metal, 1.8% rubber, 1.7% fishing gear, 1.4% glass, 1.3% cloth/paper/lumber, 35% other anthropogenic items

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Buhl-Mortensen & Buhl-Mortensen, 2018	2006-2017	Norwegian Sea	Seabed video analysis	122-2204	281 items/km^2	Fishing gear was the most common type of litter
Consoli et al., 2018	2012	South-western coast of Sicily, central Mediterranean Sea, Strait of Sicily	ROV	5-30	0 - 0.64 items/m^2 Mean: 0.11 (±0.16) items/m^2	General waste: 68% (mostly plastic objects), Fishing gear: 32%, Synthetic polymers: 73% of total debris
Maes et al., 2018	1992-2017	Northwest European seas, including Greater North Sea (GNS) and Celtic Sea (CS)	Bottom trawl	n.a.	GNS inshore: 49.0 items/km^2 GNS offshore: 40.5 items/km^2 CS inshore: 24.4 items/km^2 CS offshore: 21.7 items/km^2 Maximum recorded: 1,816-1,835 items km^{-2} at Carmarthen Bay (2003-2004)	Plastic dominance: 65-94% of total litter items across regions. Main plastic items: Bags, bottles, sheeting, and fishing gear. Other materials: Metal, glass, rubber, natural materials. Temporal trend: plastic bags decreased, fishing gear increased.
Macic et al., 2017	2012-2014	South-east Adriatic Sea	Visual census by scuba divers	0-40	2.49/km^2	54% plastics, 23% metal, 9% glass, 8% rubber, 2% cloth, 2% paper, 2% other
Tekman et al., 2017	2002, 2004, 2007, 2011, 2012, 2014	HAUSGARTEN Observatory, eastern Fram Strait (Arctic)	Towed camera	2500	6,566 items/km^2	47% plastic, 26% glass, 11% rope, 7% metal, 6% fabric, 4% paper/cardboard, pottery and timber.

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
García-Rivera et al., 2017	2014	Gulf of Alicante, Spanish Mediterranean	Bottom trawl	50-700	0–11.6kg/km^2	75.9% plastic, metal and glass by weight. Artificial polymer materials (18.56%), Metal (10.51%), Glass/ceramics (9.50%) were major categories. Fishing-related litter comprised 68.1% of all Artificial Polymers (mainly nets, longlines and pots), 37.5% of all Rubber (gear parts and boots), 26.1% of all Processed/Worked Wood (e.g. fish boxes) and 25.1% of all Metal (gear parts).
van den Beld et al., 2017	2009-2011	Bay of Biscay, North-East Atlantic Ocean	ROV with towed camera	220-2358	4,813 items/km^2	42% plastics, mostly bags or sheets, 16.2% fishing-related items, 6.1% cables and ropes, 8.6% glass bottles, 15.2% other items, 11.6% unidentified items.
Pasquini et al., 2016	2014	Northern and Central Adriatic Sea	Bottom trawl	0-100	913 items/km^2	Plastic is ubiquitous – composed of bags, packaging and mussel nets.
Strafella et al., 2016	2011-2012	Northern and Central Adriatic Sea	“Rapido” trawl	0-100	85 kg/km^2	34% plastics, 28% metal, 28% other. Rubber, wood and glass made up very small percentages
Tubau et al., 2015	2002-2011	Northwestern Mediterranean Sea	ROV	140-1731	>8000 items/km^2	72% plastics, 17% fishing gear, 8% metal
Woodall et al., 2015	2011, 2013	Submarine features in the South-west Indian Ocean ridge & equatorial Atlantic Ocean	ROV	Atlantic: 200-3000; Indian: 100-1500	Atlantic: 4.52 items ha^{-1}; Indian: 7.07 items ha^{-1}	Atlantic: 25% fishing gear, 25% glass, 25% other, 25% metals and plastics; Indian: 84% fishing gear.
Ioakeimidis et al., 2014		Saronikos, Patras and Echinades Gulfs, Limassol Gulf, Constanta Bay	Bottom trawl	0-200	24 items/km^2 - 1211 items/km^2, depending on site	Plastics were the most abundant litter type (mainly bags, bottles and sheets), followed by metals and glass/ceramics.

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Sánchez et al., 2013	2009	Italy, Greece, Spain – Northern Mediterranean	Bottom trawl	40-80	0 - 405 pieces/ha	Plastic bags and bag pieces (37%), cellophane type (28%). Hard plastics (11%), fishing-related debris (8%), hygiene-related items (2%), glass (3%), metal (3%), cloth (1%), anthropogenic wood (1%).
Mordecai et al., 2011	2007	Lisbon, Setúbal, Cascais and Nazaré Canyons located west of Portugal	ROV	741- 4574	Mean: 1100 items/km^2 Lisbon Canyon: 6616 items/km^2 (highest) Setúbal Canyon: 2463 items/km^2 Cascais Canyon: 1058 items/km^2 Nazaré Canyon: 417 items/km^2	Plastic dominated overall (68%), followed by fishing gear (10%). Composition varied by canyon: Lisbon had 86% plastic, while Nazaré had 37% fishing gear and only 25% plastic
Abu-Hilal & Al-Najjar, 2009	2003-2004	Gulf of Aqaba, Red Sea, Jordan	Divers	0-10	2.8 items/m^2 (range: 1-6 items/m^2)	Plastic: 42% (bags 61%, bottles 24%, plastic containers 13%, sheets 2%), Fishing gear: 31%, Metal: 17%, cardboard (1%), and rubber and other items accounted for less than 1%.
Koutsodendris et al., 2008	2000-2003	Four Greek Gulfs - Eastern Patras Gulf (PE), Western Patras Gulf (PW), Western Gulf of Corinth (CW), Echinades Gulf (EG), and Northern Lakonikos Gulf (LN)	Bottom trawl	15-320	72-437 items/km^2 (mean 165 items/km^2)	Plastic 56% (±23), metal 17% (±11), glass 11% (±14), synthetic 5% (±5)
Katsanevakis & Katsarou, 2004	2003	Greece, eastern Mediterranean	Visual census by scuba divers	0-25	15 items/1000 m^2	55.47% plastics (mainly bottles, cups, bags, ropes, sachets, fishing lines), 25.73% metal (mainly beverage cans, anchors, chains), 5.16% rubber/tyres, 3.53% paper-cardboard, 2.71% clothing, 2.09 glass, 0.59% ceramic, 4.73% other

Paper	Study Year	Location of Study	Method	Depth (m)	Mean Litter Density	Litter Composition
Galgani et al., 2000	1992-1998	Baltic Sea, North Sea, Celtic Sea, Bay of Biscay, different areas in the north-western basin of the Mediterranean Sea and the Adriatic Sea	Bottom trawl	10-16	1.4–3.78 items/ha, depending on location	>70% plastics (mainly bags and bottles). Fishing gear was common.

6. Composition and Abundance of Riverine Litter

To identify relevant papers on the types of litter found either floating or on riverbanks, a search of the following terms was undertaken on Scopus: (river) AND (litter OR debris) AND (composition). The search was limited to papers published between 2000 and 2026 and focused on peer-reviewed articles presenting primary research; conference papers and reviews were excluded. This resulted in 1,313 potential documents. However, a close look at these documents revealed that a large number of them concerned leaf litter or leaf debris. Therefore, the Scopus search was revised to the following: (river* OR stream* OR freshwater OR riverine) AND (aquatic litter OR riverine litter OR anthropogenic litter OR solid waste OR plastic debris OR floating debris OR floating litter) AND (composition OR characterisation OR characterization OR classification OR categorization OR typology) AND NOT (leaf litter OR leaf debris OR woody debris OR detritus). This refined search, limited to articles in English between 2000 and 2026, returned 698 results. Most of these articles fall within the topic of Environmental Sciences (57.7%) (Figure 21). The number of articles being published per year increased more than tenfold from 2000 to 2020, demonstrating the increased interest in this area (Figure 22).

The titles and abstracts of the identified articles were reviewed. Articles not meeting the literature review requirements were excluded. Articles focused on microplastics, and articles not presenting the composition of litter were also excluded – while interesting, these do not provide information on the types of litter that are found alongside or in rivers. This resulted in a final number of 23 articles that were included in this review (Table 3).

The studies that have been reviewed herein span global river systems. Most of them focus on urban rivers, although some also investigated mixed-use (urban, agricultural, natural) or low-human-activity rivers. The sampling methods and sampling locations varied. While most investigated the amount and types of litter along riverbanks, several researched floating litter, some investigated water column litter and a few collected data from litter caught through collection systems, such as screens and booms.

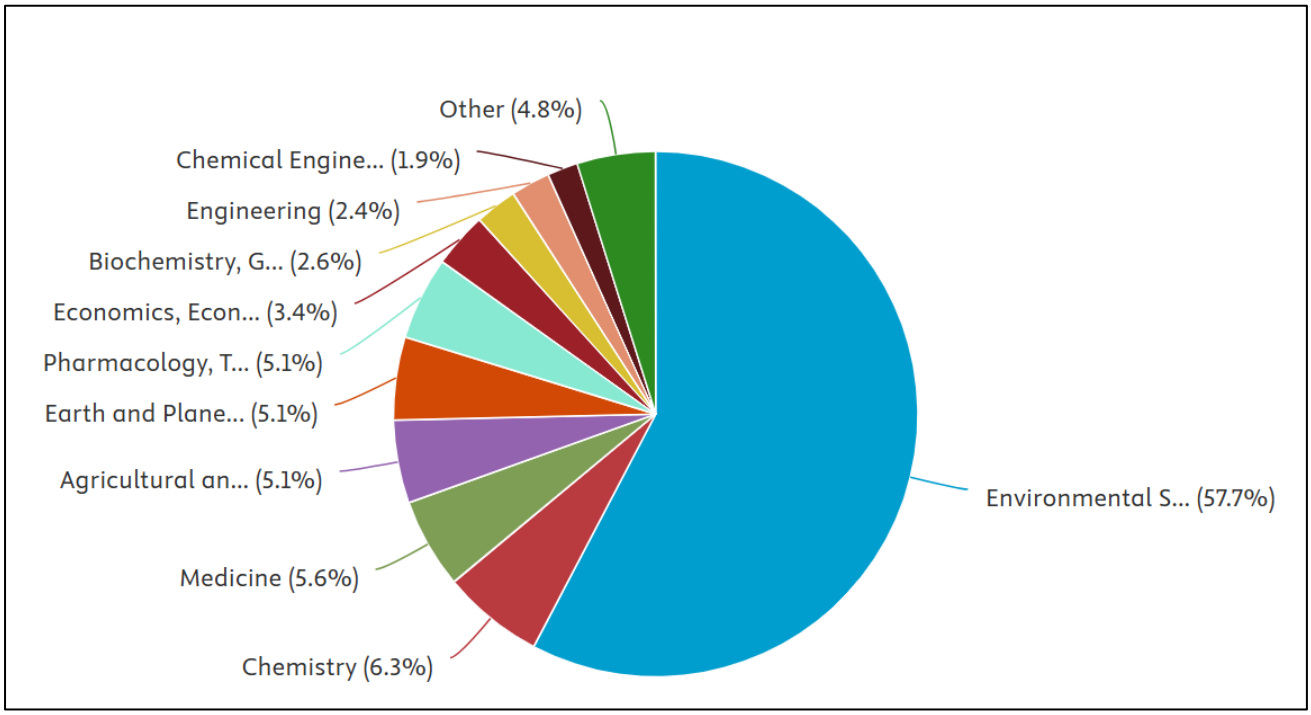


Figure 21. Research papers on riverine anthropogenic litter by subject area.

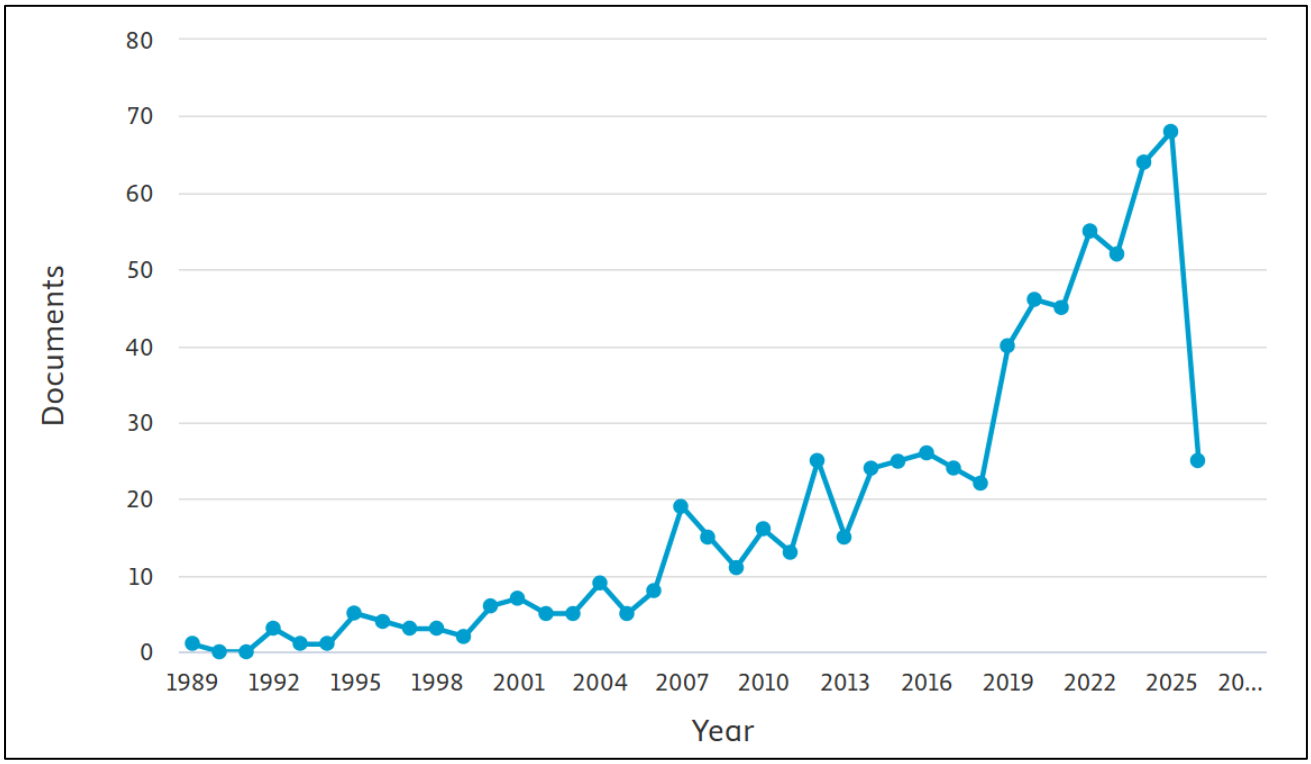


Figure 22. Research papers on anthropogenic riverine litter by year.

A complex system of capture and release of litter is at play in riparian ecosystems. Anthropogenic activities in a river's catchment area contribute a consistent input of litter into the river, which tends to accumulate during low flow conditions (Bauer-Civiello, 2019). Furthermore, activities along the river result in litter accumulation, particularly of larger pieces of litter, on the riverbanks. Rivers can thus act as reservoirs, temporarily storing litter (Dittmann et al., 2024). During times of high rainfall and flooding, litter from the river's catchment area, including public spaces, parks, and roads, finds its way towards the river through storm drains (Bauer-Civiello et al., 2019). Litter trapped by vegetation on the riverbanks, exposed to environmental conditions, including sunlight, is also mobilised and enters the river (Laverre et al., 2023; Vriend et al., 2023). By this stage, the degraded structure and reduced integrity of the litter items mean that they more readily fragment into smaller items (He et al., 2024), contributing to microplastic pollution.

Litter densities, where reported, were variable; however, they tend to increase from river sources to river mouths (e.g. Kuizenga et al., 2023; Rech et al., 2015; Schneider et al., 2021), demonstrating the role of rivers as conduits of anthropogenic litter from land to the sea. In fact, research has shown that European rivers discharge from 7×10^3 to 3×10^6 items/year into the Mediterranean (González-Fernández et al., 2021). Globally, rivers are estimated to contribute between 4.8 and 12.7 million tonnes of litter into marine environments every year (Jambeck et al., 2015). Asian rivers have been shown to discharge four times more plastics than European rivers (van Calcar & van Emmerik, 2019).

Along riverbanks, typical litter densities varied from 0.17-0.65 items/m^2, although some studies reported greater variability. For example, a study in Nigeria reported extremely high concentrations of nearly 3,500 items/m^2. There was also great variation in the reported densities of floating (surface) litter, with ranges from 10 to over 2000 items/hour. There are, of course, numerous factors that affect riverine litter densities, including seasonal variations. For example, Cesarini et al. (2023) observed the greatest amount of floating macrolitter in autumn and the lowest in summer. This is probably related to the occurrence of precipitation events, as the greatest amounts of litter were observed after autumnal rainfall events. Some literature also highlights the use of rivers as illegal waste disposal systems. For example, small illegal dumping sites were identified near rivers in the Philippines (Goutierez et al., 2024), whereas a study of waste piles in Malawi found that 89.5% of them are located along the riverbanks, showcasing how the local communities rely on the rivers to dispose of their waste (Kalonde et al., 2025). Socio-economic factors affect the presence of litter, with population density, per capita disposable income, and passenger traffic being positively correlated with plastic pollution (He et al., 2024). In fact, González-Fernández et al. (2021), who investigated floating macrolitter leaked from 42 rivers in 11 EU and near-EU countries, found that the highest contributors are high-income countries. This is because high-

income countries contain most of the investigated river basins and have high coastal population densities. These countries also host over three-quarters of the investigated small-sized drainage basins, which were found to be responsible for the highest floating macrolitter in Europe. The contribution of large basins was found to be lower, as macrolitter is more likely to be retained by vegetation and artificial barriers, dragged down to the deeper layers of the river by sediments and epiphytes, or degrade into smaller fractions. The fact that large European rivers are also regulated, often by dams, is another possible reason for the reduced observed macrolitter flows.

Urban rivers and rivers associated with higher human activity are generally more polluted than rural rivers. Riverine systems near roads and buildings display the highest accumulation of litter (Cowger et al., 2019; He et al., 2024; Schreyers et al., 2024), particularly plastics. For example, plastic transport in the Rhine River has been observed to be 2.3 times higher in urbanised areas than in areas that are considered non-urbanised (Kuizenga et al., 2023).

Plastics dominate across all regions, geomorphological areas and socio-economic conditions, constituting typically 50-97% of total litter. The most common plastic items are food packaging and wrappers, plastic bags, bottles and caps, and sanitary items such as wipes. Cigarette butts are also major contributors in several regions. Single-use plastics are ubiquitous along urban and semi-urban riverbanks, but also along the banks of less urbanised areas. Other common materials identified in riparian ecosystems include glass/ceramics (up to 20%), metal (1-11%), paper and cardboard (1-14%), and smaller percentages of textiles, rubber and wood.

The composition of litter in rivers near agricultural areas appears to be different. For example, near vineyards, Schreyers et al. (2024) noted that industrial sheeting, foamed items and non-packaging/insulation pieces are prevalent. Fortibuoni et al. (2019) noted that the litter on Italian riverbanks near agricultural areas was composed mainly of polystyrene pieces, plastic pieces less than 50 cm and plastic drink bottles.

While differences exist between studies, it is clear from the reviewed body of work that the amounts and types of litter found in riverine environments are the direct result of human activities taking place in the surrounding area. Research conducted during the COVID-19 pandemic highlights this, as it identified increased amounts of personal protective items, such as face masks and disposable gloves, floating in urban riverine environments (Cesarini et al., 2023). On the other hand, He et al. (2024) observed reduced presence of plastic litter items in areas with high forest and crop land cover, as a result of limited human activity.

Table 3. River litter density and composition as reported in the reviewed literature.

Article	Study Year	River	Urbanisation level	Study location	Method	Litter Density	Composition
Blettler et al., 2026	2021	Spree River, Berlin	Urban river	Riverbanks; Aquatic-terrestrial interface; Active channel	Visual survey	Riverbanks: 0.17 items m^{-2}	Food wrappers (34.7%), followed by cigarette butts/filters, bags, glass bottles, and other plastics. Non-plastics (4.4%).
Yousefi et al., 2025	2024-2025	Aras River, northwestern Iran		Riverbanks	Visual survey	0.378–0.656 items/m^2	Cigarette butts (46%) and plastic (27%)
Andrade-Muñoz et al., 2025	2022	Southwest Patagonia, Argentina	Urban streams, reference streams (minimal or no human intervention)	Riverbanks	Visual survey	Urban: 0.18 items/m^2 Reference: 0.01 items/m^2	Plastic bags and food wrappers
Fortibuoni et al., 2025	2021-2023	16 rivers from the North to the South of Italy	Agricultural, Urban Park, Natural, Urban	Riverbanks	Visual	0.2 items/m^2	Artificial polymer materials (56%), glass/ceramics (20%), metal (11%), and paper/cardboard (6%). Half of the items belonged to just four categories: glass bottles (17%), cigarette butts (14%), plastic pieces (11%), and wet wipes (8%)
Dittmann et al., 2024	2016-2022	4 major river systems that flow through Germany (Danube, Rhine, Weser, Elbe) and smaller rivers that discharge directly into the North and Baltic Sea	Mixed	Riverbanks	Visual	0.28 items m^{-2}	Plastic (~28 %), followed by cigarette butts (~21 %), glass (~19 %), paper (~10 %), metal (~10 %), other items (10%), food leftovers (1%)
Schreyers et al., 2024	2020-2021	Switzerland	Urban	Riverbanks	Visual		Diapers and wipes (~22%), cigarette filters (21.5%), glass bottles and pieces (13%), industrial sheeting (12.5%), food wrappers

Article	Study Year	River	Urbanisation level	Study location	Method	Litter Density	Composition
							(9.5%), packaging films (not food-related) (6.5%)
He et al., 2024	2021	Suzhou section of Beijing-Hangzhou Gran Canal (SZ), Jihgmen section of the Hanjiang River (JM), China	SZ: urban JM: rural	Floating	Trawling	SZ: 0.430 items/m^3 JM: 0.003 items/m^3	SZ: >50% take-out consumer items. Fishing and waterway items prevalent. JM: only 8 plastic items.
Gutierrez et al., 2024	2021	Pulot River, Philippines	Urban	River edge, riverbank, river crest	visual	River edge: 1.08 items/m2; riverbank, 0.49 items/m2; river crest 0.62 items/m2	42% food packaging, 27% plastic bags, 12% toiletries, 4% plastic bottles, 3% plastic cups, 2% bottle caps, 10% other plastics
Vriend et al., 2023	2021-2022	Rhine river, Netherlands		Water column	Trawl	0.78 items/1000 m^3 to 24.44 items/1000 m^3	Soft plastic film fragments 0–2.5 cm (43.2 %), soft plastic film 2.5–50 cm (31.1 %), string and cord with a diameter < 1 cm (6.4 %), sanitary wipes (4.9 %), and hard undefined plastic pieces 0–2.5 cm (3.1 %).
Laverre et al., 2023	2016-2019	Têt River (NW Mediterranean Sea)	Urban	Water surface (floating litter)	Visual	0.65 $t \cdot year^{-1}$	Plastic fraction represented 97 % of the observed litter, mainly cigarette butts (20.5 %), polystyrene fragments (18.8 %), light packaging (16.3 %), plastic fragments (12.8%), cotton buds (6.7%), bottle tops and rings (3.5%)
Mikusheva et al., 2023	2021	Northern Dvina and Onega rivers, Arctic	Urban	Water surface (floating litter)	Visual	Northern Dvina River was 250–1720 (±54) items/hour Onega River was 520–2350 (±150) items/hour.	Artificial polymers (59.6%), processed/worked wood (27.7%), paper/cardboard (8.5%), metal (2.7%), rubber (1.1%) and textiles (<1%)

Article	Study Year	River	Urbanisation level	Study location	Method	Litter Density	Composition
Cesarini et al., 2023	2021-2022	Tiber River, Rome	Urban	Water surface (floating litter)	Visual		Plastic (92.9%), paper (2.6%), rubber (1.5%), glass (1.5%), metal (0.6%), cloth/textile (0.6%) and processed wood (0.5%)
Kuizenga et al., 2023	2022	Rhine River (20 sites from Netherlands to Switzerland)	Mixed	Water surface (floating litter)	Visual	3–988 items/hou	84% plastic
Palmas et al., 2022	2018, 2020	37 river basins in Sardinia	Mixed	Riverbanks	Visual	156 items km^{-1}	Artificial polymers (70.4%), Metal (9.3%), Cloth/Textile (8.5%), Glass & Ceramic (7.4%), Other materials incl. rubber, paper, and processed wood (4.4%).
Tramoy et al., 2022	2017, 2018	Huveaune River in Marseille, South of France	Urban	Sampled waste from litter collected by a river screen	Visual	74 litter items/h (dry period) to 725 items/h (heavy rainfall episode)	Plastic debris (83%), glass/ceramics (0–3%), metal (1–6%), paper/cardboard (0–7%), processed wood (0–4%), cloth/textile (1–4%) and rubber (0–1%)
Honorato-Zimmer et al., 2021	2013, 2017	51 sites along 27 Chilean rivers	Mixed	Riverbanks, floating	Riverbanks: visual; Floating: neuston net & visual	Riverbanks: 0 to 21.8 items m^{-2} Floating: 10.1 items h^{-1}	Riverbanks: plastics (29%), paper (14%), glass (12%), cigarette butts (11%), metal (8%), and other items (23%)
Schneider et al., 2021	2020	Tamsui River, Taiwan	Mixed	Riverbanks, estuary	Visual	Riverbanks: 0.2 m^3/km to 2.8 m^3/km	Riverbanks: mostly plastic bottles, plastic bags and disposable tableware. Estuary: mostly plastic bottles and fishing-related items
Schirinzi et al., 2020	2016-2017	Llobregat and Besòs rivers, Catalonia, Spain	Urban	floating	Visual	Llobregat: 32.7 items/h; Besós: 9.9 items/h	Llobregat: 67.7% plastic, 15.2% paper, 7.7% rubber, 4.7% wood, 3.7% metal, 1.0% cloth/textile

Article	Study Year	River	Urbanisation level	Study location	Method	Litter Density	Composition
							Besòs: 49.3% plastic, 21.2% paper, 16.5% metal, 9.8% cloth/textile, 2.5% wood, 0.5% rubber
Ebere et al., 2019	2019	Five rivers in Nwangele, Imo State, South Eastern Nigeria	Urban	Riverbank	Visual	3,487 items/m^2	Plastics (59%), metal (10%), cloth (7%), paper/cardboard (7%), rubber (7%), glass/ceramics (5%), medical and agro-based waste (3%) and wood (2%).
Bauer-Civiello et al., 2019	2014-2017	Ross River, Townsville, North Queensland, Australia	Urban	Floating	Visual	N.A.	Plastics (93%), metal (5%), all other materials (2%)
Crosti et al., 2018	2016-2017	Tiber, Rome, Italy	Urban	Floating	Visual	N.A.	82% plastic, 8% paper/cardboard, 4% rubber, 3% metal, 2% processed/worked wood, 1% cloth/textiles
Malik & Manaf, 2018	2016	Sungai Batu, Kuala Lumpur, Malaysia	Urban	Litter at a collection boom	Sampling	N.A.	By weight (not item numbers): plastic (39%), cardboard, paper and tetrapak (1%), glass (4%), metal (1%), garden waste (21%), organic waste (8%)
González-Fernández, 2021	2016-2017	42 rivers/streams from 11 EU and neighbouring non-EU countries	N.A.	floating	visual	N.A.	82% plastic, 9% paper/cardboard, 4% metal, 2% processed/worked wood, 2% rubber, 1% cloth/textile

7. Composition and Abundance of Litter in Other Freshwater Ecosystems

There are very few studies available on the amounts and composition of macrolitter and/or macroplastics in freshwater ecosystems (Aslam et al., 2022; Hengstmann & Fischer, 2020). A search in Scopus for (waste OR litter OR debris) AND (lake OR pond OR freshwater) AND (composition) AND NOT (microplastic) AND NOT (leaf), limited to articles in English published from 2000 to 2026, returned 1,105 results (Figure 23).

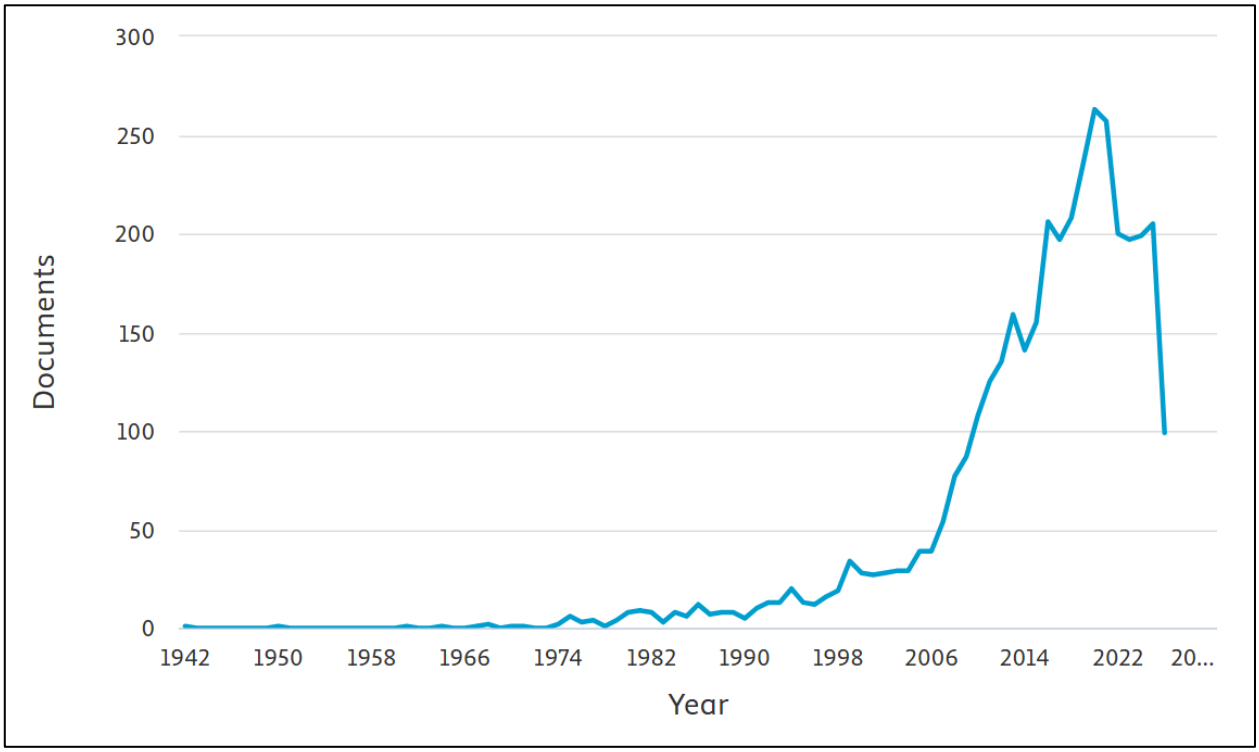


Figure 23. Documents on freshwater anthropogenic litter by year (2000 – 2026).

The titles and abstracts of these articles were reviewed, and those not including information on anthropogenic litter abundance and/or composition were excluded from further consideration. The resulting 14 papers were analysed, with the relevant information appearing in Table 4.

Plastics are overwhelmingly the dominant litter type across all freshwater ecosystems studied, accounting for 60-90% of all litter. Packaging-related items are consistently among the most abundant litter categories, particularly plastic bags, food wrappers, beverage bottles, food containers and other single-use plastic packaging. Freshwater ecosystems exhibit similar litter composition as marine ecosystems (Zbyszewski et al., 2014). Furthermore, as with marine ecosystems, human activity near

freshwater bodies heavily influences the types and abundance of litter. Sites located near cities, ports, or industrial zones consistently exhibited the highest litter densities (e.g. Aragaw, 2021; Eriksen et al., 2013; Okuku et al., 2024). Tourism and recreation are major contributors to litter, particularly on accessible beaches and ferry locations (e.g. Okuku et al., 2024; Yünlü, 2025). Cigarette butts were particularly important at recreational sites, such as those by Lake Tollense in Germany, where they represented 39% of all items (Hengstmann & Fischer, 2020). Fishing-related litter was also commonly found in freshwater environments, both on shorelines and within water bodies (e.g. Ngupula et al., 2014; Yünlü, 2025), in direct relation with fishing activities taking place within dams or lakes.

The reviewed research highlighted the role of inadequate waste management and improper waste disposal towards the pollution of freshwater systems by anthropogenic litter. Specifically, Özşeker et al. (2022) identified "improper disposal" as a main contributor of litter in freshwater systems in Türkiye, Aura et al. (2026) identified informal settlements as substantial contributors to litter in Lake Victoria (African Great Lakes), whereas Lake Hovsgol's (Mongolia) unexpectedly high pollution was attributed to "the lack of modern waste management system" (Free et al., 2014). Even in countries with advanced waste management systems, such as Canada, the effect of ineffective waste management for industrial waste, particularly plastic pellets, was highlighted (Zbyszewski & Corcoran, 2011). The abundance of these pellets, which made up to 94% of the collected litter, decreased with increasing distance from the industrial sector in the proximity of the lake. Pellets were also a significant portion of the plastic particles identified downstream from two major cities in the Laurentian Great Lakes of the United States (Eriksen et al., 2013).

Much like the research regarding marine litter, river rainfall, currents and wind strongly influence litter distribution. River transport was identified as the largest source of litter (contributing 22.93%) in Borçka Dam Lake in Türkiye (Özşeker et al., 2022), whereas wind-driven circulation was shown to create hotspots of microplastic litter on the shorelines of Lake Garda in Italy (Imhof et al., 2013).

Table 4. Reviewed article information on the abundance and composition of litter in freshwater ecosystems.

Article	Study Year	Study location	Water Body	Sampling Location	Litter Density	Composition
Aura et al., 2026	n.a.	Kisumu Bay, Kenya	Lake Victoria	9 shoreline transects across 3 land use categories: industrial areas, informal settlements, beach/landing sites	<25 items/m^2 to >250 items/m^2	Macroplastic contributions: Industrial areas: 81.03% of total items, Informal settlements: 13.22%, Beaches/landing sites: 5.75% Composition in industrial areas: miscellaneous plastics (3182), other waste (3025), plastic packaging (2081), plastic bottles (1726), and milk packaging (890) Informal settlements: other waste (2188) and glass items (157) Beaches/landing site: plastic bottles (891) and smaller quantities of food containers (49), glass items (34), and rubber items (26)
Yünlü, 2025	2024	Western Mediterranean region of Türkiye	Lake Eğirdir & Lake Kovada	13 sampling stations on lake shores	0.306-4.938 items/m^2	Lake Eğirdir: Plastic/polystyrene 78%, metal 5% Lake Kovada: Plastic/polystyrene 73%, metal 9% Mixed packaging was the most important source in both lakes, followed by fisheries in Lake Eğirdir and recreational litter in Lake Kovada. Fishing activities are intensive in both Lake Eğirdir and Lake Kovada. Abandoned fishing nets were observed on the shores and in the water of both lakes.
Özşeker et al., 2025	2022-2024	Türkiye	Borçka, Muratlı, and Torul reservoirs, Uzungöl Lake	3 sampling stations at each lake shore. Seasonal monitoring.	Mean: 3.66 ± 0.55 items/m^2 Borçka: 8.25 ± 1.52 items/m^2 Muratlı: 1.92 ± 0.12 items/m^2 Torul: 3.23 ± 0.22 items/m^2 Uzungöl: 1.23 ± 0.13 items/m^2	Plastic (59.44 %-63.95 %), metal (6.78 %-12.97 %)., glass/ceramic, paper/cardboard/textile, food.
Wulan et al., 2024	2022	Wado Area, Sumedang, West Java, Indonesia	Jatigede Reservoir		n.a.	34% organic, 15% others (dolls, bags, shoe insoles, shoes, hats, sandals, carpets, rope mines, electronic devices, metal straws, children's toys, candles, lighters, balloons, wallets, hats, LED lights, sacks, cloth, hair ties, and cables), 23% low density polyethylene (plastic bags, bubble wrap, packaging instant noodles, oil packaging, laundry soap packaging, snack packaging, flour packaging, seasoning packaging), 17% polystyrene (styrofoam), 4% polyethylene terephthalate, 3% polypropylene, 2% high density polyethylene, 2% polyvinyl chloride.

Article	Study Year	Study location	Water Body	Sampling Location	Litter Density	Composition
Okuku et al., 2024	2022	African Great Lakes and Great Rift Valley Lakes	Lake Victoria, Lake Turkana, Lake Naivasha and Lake Baringo	28 beaches and 22 nearshore water areas (floating litter)	2.890 ± 1.90 items/m^2 Lake Naivasha: 3.707 ± 1.975 items/m^2 Lake Victoria: 3.375 ± 1.825 items/m^2 Lake Baringo: 2.156 ± 1.324 items/m^2 Lake Turkana: 1.732 ± 2.276 items/m^2	Plastic (81.5%). High densities of broken glasses were observed on the beaches, Lake Victoria: fishing nets (13.5 %), soft plastics (9.1 %), and food wrappers (7.9 %). Detailed data by station in the article.
Özşeker et al., 2022	2017-2021	Türkiye	Borçka Dam Lake and Murgul Stream	7 shoreline stations: 4 on Borçka Dam Lake and 3 along Murgul Stream		Plastic (25.47-88.89%) comprised mostly of plastic pieces, bags, and foams. Metal (0-30.00%) comprised mostly of cans, bottle caps, big metal pieces and other metal pieces. Detailed data by station in the article.
Aragaw, 2021	2020	Amhara Regional State, north-western Ethiopia	Lake Tana	7 sites: 1 city, 6 small towns	Mean accumulation rates ranged from 4.9 ± 3.9 to 30.5 ± 20.2 items m^{-1} day^{-1}	Plastics (dominant, especially plastic bottles, plastic bags), Woods, Papers and cardboards, Metal, Hygiene items, Foam, and Clothes. Food packaging products comprised 88.7% of packaging debris
Hengstmann & Fischer, 2020	2017-2020	Mecklenburg-Western Pomerania, Germany	Lake Tollense	4 beaches: 2 with high, 1 with medium and 1 with low anthropogenic use	Mean: 0.2 ± 0.1 items/m^2 ; 0.5 ± 1.0 g/m^2 ; 130.9 ± 91.0 items/100 m Range: 0.1 to 0.6 items/m^2	Plastic: 71.5%, Glass: 9.7%, Paper: 7.4%, Metal: 7.1% Top item: Cigarette butts and filters (39% of all items)
Mayoma et al., 2019	2015-2018	Central and Northern regions of Malawi, Africa	Lake Malawi	3 beaches: 2 with tourism, fishing and farming, 1 port hub	0.89-5.11 items/m^2	Plastic 80.2 ± 5.0%, metal 9.5 ± 2.5%, glass 4.9 ± 3.8%, paper 4.6 ± 4.0%, and construction material 0.9 ± 1.5%. Plastic composition: plastic carrier bags (22.5–49.4%), personal hygiene products (7.15–18.6%), beverage bottles (1.9–18.8%), fishing gears (0.21–20.25%), cups (1.9–13.3%), packaging materials (1.3–13.8%), bottle caps (4.4–11.6%), lids (1.0–8.8%), and food wrappers (4.4–11.5%)
Blettler et al., 2017	2016	Santa Fe, Argentina	Setúbal Lake	n.a.	1.15 macroplastics/m^2	In order of decreasing abundance: bags, foam food containers, food wrappers, hard food containers/food service items, beverage bottles,

Article	Study Year	Study location	Water Body	Sampling Location	Litter Density	Composition
						cleaning product containers, personal care products, fishing lines, others.
Free et al., 2014	2013	Northern Mongolia	Lake Hovsgol	9 shoreline sites		Macroplastics: 77% of total items and 60% of total weight. By weight, macroplastics were dominated by plastic bottles (37%), fishing gear (25%), plastic bags (16%), and plastic fragments (18%)
Ngupula et al., 2014	2013	Tanzania	Lake Victoria	68 stations in 6 depth strata using bottom trawl	0.011-0.05 g/m^2	Multifilament gillnets (44%), monofilament gillnets (42%), longlines and hooks (7%), plastic bags (4%), floats (2%), and clothing (1%)
Hoellein et al., 2014	2011	Chicago, USA	Lake Michigan	3 shoreline sites		~35% plastic, ~30% cigarette, ~7% paper, ~12% metal, ~2% glass, ~0.5% polystyrene, ~12% other
Imhof et al., 2013	n.a.	Italy	Lake Garda	2 beaches, one in the north and one in the south	North shore: 483 ± 236 macroplastic particles/m^2 1,108 ± 983 microplastic particles/m^2. South shore: 8.3 macroplastic particles/m^2	94% of plastic pellets were found at a single beach

8. Composition and Abundance of Litter in Terrestrial Environments

In recent years, the issue of microplastics in agricultural environments has emerged as a popular research topic; however, research and data on macro-litter across terrestrial environments are scarce. In fact, identifying relevant primary research proved to be particularly challenging. Several search combinations were undertaken, focusing on articles in English, between 2000 and 2026. A search in Scopus for (litter OR debris OR waste) AND (land OR terrestrial environment) AND NOT (microplastic), returned over 9,000 documents, which was an excessive number to review. Therefore, the search was further focused using the following terms:

- A search for (plastic) AND (pollution) AND (terrestrial environment) resulted in 793 documents, mostly on microplastics.
- A search for (litter OR debris OR waste) AND (land OR terrestrial environment) AND (composition) AND NOT (microplastic) returned 1,663 documents.
- A search for (littering) AND (land) AND NOT (microplastic) resulted in 61 documents.

A very large proportion of the resulting articles that included the term ‘litter’ contained information and research that is irrelevant to the issue of anthropogenic pollution. This is because the term “litter” in agricultural and ecological settings refers to the accumulation of dead plant materials, such as fallen leaves, twigs, fruits and seeds, onto the surface of the soil. To identify the research that is relevant to this work, a review of the titles and abstracts of the resulting articles was undertaken. Articles that were irrelevant, or focused on microplastics, were excluded from the analysis. Table 5 presents the 15 articles that were eventually included in this review.

Several of the reviewed studies present urban litter data from Iran, where cigarette butts, ATM (Automated Teller Machine) receipts and plastics were the most dominant litter items around the cities. These studies found that litter density was higher in areas with mostly commercial land-use than in areas with residential land use (Gholami et al., 2020; Nejadsadeghi et al., 2024; Parsa et al., 2025; Rahimi Hezarvand et al., 2025). This could be related to the higher population density in commercial land-use areas, as well as the existence of activities/premises that are linked to littering, e.g. ATM machines, cafes and fast-food restaurants. Cigarette butts also emerge as a significant proportion of urban solid waste pollution around busy roadways in France (Ledieu et al., 2022), and in cities in Israel (Pasternak et al., 2021), Argentina (Seco Pon & Becherucci, 2012) and India (Youngblood et al., 2022).

Plastic items of various sizes and types were identified by the reviewed articles as an important terrestrial pollutant. For example, Van Caneghem et al. (2024) found large amounts of plastic beverage bottles and packaging films in Flanders, Belgium, whereas Ledieu et al. (2022) found that plastic and polystyrene pieces made up over 40% of waste from a highly frequented roadway in Nantes, France. A nationwide, scientifically based litter sampling and sorting campaign in Flanders, Belgium in 2021, collected over 18,000 tonnes of litter, of which 18.4% was plastics, 12.6% metal cans, 8.1% glass, 7.8% bulky waste, and 21.6% residual waste (OVAM, 2022a, as reported by Van Caneghem et al, 2024). Of the collected plastics, plastic packaging comprised nearly 70%. In the USA, a nationwide cleanup campaign estimated that 50 billion pieces were littered along roadways and waterways, of which 38.6% were plastics (Keep America Beautiful, 2021). Additionally, fast-food packaging, both paper and plastic, contributed significantly to the identified litter.

Plastic items also made a significant contribution to the litter found in remote or protected environments. For example, food packaging, fragments of plastic cups and water bottle caps were found on glaciers on the Italian Central-Western Alps (Parolini et al, 2021), whereas balloons and plastic bags were found in a desert environment in Arizona, USA (Zylstra, 2013).

There are various ways through which plastics can enter the terrestrial environment (Figure 24), and terrestrial plastic pollution has been estimated to be between 4 and 23 times more severe than marine plastic pollution (Horton et al., 2017). Through their longevity, continued breakdown into smaller pieces, resulting in micro- and nano-plastics, and their propensity to attract pollutants, plastics can cause significant negative impacts in soil, including on crop production and animal health.

Two of the reviewed studies looked at the presence of macrolitter on agricultural land. Stefano & Pleissner (2022) investigated the degree and composition of macroplastic contamination on two fields in Germany, one where mineralised fertiliser and liquid manure were added and another where mineralised fertiliser, liquid manure and compost were applied. They found that the area where compost was applied had a microplastic concentration of 9247 particles/ha, suggesting that compost application can be a pathway for plastic soil pollution. However, the field without compost application had 220 macroplastic particles/ha. Piehl et al (2018) also investigated the presence of macroplastics on agricultural land where agricultural plastic applications are not used, and found a mean concentration of 206 items/ha, similar to the concentration found by Stefano & Pleissner (2022) for the non-compost-receiving field. Possible pathways for these macroplastics are (i) the application of manure, as plastics are heavily used on farms, (ii) plastics unintentionally attached to agricultural equipment, and (iii) littering, especially where fields are located near roads.

Plastic source		Plastic concentration	Unit	Location	Study
Soil amendments	Compost	1200	mg kg^{-1}	Slovenia	Gajst (2016)
		2.38–180		Germany	Own data
	Sewadge sludge	1500–4000	items kg^{-1}	U.S.	Zubris and Richards (2005)
		16,700		Sweden	Magnusson and Noren (2014)
		4200–15,800		Ireland	Mahon et al. (2017)
		1000–24,000		Germany	Mintenig et al. (2017)
Irrigation and flooding	Wastewater (untreated)	627,000	items m^{-3}	Russia	HELCOM (2014)
		15,000		Sweden	Magnusson and Noren (2014)
		580,000		Finland	Talvitie et al. (2017)
		260,000–320,000		France	Dris et al. (2015b)
		1000		U.S.	Carr et al. (2016)
		15,700		Scotland	Murphy et al. (2016)
	Wastewater (treated)	7000–125,000	items m^{-3}	Russia	HELCOM (2014)
		8.25		Sweden	Magnusson and Noren (2014)
		700–3500		Finland	Talvitie et al. (2017)
		14,000–15,000		France	Dris et al. (2015b)
		250		Scotland	Murphy et al. (2016)
		0–9400 particles; 20,000 fibers		Germany	Mintenig et al. (2017)
	Lake water	48,146 (mean)	items km^{-2}	Lake Geneva (Switzerland)	Faure et al. (2012)
		0–28,097		Great Lakes: Lake Huron, Lake Superior, Lake Erie (U.S.)	Eriksen et al. (2013)
		997–44,435		Lake Hovsgol (Mongolia), remote lake	Free et al. (2014)
		microplastic: mean 91,000 (11000–220,000) macroplastic: mean 1800 (290–6500)		Lake Geneva, Lake Constance, Lake Neuchâtel, Lake Maggiore, Lake Zurich, Lake Brienz (Switzerland)	Faure et al. (2015)
		0.82–4.42	items m^{-3}	Lake Bolsena, Lake Chiusi (Italy)	Fischer et al., 2016
	River water	3300–9900	items m^{-3}	Greater London River (Great Britain)	Sofra et al. (2010)
		0–13,751		San Gabriel and Los Angeles River (USA)	Moore et al. (2011)
		0–141.65		Danube (Central Europe)	Lechner et al. (2014)
		3–106		Seine River (France)	Dris et al. (2015a)
		100–64,000		Rhine River (Europe)	Mani et al. (2015)
Atmospheric input		29–280	items m^{-2} day^{-1}	France (Paris)	Dris et al. (2015a)

Figure 24. Sources of plastics in soil and potential concentrations (from Bläsing & Amelung, 2018).

Table 5. Abundance and composition of terrestrial pollution as reported in the reviewed research.

Study	Years	Location	Type of Environment	Average Litter Density	Litter composition
Parsa et al., 2025	N.A.	Tehran, Iran	Urban	0.198 items/m^2	Cigarette butts (29.85%), paper (12%), plastic (38.43%)
Nejadsadeghi et al., 2024	N.A.	Tehran, Iran	Urban	0.182 items/m^2	Cigarette butts (29%), bottle caps (18%), paper receipts (10%)
Van Caneghem et al., 2024	2019-2021	Flanders, Belgium	N.A.	N.A.	Plastic beverage bottles (50.4%), packaging films (food and non-food combined) (19.2%), rigid packaging (food and non-food combined)(18.2%)
Ledieu et al., 2022	2020-2021	Nantes, France	Highly frequented roadway	24 kg/yr/ha	Plastic pieces (2.5 - 50 cm, 31%), cigarette butts and filters (18%), polystyrene pieces (2.5 - 50 cm, 16%), foam

Study	Years	Location	Type of Environment	Average Litter Density	Litter composition
					packaging and insulation (11%)
Stefano & Pleissner, 2022	2020	North Rhine-Westphalia, Germany	Arable land	Area with compost: 9247 particles/ha. Area without compost: 220 particles/ha.	N.A.
Gholami et al., 2020	2019	Qazvin, Iran	Urban	N.A.	Cigarette butts, ATM receipts, and candy wrappers comprised >80% of urban litter
Rahimi Hezarvand et al., 2025		Ardakan, Iran	Urban, touristic	0.547 -0.576 items/m^2	Cigarette butts (55.11%), paper (13.9%), plastic (4.9%)
Nejadsadeghi et al., 2024	N.A.	Tehran, Iran	Urban	0.182 items/m^2	Cigarette butts (29%), bottle caps (18%), and paper receipts (10%)
Parolini et al., 2021	2020	Central-Western Alps, Italy	Five glaciers	2.4 - 26.4 items/km	Food packaging (27%), mountaineering equipment (22%), technical clothes (8%), non-classified (19%)
Pasternak et al., 2021	2014	Netanya, Israel	Stormwater		Cigarette butts (33%), plastic bags (28.5%), paper (18%), single-use items (17%), sanitary items (2%)
Youngblood et al., 2022	2019	Ganges River Basin, from Bay of Bengal to Himalayas	Varied	5.9 items/m^2	Mostly plastics (75.0 – 87.7%). Mainly plastic food wrappers, tobacco sachets and cigarettes, and plastic fragments
Seco Pon & Becherucci, 2012	2008-2009	Mar del Plata, Argentina	Urban	14 items/m^2	Cigarette butts (33%), papers (31%), and plastics (22%)
Keep America Beautiful, 2021	2020	United States of America	Roadways and waterways	>2600 items/mile	Plastics (38.6%), paper (15.2%), metal (7.9%), glass (7.2%), organics (2.6%), other (28.6%)

Study	Years	Location	Type of Environment	Average Litter Density	Litter composition
Piehl et al., 2018	2015	Middle Franconia, southeast Germany	Agricultural land	206 items/ha	Films (65.43%), fragments (25.93%), other (8.64%)
Zylstra, 2013	2005-2006	Sonoran Desert, southern Arizona, USA	Desert protected area	Plastic bags: 5.6/km^2 - 35.4/km^2; Balloon clusters: 39.2/km^2 - 62.7/km^2.	Balloons and plastic bags

9. Microplastics from Agricultural Mulch Films

While it is not the aim of this report to analyse the abundance and distribution of microplastics, the fact that there is very little information about anthropogenic litter from agriculture and that all the available literature highlights the important contribution of plastic fragments, it was considered relevant to include a short review of available studies looking at the contribution of mulch films in microplastic pollution of agricultural land.

Figure 25 presents the main sources of microplastic pollution to the terrestrial environment. While some of this microplastic pollution is made by primary microplastics, such as pellets in personal care and cosmetic products, a significant portion is made by secondary microplastics, resulting from the breakdown of large plastic items, including mulch films.

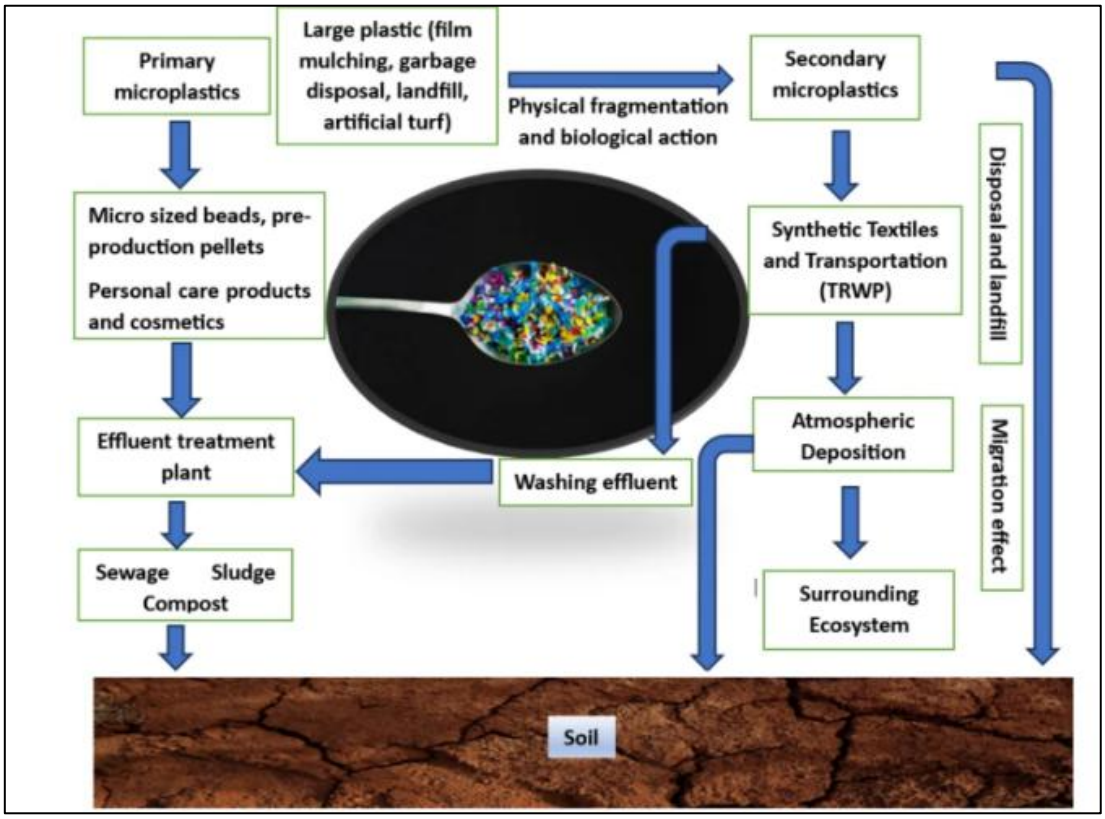


Figure 25. Sources of microplastics to the terrestrial environment. (Source: Rashid et al., 2025).

Plastic mulch application is practised in approximately 20 million hectares of farmland globally, providing agronomic benefits such as increased crop yields, improved soil moisture retention, temperature regulation, and weed suppression (Huang et al., 2020). China uses the largest amounts of mulch film, accounting for 65-90% of global use, with consumption continuing to increase despite recent efforts to promote biodegradable alternatives (Dai et al., 2025; Huang et al., 2020; Steinmetz et al., 2016; Zhang et al., 2021). Mulch films are typically manufactured from polyethylene (PE), especially low density polyethylene (LDPE) and linear low-density polyethylene (LLDPE). Although some films are collected after use, a significant portion remains unrecovered because removal is technically difficult and economically costly, resulting in the accumulation of plastics in soils (Nuñez-Rubio et al., 2025; Wang et al., 2022a; Wang et al., 2022b). Ultraviolet radiation, temperature fluctuations, mechanical stress, weathering, oxidation and microbial activity continue to fragment plastic residues left in soil, contributing to the generation of microplastics and potentially nanoplastics (Horton et al., 2017; Nuñez-Rubio et al., 2025; Zhang et al., 2021).

Plastic mulch films are a primary source of plastics in agricultural soils, particularly in intensive production systems (Sahai et al., 2025). A study on microplastic abundance across 15 arable fields in Germany found that microplastic concentrations ranged from 0 to 217.8 particles per kg of dry soil

weight, consisting mostly of polyethylene, suggesting mulch films as the primary source (Harms et al., 2021). Similarly, significantly greater concentrations of microplastics were identified in Spanish soils where mulch films were consistently used, compared to Danish soils where compost was consistently applied (2243 ± 983 MPs kg^{-1} and 888 ± 500 MPs kg^{-1}, respectively) (Beriot et al., 2021). Field surveys across China demonstrated a clear relationship between long-term mulch use and soil microplastic accumulation. Huang et al. (2020) reported increasing microplastic abundances from 0 ± 49 particles kg^{-1} after 5 years of mulching to 1,076 ± 347 particles kg^{-1} after 24 years of continuous plastic mulch application, while polymer composition matched that of the mulch films, confirming their origin. In China, the total stock of plastic mulch residues in croplands was estimated at 2.07 million tonnes in 2020, equivalent to approximately 8% of all historically used mulch films (Dai et al., 2025).

Comparative studies consistently report higher microplastic contamination in mulched than non-mulched soils. For example, Zhou et al. (2020) observed average microplastic concentrations of 571 particles kg^{-1} in mulched fields compared with 263 particles kg^{-1} in non-mulched fields, with polyethylene dominating the polymer composition. Recent work from India similarly found that soils managed with mulch films contained the highest microplastic abundances (657–803 particles kg^{-1}), exceeding concentrations in non-mulched fields. Approximately 41% of macroplastic residues recovered were identified as residual mulch film fragments (Karwadiya et al., 2025). Interestingly, this same study found that sites near roads consistently had high microplastic concentrations, regardless of whether mulch film was used or not. This is in line with the studies by Piehl et al (2018) and Stefano & Pleissner (2022) discussed in Chapter 8, which demonstrate the ubiquitous nature of plastics near roads stemming from diffuse pollution sources.

In greenhouse systems, where plastic use is particularly intensive, microplastic accumulation can be substantial. Wang et al. (2022a) reported concentrations reaching 2,216 particles kg^{-1} in abandoned greenhouse soils, with polyethylene and polypropylene fragments dominating the microplastic assemblages. Studies from Europe also suggest that mulch films contribute significantly to agricultural soil contamination. In German arable soils, 77% of polyethylene particles occurred as films, indicating likely origins from mulching and other agricultural plastic applications (Harms et al., 2021). The environmental consequences of mulch-derived microplastics include alterations to soil physicochemical properties, reductions in soil fertility, adverse effects on soil biota, and potential transfer through terrestrial food webs (Nuñez-Rubio et al., 2025; Wang et al., 2022a).

Soil-biodegradable mulch films have been developed as alternatives to conventional polyethylene mulches to minimise the long-term accumulation of persistent plastic residues in soils. However, to date, there is no standard on the in-field biodegradation of these films. The existing standard (EN-17033)

concerns laboratory conditions and requires 90% degradation by 24 months. However, in-field conditions are not as stable as laboratory conditions, so biodegradation does not follow the same rate in the field as it does in the laboratory. There are limited studies that assess the in-field degradation of biodegradable mulch film, however, they all seem to agree that while degradation is significant, it is slower than in laboratory conditions. Field studies indicate that degradation rates vary considerably with climate, material and soil properties. Griffin-LaHue et al. (2022) found that after two years of in-field residence, 4-16% of mulch residues remained, with modelling suggesting that 21-58 months may be required to achieve 90% degradation under Mediterranean conditions. Li et al. (2023) observed that biodegradable PBAT/PLA mulch films generated microplastics during field degradation, but concentrations declined continuously over time, from 350–525 particles kg^{-1} after 2.5 years to 50–125 particles kg^{-1} after 3.5 years, suggesting progressive fragmentation followed by biodegradation. Long-term field evidence regarding biodegradable mulch films remains limited. However, a study of Italian farms using biodegradable mulches for 13–15 years found no clear accumulation of mulch-derived microplastics and no adverse effects on soil functionality, supporting the potential environmental compatibility of these materials (Mazzon et al., 2026).

Despite these promising findings, uncertainties remain regarding the persistence of biodegradable mulch fragments under different environmental conditions and the influence of climate and soil characteristics on degradation rates (Convertino et al., 2024; Griffin-LaHue et al., 2022; Li et al., 2023). While laboratory studies suggest that there are no persistent microplastics formed from the disintegration of biodegradable mulch film (Schmidt et al., 2025), further long-term in-field studies are needed to effectively demonstrate this.

10. Implications for the Selection of Open Environment Biodegradation Test Sites

The literature review presented in this deliverable provides important information on the pathways through which plastic products enter the environment and the environmental compartments in which they accumulate. Since MAGICBIOMAT aims to develop biodegradable plastic-coated paper trays, which can be used in the food industry (e.g. for paper cups), and biodegradable agricultural mulch films, it is necessary to identify environmentally relevant exposure scenarios for subsequent biodegradation studies. This chapter synthesises the main findings of the previous sections and proposes representative environmental compartments for biodegradation testing.

10.1. Consumer Packaging Litter Predominantly Enters Marine and Freshwater Environments

The report demonstrates that consumer packaging items, particularly single-use plastic items, are frequently released into the environment through direct littering, overflowing waste bins, stormwater systems and inadequate waste management practices. Once littered, these items are transported by wind, rainfall and runoff into rivers, coastal zones and ultimately the marine environment. While the review did not identify a high abundance of paper items in these environmental compartments, this can be safely assumed to be because of the quick biodegradation rate of paper. However, the findings are relevant for plastic-coated paper items, such as plastic cups, where the plastic lining remains following the degradation of the paper base. It is practically impossible to determine whether fragments of plastic films result from such items; however, due to the widespread use of such packaging items and the abundance of single-use items in the environment, it is safe to say that plastic-coated paper items can be among the single-use items found in the environment.

This suggests that biodegradation studies for plastic-coated paper packaging should prioritise:

- Marine coastal environments (beach and seawater)
- Freshwater environments (rivers and streams)
- Terrestrial surface environments, where litter may remain before transport.

10.2. Beaches are Major Accumulation Zones for Littered Consumer Packaging

The literature review shows that beaches globally are dominated by consumer-related plastics such as food packaging, beverage containers, plastic bags, wrappers, bottle caps and straws, and cups. Since plastic-coated paper packaging can replace many of these products, coastal beach environments represent one of the most environmentally relevant exposure scenarios for testing biodegradability. The report findings also suggest that buried litter may be substantially more abundant than surface litter, indicating that both surface and sediment burial scenarios should be considered. Therefore, relevant test environments include:

- Beaches (surface exposure)
- Buried beach sediments
- Coastal seawater

10.3. Rivers Act as Major Transport Pathways While Lakes and Dams can Act as Litter Sinks

The studies reviewed herein identify rivers and estuaries as major conduits transporting land-based waste to the sea. River runoff, stormwater discharge and flooding emerge as important drivers of litter movement. Riverine ecosystems are also important sinks of litter, with complicated mechanisms of catch and release at play. Furthermore, other freshwater ecosystems such as dams and lakes, particularly large ones, accumulate litter items in much the same way as marine ecosystems. It is therefore important to include freshwater environments in the planned biodegradation studies since litter items may remain in freshwater systems for prolonged periods and degradation behaviour will likely differ from marine conditions.

10.4. Agricultural Plastics are Dominant in Soils

This report identifies agriculture as a significant contributor to terrestrial plastic pollution. Agricultural mulch films and greenhouse films frequently remain in soils because they are difficult to collect, they are often heavily degraded or contaminated, and collection and recycling schemes are often absent. Farmers often plough degraded mulch films into soils, resulting in long-term accumulation of plastic fragments and microplastics. Therefore, for agricultural mulch films, the primary biodegradation environment should be agricultural soil. As such, the key tests should include:

- Surface soil exposure
- Incorporated/buried soil exposure

10.5. Environmental Compartments are Highly Interconnected

The literature review clearly demonstrates that environmental compartments are linked through wind transport, rainfall and runoff, riverine transport and ocean currents. As a result, materials intended for one application may ultimately be exposed to multiple environments. For example, litter paper packaging may first reside on land, and then enter rivers and eventually the sea, or agricultural plastics may remain in soils, but fragments can be transported to freshwater or marine ecosystems. This supports conducting biodegradation tests across multiple environmental compartments rather than a single compartment.

10.6. Climatic Variability Should be Represented

The literature review demonstrates that litter accumulation and persistence are strongly influenced by rainfall patterns, seasonality, hydrodynamic conditions, temperature, tourism intensity and human

activity. Therefore, biodegradation studies should ideally be conducted under different climatic conditions in different seasons.

10.7. Proposed Priority Environments for MAGICBIOMAT Biodegradation Studies

The results of the review and the main points identified above suggest that the priority environments for the open-environment biodegradation studies that will be implemented within MAGICBIOMAT should be conducted as per Table 6.

Table 6. Proposed priority environments for the MAGICBIOMATE open-environment biodegradation study.

MAGICBIOMAT Product	Priority environments	Justification
Plastic-coated paper packaging	Coastal marine water	Major sink for consumer litter
	Beach sand/sediment	High accumulation of packaging waste
	Freshwater (rivers/streams)	Major transport pathway
	Terrestrial surface soil	Initial littering environment
Agricultural mulch film	Agricultural soil (surface and buried)	Main end-of-life environment
	Freshwater	Secondary transport pathway for fragments
	Marine environment	Lower priority, but relevant for transported fragments

11. Conclusions

This deliverable reviewed the available scientific literature on uncontrolled waste littering in the open environment to identify the principal pathways through which litter enters natural ecosystems and determine the main litter types present in different environmental compartments.

The analysis demonstrates that plastic pollution is ubiquitous across marine, freshwater and terrestrial environments. While the specific composition of litter varies geographically and according to local socio-economic factors, plastics consistently represent the most abundant material in all environmental compartments. Short-lived consumer products and packaging constitute the largest fraction of

environmental litter, reflecting both high consumption rates, short lifetimes and inadequate waste management practices.

The pathways through which litter enters the environment are diverse but interconnected. Consumer littering, ineffective waste collection and disposal systems, industrial losses, agricultural practices, and fishing and aquaculture activities contribute significantly to environmental littering. Riverine transport, stormwater runoff and hydrodynamic processes facilitate the transport and distribution of litter across ecosystems, highlighting the interconnectedness of terrestrial, freshwater and marine environments. Urbanisation, tourism intensity, proximity to river mouths, waste management performance and fishing activity emerge as good predictors of environmental littering, demonstrating the strong influence of human activities on environmental degradation.

Agricultural systems deserve particular attention, as they represent a major yet comparatively understudied source of plastic pollution. The widespread use of agricultural plastics, combined with limited collection and recycling options, results in the accumulation of plastics and microplastics in soils. This finding is especially relevant to MAGICBIOMAT given the project's interest in biodegradable alternatives for agricultural applications.

These findings of this deliverable demonstrate that environmental exposure scenarios are highly variable and compartment-specific. Consequently, biodegradation assessments within MAGICBIOMAT must encompass a range of representative environmental conditions reflecting the diversity of real-world littering scenarios. The information presented in this report provides the scientific basis for the design and implementation of the forthcoming open environment biodegradation studies, ensuring that these are environmentally relevant and aligned with the most likely pathways and destinations of littered plastic products.

12. References

Abu-Hilal, A., & Al-Najjar, T. (2009). Marine litter in coral reef areas along the Jordan Gulf of Aqaba, Red Sea. *Journal of Environmental Management*, *90*(2), 1043-1049. https://doi.org/10.1016/j.jenvman.2008.03.014

Acksen, S., Meyer, A. N., Dos Reis, O. F., Biastoch, A., Knoop, T., & Lenz, M. (2026). Comprehensive assessment of anthropogenic debris pollution on beaches of the oceanic island São Vicente, Cabo Verde. *Marine Pollution Bulletin*, *228*, 119525. https://doi.org/10.1016/j.marpolbul.2026.119525

Afshar, S. V., Boldrin, A., Astrup, T. F., Daugaard, A. E., & Hartmann, N. B. (2023). Degradation of biodegradable plastics in waste management systems and the open environment: A critical review. *Journal of Cleaner Production*, *434*, 140000. https://doi.org/10.1016/j.jclepro.2023.140000

Akarsu, C., Sönmez, V. Z., Altay, M. C., Pehlivan, T., & Sivri, N. (2022). The spatial and temporal changes of beach litter on Istanbul (Turkey) beaches as measured by the clean-coast index. *Marine Pollution Bulletin*, *176*, 113407. https://doi.org/10.1016/j.marpolbul.2022.113407

Ali, R., & Shams, Z.I. (2015). Quantities and composition of shore debris along Clifton Beach, Karachi, Pakistan. *Journal of Coastal Conservation, 19*, 527–535. https://doi.org/10.1007/s11852-015-0404-x

Alshawafi, A., Analla, M., Alwashali, E., & Aksissou, M. (2017). Assessment of marine debris on the coastal wetland of Martil in the North-East of Morocco. *Marine Pollution Bulletin*, *117*(1-2), 302-310. https://doi.org/10.1016/j.marpolbul.2017.01.079

Ambrose, K. K., Box, C., Boxall, J., Brooks, A., Eriksen, M., Fabres, J., Fylakis, G., & Walker, T. R. (2019). Spatial trends and drivers of marine debris accumulation on shorelines in South Eleuthera, The Bahamas using citizen science. *Marine Pollution Bulletin*, *142*, 145-154. https://doi.org/10.1016/j.marpolbul.2019.03.036

Anastácio, J., Candeias, J. M., Cabral, H., & Domingos, I. (2022). Relationships between marine litter and type of coastal area, in Northeast Atlantic sandy beaches. *Marine Environmental Research*, *183*, 105827. https://doi.org/10.1016/j.marenvres.2022.105827

Andrade-Muñoz, A. S., Miserendino, M. L., Quinteros, C. P., Dromaz, W. M., Abrial, E., & Di Prinzio, C. Y. (2025). Macroplastic pollution in riparian corridors of urban and pristine mountain streams in Patagonia

(Argentina). *Science of The Total Environment*, *959*, 178092. https://doi.org/10.1016/j.scitotenv.2024.178092

Andrades, R., Martins, A. S., Fardim, L. M., Ferreira, J. S., & Santos, R. G. (2016). Origin of marine debris is related to disposable packs of ultra-processed food. *Marine Pollution Bulletin*, *109*(1), 192-195. https://doi.org/10.1016/j.marpolbul.2016.05.083

Andrades, R., Pegado, T., Godoy, B. S., Reis-Filho, J. A., Nunes, J. L., Grillo, A. C., Machado, R. C., Santos, R. G., Dalcin, R. H., Freitas, M. O., Kuhnen, V. V., Barbosa, N. D., Adelir-Alves, J., Albuquerque, T., Bentes, B., & Giarrizzo, T. (2020). Anthropogenic litter on Brazilian beaches: Baseline, trends and recommendations for future approaches. *Marine Pollution Bulletin*, *151*, 110842. https://doi.org/10.1016/j.marpolbul.2019.110842

Andreussi, C.K., de Ramos, B., Zanetti, D.G., de Lima, T. M. & Leonel, J. (2025). Macro and mesoplastis at Joaquina Beach, southern Brazil: a case study. *Ocean and Coastal Research, 73*. https://doi.org/10.1590/2675-2824073.23184

Anfuso, G., Bolívar-Anillo, H. J., Asensio-Montesinos, F., Portantiolo Manzolli, R., Portz, L., & Villate Daza, D. A. (2020). Beach litter distribution in Admiralty Bay, King George Island, Antarctica. *Marine Pollution Bulletin*, *160*, 111657. https://doi.org/10.1016/j.marpolbul.2020.111657

Angiolillo, M., & Fortibuoni, T. (2020). Impacts of Marine Litter on Mediterranean Reef Systems: From Shallow to Deep Waters. *Frontiers in Marine Science*, *7*, 581966. https://doi.org/10.3389/fmars.2020.581966

Angiolillo, M., Fortibuoni, T., Di Lorenzo, B., & Tunesi, L. (2023). First baseline assessment of seafloor litter on Italian coralligenous assemblages (Mediterranean Sea) in accordance with the European Marine Strategy Framework Directive. *Marine Pollution Bulletin*, *187*, 114597. https://doi.org/10.1016/j.marpolbul.2023.114597

Angiolillo, M., Gérigny, O., Valente, T., Fabri, M., Tambute, E., Rouanet, E., Claro, F., Tunesi, L., Vissio, A., Daniel, B., & Galgani, F. (2021). Distribution of seafloor litter and its interaction with benthic organisms in deep waters of the Ligurian Sea (Northwestern Mediterranean). *Science of The Total Environment*, *788*, 147745. https://doi.org/10.1016/j.scitotenv.2021.147745

Aragaw, T. A. (2021). The macro-debris pollution in the shorelines of Lake Tana: First report on abundance, assessment, constituents, and potential sources. *Science of The Total Environment*, *797*, 149235. https://doi.org/10.1016/j.scitotenv.2021.149235

Aranoco, A. P., Albolote, J. M. G., Alimbon, J. A., & Caga-anan, K. P. (2023). Beach litter occurrence along the shoreline of Mabini Protected Landscape and Seascape, Davao de Oro, Philippines. *Marine Pollution Bulletin*, *195*, 115579. https://doi.org/10.1016/j.marpolbul.2023.115579

Araújo, M. C., Silva-Cavalcanti, J. S., & Costa, M. F. (2018). Anthropogenic Litter on Beaches With Different Levels of Development and Use: A Snapshot of a Coast in Pernambuco (Brazil). *Frontiers in Marine Science*, *5*, 310405. https://doi.org/10.3389/fmars.2018.00233

Arun Kumar, A., Sivakumar, R., Sai Rutwik Reddy, Y., Bhagya Raja, M.V., Nishanth, T., & Revanth, V. (2016). Preliminary study on marine debris pollution along Marina beach, Chennai, India. *Regional Studies in Marine Science*, *5*, 35-40. https://doi.org/10.1016/j.rsma.2016.01.002

Asensio-Montesinos, F., Anfuso, G., Aguilar-Torrelo, M. T., & Ramírez, M. O. (2021). Abundance and Temporal Distribution of Beach Litter on the Coast of Ceuta (North Africa, Gibraltar Strait). *Water*, *13*(19). https://doi.org/10.3390/w13192739

Aslam, S., Tzoraki, O. & Krasakopoulou, E. (2022). Anthropogenic litter in freshwater bodies and their estuaries: an empirical analysis in Lesvos, Greece. *Environmental Science and Pollution Research,* 29, 16563–16575. https://doi.org/10.1007/s11356-021-16793-z

Atmaja, P. S. P., Putra Suardana, A. A. M. A., Krisna Laharjana, I. K. A., Suteja, Y., & Purwiyanto, A. I. S. (2025). Macro debris accumulation in seagrass meadows along varying levels of tourism pressure in Bali, Indonesia. *Regional Studies in Marine Science*, *90*, 104482. https://doi.org/10.1016/j.rsma.2025.104482

Aura, C. M., Gichuru, N., Otuo, P., Wandago, S., Owino, B., Nyamweya, C., & Odoli, C. (2026). Quantification of macroplastics and litter dynamics in a highly active bay of Lake Victoria. *Journal of Great Lakes Research*, *52*(3), 102824. https://doi.org/10.1016/j.jglr.2026.102824

Azman, M. A., Ramli, M. Z., Che Othman, S. F., & Shafiee, S. A. (2021). The distribution of marine debris along the Pahang coastline, Malaysia during the Southwest and Northeast Monsoons. *Marine Pollution Bulletin*, *170*, 112630. https://doi.org/10.1016/j.marpolbul.2021.112630

Baak, J. E., Brown, Z. O., Provencher, J. F., & Mallory, M. L. (2022). A rapid assessment technique for coastal plastic debris sampling: Applications for remote regions and community science. *Marine Pollution Bulletin*, *178*, 113641. https://doi.org/10.1016/j.marpolbul.2022.113641

Banaee, M., Multisanti, C. R., Impellitteri, F., Piccione, G., & Faggio, C. (2024). Environmental toxicology of microplastic particles on fish: A review. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *287*, 110042. https://doi.org/10.1016/j.cbpc.2024.110042

Barnardo, T., Van Niekerk, T. M., Pichegru, L., & Marlin, D. (2021). The first baseline estimation of marine litter in Port Elizabeth, South Africa. *Marine Pollution Bulletin*, *172*, 112903. https://doi.org/10.1016/j.marpolbul.2021.112903

Bastami, K. D., Taheri, M., Raisi, H., Podolyako, S., Biryukova, M., Mehdinia, A., & Radmanesh (Manbohi), A. (2025). Spatial and temporal distribution of marine debris in coastal sediment of South Caspian Sea: Effect on coastal nematode communities. *Science of The Total Environment*, *1003*, 180570. https://doi.org/10.1016/j.scitotenv.2025.180570

Bat, L., Öztekin, A., Öztürk, D. K., Gürbüzer, P., Özsandıkçı, U., Eyüboğlu, B., & Öztekin, H. C. (2022). Beach litter contamination of the Turkish middle Black Sea coasts: Spatial and temporal variation, composition, and possible sources. *Marine Pollution Bulletin*, *185*, 114248. https://doi.org/10.1016/j.marpolbul.2022.114248

Bauer-Civiello, A., Critchell, K., Hoogenboom, M., & Hamann, M. (2019). Input of plastic debris in an urban tropical river system. *Marine Pollution Bulletin*, *144*, 235-242. https://doi.org/10.1016/j.marpolbul.2019.04.070

Beriot, N., Lwanga, E. H., & Geissen, V. (2021). Sources of Light Density Microplastic Related to Two Agricultural Practices: The Use of Compost and Plastic Mulch. *Environments*, *8*(4). https://doi.org/10.3390/environments8040036

Bettencourt, S., Lucas, C., Costa, S., & Caeiro, S. (2023). Monitoring marine litter on Funchal beaches (Madeira Island): Insights for litter management. *Regional Studies in Marine Science*, *63*, 102991. https://doi.org/10.1016/j.rsma.2023.102991

BIS Research. (May 18, 2023). Market size of agricultural films worldwide in 2021, with a forecast for 2027, by product (in million U.S. dollars) [Graph]. In *Statista*. Retrieved June 18, 2026, from https://www.statista.com/statistics/1386470/global-agricultural-films-market-value-by-product/

Bjorndal, K. A., Bolten, A. B., & Lagueux, C. J. (1994). Ingestion of marine debris by juvenile sea turtles in coastal Florida habitats. Marine Pollution Bulletin, 28, 154–158.

Blanke, J. M., Steinberg, M. K., & Donlevy, J. P. (2021). A baseline analysis of marine debris on southern islands of Belize. *Marine Pollution Bulletin*, *172*, 112916. https://doi.org/10.1016/j.marpolbul.2021.112916

Bläsing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of The Total Environment*, *612*, 422-435. https://doi.org/10.1016/j.scitotenv.2017.08.086

Blettler, M., Shumilova, O., Gallitelli, L., & Sukhodolov, A. (2026). Macroplastic in urban waterways: Assessing storage in Berlin's Spree River. *Environmental Research*, *296*, 123990. https://doi.org/10.1016/j.envres.2026.123990

Blettler, M.C.M., Ulla, M.A., Rabuffetti, A.P., & Garello, N. (2017). Plastic pollution in freshwater ecosystems: Macro-, meso-, and microplastic debris in a floodplain lake. *Environmental Monitoring and Assessment, 189*, 581. https://doi.org/10.1007/s10661-017-6305-8

Bouzekry, A., Mghili, B., & Aksissou, M. (2022). Addressing the challenge of marine plastic litter in the Moroccan Mediterranean: A citizen science project with schoolchildren. *Marine Pollution Bulletin*, *184*, 114167. https://doi.org/10.1016/j.marpolbul.2022.114167

Brabo, L., De Oliveira, H. A., Pegado, T., Andrades, R., Keppeler, F. W., De Araujo Sampaio, M., Vasconcelos, F. J. M., Dantas, A. D., Carneiro, R. K. S., Cottens, K. F., Rangel-Buitrago, N. G., Mont'Alverne, T. F., Soares, M. O., & Giarrizzo, T. (2026). A multidriver assessment of beach litter accumulation rates. *Marine Pollution Bulletin*, *223*, 119083. https://doi.org/10.1016/j.marpolbul.2025.119083

Bravo, M., De los Ángeles Gallardo, M., Luna-Jorquera, G., Núñez, P., Vásquez, N., & Thiel, M. (2009). Anthropogenic debris on beaches in the SE Pacific (Chile): Results from a national survey supported by volunteers. *Marine Pollution Bulletin*, *58*(11), 1718-1726. https://doi.org/10.1016/j.marpolbul.2009.06.017

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., & Thompson, R.C., (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). *Environmental Science & Technology, 42*, 5026–5031. https://doi.org/10.1021/es800249a

Buhl-Mortensen, P., & Buhl-Mortensen, L. (2018). Impacts of Bottom Trawling and Litter on the Seabed in Norwegian Waters. *Frontiers in Marine Science*, *5*, 319114. https://doi.org/10.3389/fmars.2018.00042

Burgess, H.K., Herring C.E., Lippiatt S., Lowe S., & Uhrin A.V. (2021). *NOAA Marine Debris Monitoring and Assessment Project Shoreline Survey Guide*. NOAA Technical Memorandum NOS OR&R 56. 20 pp. DOI 10.25923/g720-2n18

Büyükdeveci, F., & Gündoğdu, S. (2021). Composition and abundance of benthic marine litter in the fishing grounds of Iskenderun Bay, northeastern Levantine coast of Turkey. *Marine Pollution Bulletin*, *172*, 112840. https://doi.org/10.1016/j.marpolbul.2021.112840

Castellan, G., Marchese, F., Lüdmann, T., Taviani, M., & Westphal, H. (2025). Deep-sea marine litter from visual surveys: New findings from offshore Al Wajh, Red Sea (Saudi Arabia). *Regional Studies in Marine Science*, *89*, 104357. https://doi.org/10.1016/j.rsma.2025.104357

Cavalcante, R. M., Pinheiro, L. S., Teixeira, C. E., Paiva, B. P., Fernandes, G. M., Brandão, D. B., Frota, F. F., Filho, F. J., & Schettini, C. A. (2020). Marine debris on a tropical coastline: Abundance, predominant sources and fate in a region with multiple activities (Fortaleza, Ceará, northeastern Brazil). *Waste Management*, *108*, 13-20. https://doi.org/10.1016/j.wasman.2020.04.026

Cerrillo-Escoriza, J., Lobo, F. J., Puga-Bernabéu, Á., Rueda, J. L., Bárcenas, P., Sánchez-Guillamón, O., Serna Quintero, J. M., Pérez Gil, J. L., Murillo, Y., Caballero-Herrera, J. A., López-Quirós, A., Mendes, I., & Pérez-Asensio, J. N. (2023). Origin and driving mechanisms of marine litter in the shelf-incised Motril, Carchuna, and Calahonda canyons (northern Alboran Sea). *Frontiers in Marine Science*, *10*, 1098927. https://doi.org/10.3389/fmars.2023.1098927

Cerqueira, M. (2025). Exploring marine litter abundance and composition on a rural sandy beach in Portugal. *Case Studies in Chemical and Environmental Engineering*, *11*, 101071. https://doi.org/10.1016/j.cscee.2024.101071

Cesarini, G., Crosti, R., Secco, S., Gallitelli, L., & Scalici, M. (2023). From city to sea: Spatiotemporal dynamics of floating macrolitter in the Tiber River. *Science of The Total Environment*, *857*, 159713. https://doi.org/10.1016/j.scitotenv.2022.159713

Charlton-Howard, H.S., Bond, A.L., Rivers-Auty, J., Lavers, J.L., 2023. 'Plasticosis': characterising macro- and microplastic-associated fibrosis in seabird tissues. J. Hazard. Mater. 450, 131090. https://doi.org/10.1016/j.jhazmat.2023.131090

Chen, H., Wang, S., Guo, H., Lin, H., & Zhang, Y. (2020). A nationwide assessment of litter on China's beaches using citizen science data. *Environmental Pollution*, *258*, 113756. https://doi.org/10.1016/j.envpol.2019.113756

Cheshire, A.C., Adler, E., Barbiere, J., Cohen, Y., Evans, S., Jarayabhand, S., Jeftic, L., et al., (2009). *UNEP/IOC guidelines on survey and monitoring of marine litter*. UNEP Regional Seas Reports and Studies, no. 186; IOC Technical Series no. 83, xii + 120 pp

Chiba, S., Saito, H., Fletcher, R., Yogi, T., Kayo, M., Miyagi, S., Ogido, M., & Fujikura, K. (2018). Human footprint in the abyss: 30 year records of deep-sea plastic debris. *Marine Policy*, *96*, 204-212. https://doi.org/10.1016/j.marpol.2018.03.022

Chitaka, T. Y., & Von Blottnitz, H. (2018). Accumulation and characteristics of plastic debris along five beaches in Cape Town. *Marine Pollution Bulletin*, *138*, 451-457. https://doi.org/10.1016/j.marpolbul.2018.11.065

Consoli, P., Falautano, M., Sinopoli, M., Perzia, P., Canese, S., Esposito, V., Battaglia, P., Romeo, T., Andaloro, F., Galgani, F., & Castriota, L. (2018). Composition and abundance of benthic marine litter in a coastal area of the central Mediterranean Sea. *Marine Pollution Bulletin*, *136*, 243-247. https://doi.org/10.1016/j.marpolbul.2018.09.033

Consoli, P., Romeo, T., Angiolillo, M., Canese, S., Esposito, V., Salvati, E., Scotti, G., Andaloro, F., & Tunesi, L. (2019). Marine litter from fishery activities in the Western Mediterranean sea: The impact of entanglement on marine animal forests. *Environmental Pollution*, *249*, 472-481. https://doi.org/10.1016/j.envpol.2019.03.072

Consoli, P., Sinopoli, M., Deidun, A., Canese, S., Berti, C., Andaloro, F., & Romeo, T. (2020). The impact of marine litter from fish aggregation devices on vulnerable marine benthic habitats of the central Mediterranean Sea. *Marine Pollution Bulletin*, *152*, 110928. https://doi.org/10.1016/j.marpolbul.2020.110928

Consoli, P., Esposito, V., Battaglia, P., Perzia, P., Scotti, G., D'Alessandro, M., Canese, S., Andaloro, F., & Romeo, T. (2021). Marine litter pollution associated with hydrothermal sites in the Aeolian archipelago (western Mediterranean Sea). *Science of The Total Environment*, *773*, 144968. https://doi.org/10.1016/j.scitotenv.2021.144968

Convertino, F., Carroccio, S. C., Cocca, M. C., Dattilo, S., Dell'Acqua, A. C., Gargiulo, L., Nizzetto, L., Riccobene, P. M., Schettini, E., Vox, G., Zannini, D., & Cerruti, P. (2024). The fate of post-use biodegradable PBAT-based mulch films buried in agricultural soil. *Science of The Total Environment*, *948*, 174697. https://doi.org/10.1016/j.scitotenv.2024.174697

Cook, E., Ionkova, K., Bhada-Tata, P., Yadav, S., van Woerden, F. (2026). *What a Waste 3.0: Global Snapshot of Solid Waste Management Toward Circularity until 2050*. Urban Development Series. Washington, DC: World Bank. DOI: 10.1596/978-1-4648-2309-1. License: Creative Commons Attribution CC BY 3.0 IGO.

Corbau, C., Lazarou, A., Gazale, V., Nardin, W., Simeoni, U., & Carboni, D. (2021). What can beach litter tell about local management: A comparison of five pocket beaches of the North Sardinia island (Italy). *Marine Pollution Bulletin*, *174*, 113170. https://doi.org/10.1016/j.marpolbul.2021.113170

Cordova, M. R., Iskandar, M. R., Muhtadi, A., Saville, R., & Riani, E. (2022). Spatio-temporal variation and seasonal dynamics of stranded beach anthropogenic debris on Indonesian beach from the results of nationwide monitoring. *Marine Pollution Bulletin*, *182*, 114035. https://doi.org/10.1016/j.marpolbul.2022.114035

Cowger, W., Gray, A. B., & Schultz, R. C. (2019). Anthropogenic litter cleanups in Iowa riparian areas reveal the importance of near-stream and watershed scale land use. *Environmental Pollution*, *250*, 981-989. https://doi.org/10.1016/j.envpol.2019.04.052

Crosti, R., Arcangeli, A., Campana, I., Paraboschi, M., & González-Fernández, D. (2018). 'Down to the river': amount, composition, and economic sector of litter entering the marine compartment, through the Tiber river in the Western Mediterranean Sea. *Rendiconti Lincei. Scienze Fisiche e Naturali, 29*, 859–866. https://doi.org/10.1007/s12210-018-0747-y

Currie, J. J., Sullivan, F. A., Beato, E., Machernis, A. F., Olson, G. L., & Stack, S. H. (2023). The impact of the anthropause caused by the COVID-19 pandemic on beach debris accumulation in Maui, Hawai'i. *Scientific Reports*, *13*(1), 17729. https://doi.org/10.1038/s41598-023-44944-4

Dağtekin, M., Kasapoğlu, N., Ok, M., İlhan, S., Büyükdeveci, F., Erik, G., Özsandikçi, U., Mısır, D. S., & Gündoğdu, S. (2025). Assessment of spatiotemporal distribution of benthic marine litter for the southern Black Sea coasts of Türkiye. *Marine Pollution Bulletin*, *216*, 117940. https://doi.org/10.1016/j.marpolbul.2025.117940

Dai, J., Hu, C., Flury, M., Huang, Y., Rillig, M. C., Ji, D., Peng, J., Fei, J., Huang, Q., Xiong, Y., Yang, N., Jones, D. L., Wang, J., & Ding, F. (2025). National Inventory of Plastic Mulch Residues in Chinese Croplands From 1993 to 2050. *Global Change Biology*, *31*(6), e70297. https://doi.org/10.1111/gcb.70297

Damian, M., Harris, A., Aussage, J., & Fraser, G. S. (2022). Seasonal deposition of marine debris on an important marine turtle nesting beach in Costa Rica. *Marine Pollution Bulletin*, *177*, 113525. https://doi.org/10.1016/j.marpolbul.2022.113525

D'Angelo, A., Trenholm, N., Loose, B., Glastra, L., Strock, J., & Kim, J. (2023). Microplastics Distribution within Western Arctic Seawater and Sea Ice. *Toxics*, *11*(9). https://doi.org/10.3390/toxics11090792

Daniel, D. B., Thomas, S. N., & Thomson, K. (2019). Assessment of fishing-related plastic debris along the beaches in Kerala Coast, India. *Marine Pollution Bulletin*, *150*, 110696. https://doi.org/10.1016/j.marpolbul.2019.110696

Das, N., De, K., Sen, A., & Maiti, B. (2025). Anthropogenic litter pollution in the mangrove blue carbon ecosystem: Unveiling the spatial distribution, composition, source delineation and mitigation measures along the Goa coast, India. *Journal of Hazardous Materials Advances*, *18*, 100679. https://doi.org/10.1016/j.hazadv.2025.100679

De, K., Sautya, S., Dora, G. U., Gaikwad, S., Katke, D., & Salvi, A. (2023). Mangroves in the "Plasticene": High exposure of coastal mangroves to anthropogenic litter pollution along the Central-West coast of India. *Science of The Total Environment*, *858*, 160071. https://doi.org/10.1016/j.scitotenv.2022.160071

Debrot, A. O., Van Rijn, J., Bron, P. S., & De León, R. (2013). A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean. *Marine Pollution Bulletin*, *71*(1-2), 325-329. https://doi.org/10.1016/j.marpolbul.2013.01.027

Derraik, J. (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin, 44*, 842– 852. https://doi.org/10.1016/S0025-326X(02)00220-5

De Scisciolo, T., Mijts, E. N., Becker, T., & Eppinga, M. B. (2016). Beach debris on Aruba, Southern Caribbean: Attribution to local land-based and distal marine-based sources. *Marine Pollution Bulletin*, *106*(1-2), 49-57. https://doi.org/10.1016/j.marpolbul.2016.03.039

De Veer, D., Baeza-Álvarez, J., Bolaños, S., Cavour Araya, S., Darquea, J. J., Díaz Poblete, M. A., Domínguez, G., Holtmann-Ahumada, G., Honorato-Zimmer, D., Gaibor, N., Gallardo, M. D. L. Á., Guevara

Torrejón, V., León Chumpitaz, A., Marcús Zamora, L., Mora, V., Muñoz Araya, J. M., Pernía, B., Purca, S., Rivadeneira, M. M., . . . Thiel, M. (2023). Citizen scientists study beach litter along 12,000 km of the East Pacific coast: A baseline for the International Plastic Treaty. *Marine Pollution Bulletin*, *196*, 115481. https://doi.org/10.1016/j.marpolbul.2023.115481

Digka, N., Tsangaris, C., Torre, M., Anastasopoulou, A., Zeri, C. (2018). Microplastics in mussels and fish from the Northern Ionian Sea. *Marine Pollution Bulletin, 135*, 30–40. https://doi.org/10.1016/j.marpolbul.2018.06.063

Dilkes-Hoffman, L., Ashworth, P., Laycock, B., Pratt, S., & Lant, P. (2019). Public attitudes towards bioplastics – knowledge, perception and end-of-life management. *Resources, Conservation and Recycling*, *151*, 104479. https://doi.org/10.1016/j.resconrec.2019.104479

Dittmann, S., Kiessling, T., Knickmeier, K., Schönberg, J., Brennecke, D., Hinzmann, M., Knoblauch, D., & Thiel, M. (2024). Temporal variability of litter pollution of rivers in Germany – A long-term assessment by schoolchildren as citizen scientists. *Marine Pollution Bulletin*, *209*, 117253. https://doi.org/10.1016/j.marpolbul.2024.117253

Duhec, A. V., Jeanne, R. F., Maximenko, N., & Hafner, J. (2015). Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. *Marine Pollution Bulletin*, *96*(1-2), 76-86. https://doi.org/10.1016/j.marpolbul.2015.05.042

Dunlop, S., Dunlop, B., & Brown, M. (2020). Plastic pollution in paradise: Daily accumulation rates of marine litter on Cousine Island, Seychelles. *Marine Pollution Bulletin*, *151*, 110803. https://doi.org/10.1016/j.marpolbul.2019.110803

Duong, L. T., Nguyen, H. T. L., Nguyen, T. T. H., Dang, Q. T., Dao, N. N., Nguyen, K. T., Duong, D. C., Tran, N. T. H., Nguyen, H. T., & Nguyen, B. Q. (2025). Abundance, distribution, and seasonal variation of marine litter on the beaches of central Vietnam. *Marine Pollution Bulletin*, *216*, 118046. https://doi.org/10.1016/j.marpolbul.2025.118046

Ebere, E.C., Wirnkor, V.A., Ngozi, V.E., & Chukwuemeka, I.S. (2019). Macrodebris and microplastics pollution in Nigeria: first report of abundance, distribution and composition. *Environmental Analysis Health and Toxicology*, 34(4): e2019012. https://doi.org/10.5620/eaht.e2019012

Edward, J. P., Jayanthi, M., Einarsson, H. A., Kannan, R., Laju, R., Jeyasanta, K. I., Sathish, N., & Patterson, J. (2025). Assessment of beach litter, including Abandoned, Lost, or Discarded Fishing Gear (ALDFG),

along the coast of Tamil Nadu, India: Magnitude, sources, composition, pollution status, and management strategies. *Marine Pollution Bulletin*, *213*, 117700. https://doi.org/10.1016/j.marpolbul.2025.117700

Edyvane, K., Dalgetty, A., Hone, P., Higham, J., & Wace, N. (2004). Long-term marine litter monitoring in the remote Great Australian Bight, South Australia. *Marine Pollution Bulletin*, *48*(11-12), 1060-1075. https://doi.org/10.1016/j.marpolbul.2003.12.012

Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., & Amato, S. (2013). Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin*, *77*(1-2), 177-182. https://doi.org/10.1016/j.marpolbul.2013.10.007

Ertaş, A. (2021). Assessment of beach litter pollution in Adana Akyatan Lagoon Coast of the East Mediterranean. *Marine Pollution Bulletin*, *163*, 111943. https://doi.org/10.1016/j.marpolbul.2020.111943

European Bioplastics (2025). *Bioplastics Market Development Update 2025*. Brussels: European Bioplastics. Available from: https://docs.european-bioplastics.org/publications/market_data/2025/EUBP_Market_Data_Report_2025.pdf. Accessed on 17 June 2026.

European Commission (2018). Impact Assessment accompanying the document 'Proposal for a Directive of the European Parliament and of the Council on port reception facilities for the delivery of waste from ships, repealing Directve 2000/59/EC and amending Directive 2009/16/EC and Directive 2010/65/EU. Strassburg. https://eur-lex.europa.eu/ legal-content/EN/TXT/HTML/?uri=CELEX:52018SC0021&rid=3

European Commission (2023). Commission Staff Working Document Impact Assessment Report: Combatting microplastic pollution in the European Union. Accompanying the document Proposal for a Regulation of the European Parliament and of the Council on preventing plastic pellet losses to reduce microplastic pollution. SWD/2023/332 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2023%3A0332%3AFIN Accessed on: 18 June 2026.

European Sea Ports Organization [ESPO] (2022) Environmental Report 2022-EcoPortsinSights 2022. ESPO EUR-Lex (2023) Circular Economy. Accessed 18 June 2026, from https://eur-lex.europa.eu/EN/legal-content/gloss ary/circular-economy.htm

European Union (2019). Directive (EU) 2019/883 of the European Parliament and of the Council of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU and repealing Directive 2000/59/EC (Text with EEA relevance) PE/85/2018/REV/1. *Official Journal of the European Union*, 151:116–142

Fakiris, E., Papatheodorou, G., Kordella, S., Christodoulou, D., Galgani, F., & Geraga, M. (2022). Insights into seafloor litter spatiotemporal dynamics in urbanized shallow Mediterranean bays. An optimized monitoring protocol using towed underwater cameras. *Journal of Environmental Management*, *308*, 114647. https://doi.org/10.1016/j.jenvman.2022.114647

Fadare, O. O., Akinbile, A. A., Makinde, O. W., Ogundele, K., Ajagbe, E. F., & Ilechukwu, I. (2022). Spatiotemporal variations in marine litter along the Gulf of Guinea coastline, Araromi seaside, Nigeria. *Marine Pollution Bulletin*, *183*, 114048. https://doi.org/10.1016/j.marpolbul.2022.114048

FAO. (2020). *The State of World Fisheries and Aquaculture 2020*. *Sustainability in action*. Rome. https://doi.org/10.4060/ca9229

FAO. (2021). *Assessment of agricultural plastics and their sustainability – A call for action*. Rome. https://doi.org/10.4060/cb7856en

FAO. (2025). World fish production from 2007 to 2024, with a forecast for 2025, by fishing and aquaculture (in million metric tons) [Graph]. In *Statista*. Retrieved June 30, 2026, from https://www.statista.com/statistics/272311/world-fish-production-by-fishing-and-aquaculture-since-2004/

Fetisov, S., Esiukova, E., Lobchuk, O., & Chubarenko, I. (2024). Abundance and mass of plastic litter on sandy shore: Contribution of stormy events. *Marine Pollution Bulletin*, *207*, 116911. https://doi.org/10.1016/j.marpolbul.2024.116911

Finger, J. V. G., Corá, D. H., Convey, P., Cruz, F. S., Petry, M. V., & Krüger, L. (2021). Anthropogenic debris in an Antarctic Specially Protected Area in the maritime Antarctic. *Marine Pollution Bulletin*, *172*, 112921. https://doi.org/10.1016/j.marpolbul.2021.112921

Folbert, M., Stoorvogel, J., & Löhr, A. (2025). Plastic pellet spills and leakages during maritime transportation: A transdisciplinary approach to understand the complex causal pathways. *Marine Pollution Bulletin*, *218*, 118194. https://doi.org/10.1016/j.marpolbul.2025.118194

Fortibuoni, T., Amadesi, B., & Vlachogianni, T. (2020). Composition and abundance of macrolitter along the Italian coastline: The first baseline assessment within the european Marine Strategy Framework Directive. *Environmental Pollution*, *268*, 115886. https://doi.org/10.1016/j.envpol.2020.115886

Fortibuoni, T., Di Vito, S. & Scocchera, E. (2025). Preliminary assessment of waste accumulation along riverbanks in Italy. *Environmental Science and Pollution Research, 32*, 2398–2410. https://doi.org/10.1007/s11356-025-35899-2

Fortibuoni, T., Ronchi, F., Mačić, V., Mandić, M., Mazziotti, C., Peterlin, M., Prevenios, M., Prvan, M., Somarakis, S., Tutman, P., Varezić, D. B., Virsek, M. K., Vlachogianni, T., & Zeri, C. (2019). A harmonized and coordinated assessment of the abundance and composition of seafloor litter in the Adriatic-Ionian macroregion (Mediterranean Sea). *Marine Pollution Bulletin*, *139*, 412-426. https://doi.org/10.1016/j.marpolbul.2019.01.017

Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. (2014). High-levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin*, *85*(1), 156-163. https://doi.org/10.1016/j.marpolbul.2014.06.001

Fruergaard, M., Laursen, S. N., Larsen, M. N., Posth, N. R., Niebe, K. B., Bentzon-Tarp, A., Svenningsen, S. K., Acevedo N., L. I., Trinh, B., Tran-Thi, P. T., Doan-Nhu, H., Nguyen-Ngoc, L., & Andersen, T. J. (2022). Abundance and sources of plastic debris on beaches in a plastic hotspot, Nha Trang, Viet Nam. *Marine Pollution Bulletin*, *186*, 114394. https://doi.org/10.1016/j.marpolbul.2022.114394

Gacutan, J., Tait, H., Johnston, E. L., & Clark, G. F. (2023). Assessing human and physical drivers of macro-plastic debris spatially across Queensland, Australia. *Environmental Pollution*, *330*, 121731. https://doi.org/10.1016/j.envpol.2023.121731

Gacutan, J., Tait, H., Jones, J., Charlesworth, B., & Hood, L. (2024). Citizen science supports national reporting of a Sustainable Development Goal indicator: A case study of plastic debris density on beaches. *Environmental Science & Policy*, *161*, 103870. https://doi.org/10.1016/j.envsci.2024.103870

Gaibor, N., Condo-Espinel, V., Cornejo-Rodríguez, M. H., Darquea, J. J., Pernia, B., Domínguez, G. A., Briz, M. E., Márquez, L., Laaz, E., Alemán-Dyer, C., Avendaño, U., Guerrero, J., Preciado, M., Honorato-Zimmer, D., & Thiel, M. (2020). Composition, abundance and sources of anthropogenic marine debris on the beaches from Ecuador – A volunteer-supported study. *Marine Pollution Bulletin*, *154*, 111068. https://doi.org/10.1016/j.marpolbul.2020.111068

Galgani, F., Leaute, J., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., Mahe, J., Poulard, J., & Nerisson, P. (2000). Litter on the Sea Floor Along European Coasts. *Marine Pollution Bulletin*, *40*(6), 516-527. https://doi.org/10.1016/S0025-326X(99)00234-9

Galgani, F., Ruiz Orejon Sanchez Pastor, L., Ronchi, F., Tallec, K., Fischer, E., Matiddi, M., Anastasopoulou, A., et al. (2023). *Guidance on the monitoring of marine litter in European seas*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/59137, JRC133594.

Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin, 92*, 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

García-Rivera, S., Lizaso, J. L. S., & Millán, J. M. B. (2017). Composition, spatial distribution and sources of macro-marine litter on the Gulf of Alicante seafloor (Spanish Mediterranean). *Marine Pollution Bulletin*, *121*(1-2), 249-259. https://doi.org/10.1016/j.marpolbul.2017.06.022

Garofalo, G., Quattrocchi, F., Bono, G., Di Lorenzo, M., Di Maio, F., Falsone, F., Gancitano, V., Geraci, M., Lauria, V., Massi, D., Scannella, D., Titone, A., & Fiorentino, F. (2020). What is in our seas? Assessing anthropogenic litter on the seafloor of the central Mediterranean Sea. *Environmental Pollution*, *266*, 115213. https://doi.org/10.1016/j.envpol.2020.115213

GESAMP (2019). Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J., Turra A. and Galgani F. editors), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, 130p.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*. https://doi.org/10.1126/sciadv.1700782

Gholami, M., Torkashvand, J., Rezaei Kalantari, R. et al. Study of littered wastes in different urban land-uses: An 6 environmental status assessment. J Environ Health Sci Engineer 18, 915–924 (2020). https://doi.org/10.1007/s40201-020-00515-7

Giovacchini, A., Merlino, S., Locritani, M., & Stroobant, M. (2018). Spatial distribution of marine litter along italian coastal areas in the Pelagos sanctuary (Ligurian Sea - NW Mediterranean Sea): A focus on natural and urban beaches. *Marine Pollution Bulletin*, *130*, 140-152. https://doi.org/10.1016/j.marpolbul.2018.02.042

González-Fernández, D., Cózar, A., Hanke, G., Viejo, J., Morales-Caselles, C., Bakiu, R., Barceló, D., Bessa, F., Bruge, A., Cabrera, M., Castro-Jiménez, J., Constant, M., Crosti, R., Galletti, Y., Kideys, A. E., Machitadze, N., Pogojeva, M., Ratola, N., Rigueira, J., . . . Tourgeli, M. (2021). Floating macrolitter leaked from Europe into the ocean. *Nature Sustainability*, *4*(6), 474-483. https://doi.org/10.1038/s41893-021-00722-6

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings– Entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B, 364*, 2013–2025. https://doi.org/10.1098/rstb.2008.0265

Griffin-LaHue, D., Ghimire, S., Yu, Y., Scheenstra, E. J., Miles, C. A., & Flury, M. (2022). In-field degradation of soil-biodegradable plastic mulch films in a Mediterranean climate. *Science of The Total Environment*, *806*, 150238. https://doi.org/10.1016/j.scitotenv.2021.150238

Gutierrez, C., Escañan, A.S., Lubguban, A.A., Amparado, R.F., Guihawan, J.Q., & Bacosa, H.P. (2024). Plastic litter assessment of the riverbanks of Pulot River and its tributary in Sofronio Española, Palawan Island, Philippines. *Journal of Marine and Island Cultures*, 13(1). DOI: 10.21463/jmic.2024.13.1.05

Hanke, G., Canals, M., Vescovo, V., MacDonald, T., Martini, E., Ruiz-Orejón, L. F., Galgani, F., Palma, M., Papatheodorou, G., Ioakeimidis, C., Sakellariou, D., Drakopoulou, P., & Fakiris, E. (2025). Marine litter in the deepest site of the Mediterranean Sea. *Marine Pollution Bulletin*, *213*, 117610. https://doi.org/10.1016/j.marpolbul.2025.117610

Hardesty, D.B., Barrett, J., Lawson, T.J., Mann, V., Roman, L., Schuyler, Q., Wilcox, C., & Willis, K. (2026). CSIRO marine litter monitoring methods handbook. v1. CSIRO. Data Collection. https://doi.org/10.25919/2ztr-pz04

Harms, I. K., Diekötter, T., Troegel, S., & Lenz, M. (2021). Amount, distribution and composition of large microplastics in typical agricultural soils in Northern Germany. *Science of The Total Environment*, *758*, 143615. https://doi.org/10.1016/j.scitotenv.2020.143615

Hassan H.O., Ayeta E.G., Ibrahim, A.A., Omar, M.F., Abdi, S.M, Houmed, Y.K., Dirie, A.M., & Faseyi, C.A. (2024). The first assessment of marine litter on Somalian coast: The case of Liido Beach, Mogadishu. *Heliyon*, 10(4) e26593. https://doi.org/10.1016/j.heliyon.2024.e26593

Hassan, I. A., Younis, A., Al Ghamdi, M. A., Almazroui, M., Basahi, J. M., El-Sheekh, M. M., Abouelkhair, E. K., Haiba, N. S., Alhussaini, M. S., Hajjar, D., Abdel Wahab, M. M., & El Maghraby, D. M. (2022).

Contamination of the marine environment in Egypt and Saudi Arabia with personal protective equipment during COVID-19 pandemic: A short focus. *Science of The Total Environment*, *810*, 152046. https://doi.org/10.1016/j.scitotenv.2021.152046

He, Y., Lu, J., Li, C., Wang, X., Jiang, C., Zhu, L., Bu, X., Jabeen, K., Vo, T. T., & Li, D. (2024). From pollution to solutions: Insights into the sources, transport and management of plastic debris in pristine and urban rivers. *Environmental Research*, *245*, 118024. https://doi.org/10.1016/j.envres.2023.118024

Hengstmann, E., & Fischer, E. K. (2020). Anthropogenic litter in freshwater environments – Study on lake beaches evaluating marine guidelines and aerial imaging. *Environmental Research, 189*, 109945. https://doi.org/10.1016/j.envres.2020.109945

Hengstmann, E., Gräwe, D., Tamminga, M., & Fischer, E. K. (2017). Marine litter abundance and distribution on beaches on the Isle of Rügen considering the influence of exposition, morphology and recreational activities. *Marine Pollution Bulletin*, *115*(1-2), 297-306. https://doi.org/10.1016/j.marpolbul.2016.12.026

Herrera, A., Rivera, J. A., Moreno, T., Martínez, I., & Gómez, M. (2022). First inventory of marine debris on Alegranza, an uninhabited island in the Northeast Atlantic. *Marine Pollution Bulletin*, *178*, 113604. https://doi.org/10.1016/j.marpolbul.2022.113604

Hoellein, T., Rojas, M., Pink, A., Gasior, J., & Kelly, J. (2014). Anthropogenic Litter in Urban Freshwater Ecosystems: Distribution and Microbial Interactions. *PLOS ONE*, *9*(6), e98485. https://doi.org/10.1371/journal.pone.0098485

Hong, S., Lee, J., Kang, D., Choi, H., & Ko, S. (2014). Quantities, composition, and sources of beach debris in Korea from the results of nationwide monitoring. *Marine Pollution Bulletin*, *84*(1-2), 27-34. https://doi.org/10.1016/j.marpolbul.2014.05.051

Hong, S., Lee, J., & Lim, S. (2017). Navigational threats by derelict fishing gear to navy ships in the Korean seas. *Marine Pollution Bulletin*, *119*(2), 100-105. https://doi.org/10.1016/j.marpolbul.2017.04.006

Honorato-Zimmer, D., Kiessling, T., Gatta-Rosemary, M., Kroeger Campodónico, C., Núñez-Farías, P., Rech, S., & Thiel, M. (2021). Mountain streams flushing litter to the sea – Andean rivers as conduits for plastic pollution. *Environmental Pollution*, *291*, 118166. https://doi.org/10.1016/j.envpol.2021.118166

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment, 586, 127–141*. https://doi.org/10.1016/j.scitotenv.2017.01.190

Huang, Y., Liu, Q., Jia, W., Yan, C., & Wang, J. (2020). Agricultural plastic mulching as a source of microplastics in the terrestrial environment. *Environmental Pollution*, *260*, 114096. https://doi.org/10.1016/j.envpol.2020.114096

Huntington, T (2019). *Marine Litter and Aquaculture Gear – White Paper*. Report produced by Poseidon Aquatic Resources Management Ltd for the Aquaculture Stewardship Council. 20 pp plus appendices.

Iglesias, I., Lupiac, M., Vieira, L., Antunes, S., Mira-Veiga, J., Sousa-Pinto, I., & Lobo, A. (2023). Socio-economic factors affecting the distribution of marine litter: The Portuguese case study. *Marine Pollution Bulletin*, *193*, 115168. https://doi.org/10.1016/j.marpolbul.2023.115168

Ilechukwu, I., Das, R. R., Jamodiong, E. A., Borghi, S., Manzano, G. G., Hakim, A. A., & Reimer, J. D. (2024). Abundance and distribution of marine litter on the beaches of Okinawa Island, Japan. *Marine Pollution Bulletin*, *200*, 116036. https://doi.org/10.1016/j.marpolbul.2024.116036

Imhof, H.K., Ivleva, N.P., Schmid, J., Niessner, R. & Laforsch, C. (2013). Contamination of beach sediments of a subalpine lake with microplastic particles. *Current Biology*, 23 (19), pp. R867-868. https://doi.org/10.1016/j.cub.2013.09.001

Inal, A., Bachouche, S., Rouidi, S., & Bouhadja, A. (2025). Distribution and composition of seafloor macrolitter in the trawlable fishing areas along the Algerian coast (Western Mediterranean). *Marine Pollution Bulletin*, *211*, 117468. https://doi.org/10.1016/j.marpolbul.2024.117468

Incera, M., Valbuena, L., Falcón, J., González, E., González-Porto, M., Martín-García, L., Martín-Sosa, P., & Gago, J. (2024). Assessment of seabed litter at Concepción Seamount (Canary island) using a remotely operated towed vehicle. *Environmental Pollution*, *346*, 123654. https://doi.org/10.1016/j.envpol.2024.123654

Inteca, G., Hagy, B., Silva, I., Amoda, C., Cululo, A., & Farooq, H. (2023). The tourism industry keeps beaches clean in Mozambique. *Marine Pollution Bulletin*, *196*, 115615. https://doi.org/10.1016/j.marpolbul.2023.115615

Ioakeimidis, C., Zeri, C., Kaberi, H., Galatchi, M., Antoniadis, K., Streftaris, N., Galgani, F., Papathanassiou, E., & Papatheodorou, G. (2014). A comparative study of marine litter on the seafloor of coastal areas in the Eastern Mediterranean and Black Seas. *Marine Pollution Bulletin*, *89*(1-2), 296-304. https://doi.org/10.1016/j.marpolbul.2014.09.044

Islam, M. S., Phoungthong, K., Islam, A. R. M. T., Ali, M. M., Ismail, Z., Shahid, S., Kabir, M. H., & Idris, A. M. (2022). Sources and management of marine litter pollution along the Bay of Bengal coast of Bangladesh. *Marine Pollution Bulletin, 185*, 114362. https://doi.org/10.1016/j.marpolbul.2022.114362

Isobe, A., & Iwasaki, S. (2022). The fate of missing ocean plastics: Are they just a marine environmental problem? *Science of The Total Environment*, *825*, 153935. https://doi.org/10.1016/j.scitotenv.2022.153935

ISOTECH Ltd (2026). SeaClear2.0 Stakeholder Workshops: Co-designed Activities for Tackling Marine Litter – Stakeholder Workshop in Venice, Italy. Available from: https://www.seaclear2.eu/wp-content/uploads/2026/06/Venice-Workshop-Results-for-SC2-Website_17.06.2026.pdf Accessed on: 18 June 2026

Jang, Y. C., Ranatunga, R., Mok, J. Y., Kim, K. S., Hong, S. Y., Choi, Y. R., & Gunasekara, A. (2018). Composition and abundance of marine debris stranded on the beaches of Sri Lanka: Results from the first island-wide survey. *Marine Pollution Bulletin*, *128*, 126-131. https://doi.org/10.1016/j.marpolbul.2018.01.018

Janik, H., Sienkiewicz, M., Przybytek, A., Guzmn, A., Kucinska-Lipka, J. & Kosakowska, A. (2018). Novel Biodegradable Potato Starch-based Compositions as Candidates in Packaging Industry, Safe for Marine Environment. *Fibers and Polymers,* 19, 1166–1174. https://doi.org/10.1007/s12221-018-7872-1

Jaquemet, S. (2024). A first assessment of marine litter on a beach of an uninhabited island in the Mozambique Channel. *Western Indian Ocean Journal of Marine Science*, *23*(1), 1–7. https://doi.org/10.4314/wiojms.v23i1.1

Jokar, Z., Banavi, N., Taghizadehfard, s., Hassani, F., Solimani, R., Azarpira, N., Dehghani, H., Dezhgahi, A., Sanati, A.M., Farjadfard, S., & Ramavandi, B. (2024). Marine litter along the shores of the Persian Gulf, Iran. *Heliyon*, 10(9), e30853. https://doi.org/10.1016/j.heliyon.2024.e30853

Kalonde, P.K., Mwapasa, T., Mthawanji, R., Chidziwisano, K., Morse, T., Torguson, J.S., Jones, C.M.m Quilliam, R.S., Feasev, N.A., Henrion, M.Y.R., Stanton, M.C., & Blinnikov, M.S. (2025). Mapping waste piles

in an urban environment using ground surveys, manual digitization of drone imagery, and object based image classification approach. *Environmental Monitoring and Assessment,* 197 (374). https://doi.org/10.1007/s10661-025-13675-6

Kannan, G., Kolandhasamy, P., Anbukkarasu, S., Sigamani, S., Ayyappan, S., & Rajendran, R. (2023). Marine plastics on the beaches of Cuddalore coast, Southeast coast of India: A assessment of their abundance during Covid lockdown and post lockdown. *Regional Studies in Marine Science*, *65*, 103051. https://doi.org/10.1016/j.rsma.2023.103051

Karbalaei, S., Hanachi, P., Walker, T.R., & Cole, M. (2018). Occurrence, sources, human health impacts and mitigation of microplastic pollution. *Environmental Science and Pollution Research, 25* (36), 36046–36063. https://doi.org/10.1007/s11356-018-3508-7

Karwadiya, J., Kerketta, A. R., Pathak, S. K., Srivastava, S., & Darbha, G. K. (2025). Agronomic practices and road proximity drive plastic pollution in agricultural soils: Insights from Bihar, India on weathering, elemental association, and ecological risk. *Environmental Pollution*, *384*, 126975. https://doi.org/10.1016/j.envpol.2025.126975

Kasa, V. P., Brahmandam, A. K. S., Samal, B., Cheela, V. R. S., Dubey, B. K., & Pathak, K. (2025). Assessment of coastal litter trends in tourist vs. Non-tourist beaches: A case study from Indian coastal smart city. *Science of The Total Environment*, *959*, 178339. https://doi.org/10.1016/j.scitotenv.2024.178339

Katsanevakis, S., & Katsarou, A. (2004). Influences on the Distribution of Marine Debris on the Seafloor of Shallow Coastal Areas in Greece (Eastern Mediterranean). *Water, Air, & Soil Pollution,159*, 325–337. https://doi.org/10.1023/B:WATE.0000049183.17150.df

Kausar, A., Hussain, U., Siddiqui, H. F., Ashraf, A., Goroneskul, M., Ouiya, F., Khan, A. H., Malik, M., Borysenko, V. & Sivik, O. (2025). Evaluating marine debris pollution: A study of Sandspit and Clifton beaches in Karachi coast. Ecological Engineering & Environmental Technology, 26(5), 96–106. https://doi.org/10.12912/27197050/202925

Keep America Beautiful, 2021. *Keep America Beautiful 2020 National Litter Survey Summary Report*. Accessed: 08 May 2026. https://kab.org/wp-content/uploads/2021/05/Litter-Study-Summary-Report-May-2021_final_05172021.pdf

Kesavan, S., Jayakumar, N., Santhoshkumar, S., Subburaj, A., & Balasundari, S. (2024). Dynamics of marine debris in the point calimere wildlife and bird sanctuary wetland, southeastern coast of India. *Ocean & Coastal Management*, *251*, 107097. https://doi.org/10.1016/j.ocecoaman.2024.107097

Khadanga, M. K., Behera, A. K., Swain, G. K., Dora, D. P., Padhi, C. P., Mishra, R. K., Pradhan, S., Barik, S., Mohanty, P. K., Mishra, P., & Patro, S. (2022). Evaluation of the status of marine plastic pollution along a tourist beach of Bay of Bengal during lockdown and post lockdown. *Marine Pollution Bulletin*, *182*, 113970. https://doi.org/10.1016/j.marpolbul.2022.113970

Kiruba-Sankar, R., Saravanan, K., Adamala, S., Selvam, K., Kumar, K. L., & Praveenraj, J. (2023). First report of marine debris in Car Nicobar, a remote oceanic Island in the Nicobar archipelago, Bay of Bengal. *Regional Studies in Marine Science*, *61*, 102845. https://doi.org/10.1016/j.rsma.2023.102845

Kiruba-Sankar, R., Selvam, K., Adamala, S., Saravanan, K., Eswaran, Y., Raj, J., Soratur, A., & Ram, M. (2025). First assessment of anthropogenic marine debris (AMD) in the mangroves of Andaman and Nicobar archipelago, Bay of Bengal. *Regional Studies in Marine Science*, *83*, 104091. https://doi.org/10.1016/j.rsma.2025.104091

Kokić, I., Ćetković, I., Pešić, A., Nikolić, S. & Mandić, M. (2025). Assessment of seafloor marine litter along the Montenegrin coast through Fishing for Litter initiatives. *Acta Adriatica, 66: 57-68*. https://acta.izor.hr/ojs/index.php/acta/article/view/1487

Kole, P. J., Löhr, A. J., J Van Belleghem, G. A., & J Ragas, A. M. (2017). Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. *International Journal of Environmental Research and Public Health*, *14*(10), 1265. https://doi.org/10.3390/ijerph14101265

Koutsodendris, A., Papatheodorou, G., Kougiourouki, O., & Georgiadis, M. (2008). Benthic marine litter in four Gulfs in Greece, Eastern Mediterranean; abundance, composition and source identification. *Estuarine, Coastal and Shelf Science*, *77*(3), 501-512. https://doi.org/10.1016/j.ecss.2007.10.011

Kouvara, K., Lazou-Laskaridis, E., Xirotagarou, P., Christodoulou, D., Dimas, X., Geraga, M., Giovos, I., Charitou, A., Gerovasileiou, V., Galgani, F., & Papatheodorou, G. (2025). Assessing marine litter and its ecological impact on the seafloor of Thermaikos Gulf (NE Mediterranean Sea, Greece): Insights from ROV and diver surveys. *Marine Pollution Bulletin*, *217*, 118109. https://doi.org/10.1016/j.marpolbul.2025.118109

Krelling, A. P., Antunes, C. V., & Broadhurst, M. K. (2023). Investigating variability among fisheries litter accumulation on beaches in Paraná, Brazil. *Marine Pollution Bulletin*, *187*, 114607. https://doi.org/10.1016/j.marpolbul.2023.114607

Kuizenga, B., Tasseron, P. F., Wendt-Potthoff, K., & Van Emmerik, T. H. (2023). From source to sea: Floating macroplastic transport along the Rhine river. *Frontiers in Environmental Science*, *11*, 1180872. https://doi.org/10.3389/fenvs.2023.1180872

Kuo, F., & Huang, H. (2014). Strategy for mitigation of marine debris: Analysis of sources and composition of marine debris in northern Taiwan. *Marine Pollution Bulletin*, *83*(1), 70-78. https://doi.org/10.1016/j.marpolbul.2014.04.019

Laist, D. (1997). Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Marine debris: sources, impacts and solutions. Springer, New York, pp. 99– 139

Laverre, M., Kerhervé, P., Constant, M., Weiss, L., Charrière, B., Stetzler, M., González-Fernández, D., & Ludwig, W. (2023). Heavy rains control the floating macroplastic inputs into the sea from coastal Mediterranean rivers: A case study on the Têt River (NW Mediterranean Sea). Science of The Total Environment, 877, 162733. https://doi.org/10.1016/j.scitotenv.2023.162733

Lavers, J. L., Dicks, L., Dicks, M. R., & Finger, A. (2019). Significant plastic accumulation on the Cocos (Keeling) Islands, Australia. *Scientific Reports*, *9*(1), 7102. https://doi.org/10.1038/s41598-019-43375-4

Ledieu, L., Tramoy, R., Ricordel, S., Astrie, D., Tassin, B., & Gasperi, J. (2022). Amount, composition and sources of macrolitter from a highly frequented roadway. *Environmental Pollution*, *303*, 119145. https://doi.org/10.1016/j.envpol.2022.119145

Lee, W. Y., Lan, K. W., Naimullah, M., Lim, I. C., Chen, Y. K., & Wu, Y. L. (2025). Derelict fishing gear in relation to the characteristics of coastal fisheries in Taiwan. *ICES Journal of Marine Science*, *82*(4). https://doi.org/10.1093/icesjms/fsaf046

Li, S., Ding, F., Flury, M., & Wang, J. (2023). Dynamics of macroplastics and microplastics formed by biodegradable mulch film in an agricultural field. *Science of The Total Environment*, *894*, 164674. https://doi.org/10.1016/j.scitotenv.2023.164674

Li, X., Bookman, R., & Segal, Y. (2025). Unveiling the levant basin as a unique sink for plastic bags and packaging through comprehensive multi-marker analysis. *Marine Pollution Bulletin*, *221*, 118492. https://doi.org/10.1016/j.marpolbul.2025.118492

Liao, J., & Chen, Q. (2021). Biodegradable plastics in the air and soil environment: Low degradation rate and high microplastics formation. *Journal of Hazardous Materials*, *418*, 126329. https://doi.org/10.1016/j.jhazmat.2021.126329

Liebezeit, G. (2008). Marine litter on the Kachelotplate, Lower Saxonian Wadden Sea. *Senckenbergiana maritima* 38, 147–151. https://doi.org/10.1007/BF03055291

Lima, A. K. D. S., Silva, A. C., Pereira, L. F., Bezerra, C. M., Soares, L. S., Castro, A. C. L. D., Marinho, Y. F., Funo, I. C. D. S. A., & Lourenço, C. B. (2022). Anthropogenic litter on the macrotidal sandy beaches of the Amazon region. *Marine Pollution Bulletin*, *184*, 114124. https://doi.org/10.1016/j.marpolbul.2022.114124

Lively and Good (2019). *Ghost Fishing. World Seas: An Environmental Evaluation (Second Edition)*, pp. 183–196.

Locritani, M., Merlino, S., & Abbate, M. (2019). Assessing the citizen science approach as tool to increase awareness on the marine litter problem. *Marine Pollution Bulletin*, *140*, 320-329. https://doi.org/10.1016/j.marpolbul.2019.01.023

Loizidou, X.I., Loizides, M.I. & Orthodoxou, D.L. (2018). Persistent marine litter: small plastics and cigarette butts remain on beaches after organized beach cleanups. *Environmental Monitoring and Assessment, 190*, 414. https://doi.org/10.1007/s10661-018-6798-9

Loulad, S., Houssa, R., Ouamari, N. E., & Rhinane, H. (2019). Quantity and spatial distribution of seafloor marine debris in the Moroccan Mediterranean Sea. *Marine Pollution Bulletin*, *139*, 163-173. https://doi.org/10.1016/j.marpolbul.2018.12.036

Lozoya, J. P., González-Pleiter, M., Lacerot, G., De Feo, B., Krojmal, E., Edo, C., Fernández-Piñas, F., Rosal, R., & Teixeira de Mello, F. (2026). Plastic debris on the shores of Bahía Esperanza/Hope Bay: Stranded testimony of the historical occupation in the northern Antarctic Peninsula. *Science of The Total Environment*, *1015*, 181410. https://doi.org/10.1016/j.scitotenv.2026.181410

Lumilan, D. R. T., Shiu, R., & Bacosa, H. P. (2025). Differentiating macroplastic and mesoplastic pollution on relatively clean beaches of central Philippines. *Marine Environmental Research*, *207*, 107092. https://doi.org/10.1016/j.marenvres.2025.107092

Macic, V., Mandic, M., Pestoric, B., Gacic, Z., & Paunovic, M. (2017). First assessment of marine litter in shallow south-east Adriatic Sea. *Fresenius Environmental Bulleting,* 26(7): 4834-4840.https://www.researchgate.net/publication/318860151_First_assessment_of_marine_litter_in_shallow_south-east_adriatic_sea [accessed Feb 16 2026].

Maes, T., Barry, J., Leslie, H., Vethaak, A., Nicolaus, E., Law, R., Lyons, B., Martinez, R., Harley, B., & Thain, J. (2018). Below the surface: Twenty-five years of seafloor litter monitoring in coastal seas of North West Europe (1992–2017). *Science of The Total Environment*, *630*, 790-798. https://doi.org/10.1016/j.scitotenv.2018.02.245

Mahon, A.M., O'Connell, B., Healy, M.G., O'Connor, I., Officer, R., Nash, R. & Morrison, L. (2017). *Environmental Science & Technology*, *51* (2), 810-818. DOI: 10.1021/acs.est.6b04048

Malik, N.K.A., & Manaf, L.A. (2018). Potential recyclable materials derived from riverine litter at log boom Sungai Batu in Kuala Lumpur. *Journal of Material Cycles and Waste Management, 20*, 1063–1072. https://doi.org/10.1007/s10163-017-0670-9

Manullang, C. Y. (2020). Distribution of plastic debris pollution and it is implications on mangrove vegetation. *Marine Pollution Bulletin*, *160*, 111642. https://doi.org/10.1016/j.marpolbul.2020.111642

Martin, C., Almahasheer, H., & Duarte, C. M. (2019). Mangrove forests as traps for marine litter. *Environmental Pollution*, *247*, 499-508. https://doi.org/10.1016/j.envpol.2019.01.067

Martínez-Dios, A., De la Torriente, A., González-Irusta, R., Aguilar, R., Serrano, A., Foglini, F., & Lo Iacono, C. (2025). Assessing marine litter on the VMEs of el Seco de los Olivos (W Mediterranean Sea). *Marine Pollution Bulletin*, *215*, 117802.

Martynova, A., Rodrigue, M., Pieribone, V., Qurban, M., & Duarte, C. M. (2024). Density and distribution patterns of seafloor macrolitter in the eastern Red Sea. *Science of The Total Environment*, *953*, 176042. https://doi.org/10.1016/j.scitotenv.2024.176042

Mayoma, B.S., Mjumira, I.S., Efudala, A., Syberg, K., & Khan, F.R. (2019). Collection of Anthropogenic Litter from the Shores of Lake Malawi: Characterization of Plastic Debris and the Implications of Public Involvement in the African Great Lakes. *Toxics*, 7 (4), p. 64. 10.3390/toxics7040064

Mazzon, M., Edo, C., Guerrini, S., Gioacchini, P., Cupi, J., Malena, P., Rosal, R., & Marzadori, C. (2026). Long-term biodegradable mulch films application in agricultural fields: Effects on soil functionality and microplastic generation. *Journal of Environmental Management*, *398*, 128594. https://doi.org/10.1016/j.jenvman.2026.128594

Meyerjürgens, J., Schöneich-Argent, R. I., & Badewien, T. H. (2022). An exploratory analysis of seabed litter dynamics in the SE German Bight. *Marine Pollution Bulletin*, *177*, 113515. https://doi.org/10.1016/j.marpolbul.2022.113515

Mghili, B., Analla, M., Aksissou, M., & Aissa, C. (2020). Marine debris in Moroccan Mediterranean beaches: An assessment of their abundance, composition and sources. *Marine Pollution Bulletin*, *160*, 111692. https://doi.org/10.1016/j.marpolbul.2020.111692

Mghili, B., Hasni, S., Ben-Haddad, M., Rangel-Buitrago, N., Keznine, M., Lamine, I., Hamiche, F. Z., Haddaoui, H., Abelouah, M. R., Demiathi, M., Oubahaouali, B., Jellal, N., Touaf, M., Ahannach, Y., Hassou, N., Cherradi, S., & Aksissou, M. (2024). Plastic pollution on Moroccan beaches: Toward baselines for large-scale assessment. *Marine Pollution Bulletin*, *201*, 116288. https://doi.org/10.1016/j.marpolbul.2024.116288

Mghili, B., Keznine, M., Hasni, S., & Aksissou, M. (2023). Abundance, composition and sources of benthic marine litter trawled-up in the fishing grounds on the Moroccan Mediterranean coast. *Regional Studies in Marine Science*, *63*, 103002. https://doi.org/10.1016/j.rsma.2023.103002

Mikusheva, M., Pogojeva, M., Kotova, E., Kozhevnikov, A., Danilova, E., Berezina, A., & Yakushev, E. (2023). Floating Riverine Litter Flux to the White Sea: Seasonal Changes in Abundance and Composition. *Journal of Marine Science and Engineering*, *11*(2). https://doi.org/10.3390/jmse11020293

Mohee, R., Surroop, D., Mudhoo, A., & Rughooputh, B. K. (2012). Inventory of waste streams in an industrial port and planning for a port waste management system as per ISO14001. *Ocean & Coastal Management*, *61*, 10-19. https://doi.org/10.1016/j.ocecoaman.2012.02.003

Mokos, M., Zamora Martinez, I. & Zubak, I. (2019) Is central Croatian Adriatic Sea under plastic attack? Preliminary results of composition, abundance and sources of marine litter on three beaches. *Rendiconti Lincei. Scienze Fisiche e Naturali,* 30, 797–806. https://doi.org/10.1007/s12210-019-00851-3

Monchanin, C., Desmolles, M., Rivetta, K., Saramul, S., Charoenpong, C., & Mehrotra, R. (2024). Spatiotemporal variations in marine macro-litter pollution along the shoreline of Koh Mun Nai, an uninhabited island in the Gulf of Thailand. *Environmental Pollution*, *352*, 124098. https://doi.org/10.1016/j.envpol.2024.124098

Monràs-Riera, P., Lozoya, J. P., Teixeira de Mello, F., & Avila, C. (2025). Stranded beach debris in the West Antarctic Peninsula: Quantification and distribution of marine litter. *Environmental Pollution*, *375*, 126366. https://doi.org/10.1016/j.envpol.2025.126366

Mordecai, G., Tyler, P. A., Masson, D. G., & Huvenne, V. A. (2011). Litter in submarine canyons off the west coast of Portugal. *Deep Sea Research Part II: Topical Studies in Oceanography*, *58*(23-24), 2489-2496. https://doi.org/10.1016/j.dsr2.2011.08.009

Munari, C., Corbau, C., Simeoni, U., & Mistri, M. (2016). Marine litter on Mediterranean shores: Analysis of composition, spatial distribution and sources in north-western Adriatic beaches. *Waste Management*, *49*, 483-490. https://doi.org/10.1016/j.wasman.2015.12.010

Nadal, M., Alomar, C., & Deudero, S. (2016). High levels of microplastic ingestion by the semipelagic fish bogue Boops boops (L.) around the Balearic Islands. *Environmental Pollution, 214*, 517–523. https://doi.org/10.1016/j.envpol.2016.04.054

Napper, I.E., & Thompson, R.C. (2019). Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period. *Environmental Science and Technology*, 53 (9), pp. 4775-4783, 10.1021/acs.est.8b06984

Neelavannan, K., Pulikkoden, A., Jinoy, G., Meleppura, R., Panickan, P., Rajaneesh, K. M., Dixit, S., Bawazeer, A., Reshi, O., Ponnambalam, M., Joydas, T., Maneja, R. H., Albert, J., & Alhems, L. (2025). Geospatial distribution and anthropogenic litter impact on coastal mangrove ecosystems from the Saudi Arabia coast of the Gulf. *Scientific Reports*, *15*(1), 15964. https://doi.org/10.1038/s41598-025-98136-3

Nejadsadeghi, E., Khosravani, F., Morovati, M., Delavari Heravi, M., Moein, H., Habibi Dowlatabad, A., Hossaini Motlagh, A., & Ghasemi, A. (2024). Study of pollution status in urban environment caused by

attitude and waste littering behavior of citizens. *Scientific Reports*, *14*(1), 25570. https://doi.org/10.1038/s41598-024-76238-8

Nelms, S., Coombes, C., Foster, L., Galloway, T., Godley, B., Lindeque, P., & Witt, M. (2017). Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data. *Science of The Total Environment*, *579*, 1399-1409. https://doi.org/10.1016/j.scitotenv.2016.11.137

Ngupula, G.W., Kayanda, R.J., & Mashafi, C.A. (2014). Abundance, composition and distribution of solid wastes in the Tanzanian waters of Lake Victoria. *African Journal of Aquatic Science*, *39*, 229–232. https://doi.org/10.2989/16085914.2014.924898

Nisanth, H. P., Punnakkal, H. P., Sukumarapillai, A., & Kumar, A. B. (2025). Marine litter pollution in inhabited and uninhabited Lakshadweep islands, Indian Ocean. *Marine Pollution Bulletin*, *217*, 118062. https://doi.org/10.1016/j.marpolbul.2025.118062

Nizzetto, L., Futter, M., & Langaas, S. (2016). *Environmental Science & Technology*, *50* (20), 10777-10779. DOI: 10.1021/acs.est.6b04140

Nuñez-Rubio, M., Edo, C., Gálvez-Blanca, V., Valenzuela-Lázaro, J. M., Pulido-Reyes, G., González-Pleiter, M., Fernández-García-del-Rincón, L., Leganés, F., Fernández-Piñas, F., & Rosal, R. (2025). Beyond the greenhouse: The spread of plastic pollution from an intensively cultivated agricultural area. *Emerging Contaminants*, *11*(4), 100560. https://doi.org/10.1016/j.emcon.2025.100560

Okuku, E., Mokeira Kombo, M., Sezi Mwalugha, C., Mbuche Chiphatsi, M., Otieno, K., Chepkemboi, P., Omondi Owato, G., & Odhiambo Otieno, C. (2024). Anthropogenic litter pollution in selected African transboundary and Great Rift Valley lakes. *Journal of Great Lakes Research*, *50*(5), 102382. https://doi.org/10.1016/j.jglr.2024.102382

Orthodoxou, D. L., Loizidou, X. I., Baldwin, C., Kocareis, C., Karonias, A., & Ateş, M. A. (2022). Seasonal and geographic variations of marine litter: A comprehensive study from the island of Cyprus. *Marine Pollution Bulletin*, *177*, 113495. https://doi.org/10.1016/j.marpolbul.2022.113495

OSPAR Commission (2010). Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area. ISBN 90 3631 973 9

Otley, H., & Ingham, R. (2003). Marine debris surveys at Volunteer Beach, Falkland Islands, during the summer of 2001/02. *Marine Pollution Bulletin*, *46*(12), 1534-1539. https://doi.org/10.1016/S0025-326X(03)00314-X

Ouyang, X., & Yang, Z. (2022). Characteristics and patterns of marine debris in the Chinese beach-sea continuum. *Frontiers in Marine Science*, *9*, 1031714. https://doi.org/10.3389/fmars.2022.1031714

Owens, K. A., Sarasamma, J. D., Conlon, K., Kiruba, S., Biju, A., Vijay, N., Subramanian, M., Vijayamma, S. A., Jayadev, A., Hoon, V., Padgett, R., Khanolkar, P. J., Kakavipure, D. K., Mohan, P. M., Chattopadhyay, S., & Khanolkar, C. (2022). Empowering Local Practitioners to Collect and Report on Anthropogenic Riverine and Marine Debris Using Inexpensive Methods in India. *Sustainability*, *14*(3). https://doi.org/10.3390/su14031928

Özden, Ö., Yıldırım, S., Fuller, W. J., & Godley, B. J. (2021). Anthropogenic marine litter on the north coast of Cyprus: Insights into marine pollution in the eastern Mediterranean. *Marine Pollution Bulletin*, *165*, 112167. https://doi.org/10.1016/j.marpolbul.2021.112167

Özşeker, K., Terzi, Y. & Erüz, C. (2022). Solid waste composition and COVID-19-induced changes in an inland water ecosystem in Turkey. *Environmental Science and Pollution Research,* 29, 54596–54605 (2022). https://doi.org/10.1007/s11356-022-19750-6

Özşeker, K., Terzi, Y., & Seyhan, K. (2025). Long-term monitoring (2022–2024) of solid waste pollution in inland water ecosystems of Türkiye: Spatial and temporal dynamics. *Waste Management*, *201*, 114807. https://doi.org/10.1016/j.wasman.2025.114807

Palmas, F., Cau, A., Podda, C., Musu, A., Serra, M., Pusceddu, A., & Sabatini, A. (2022). Rivers of waste: Anthropogenic litter in intermittent Sardinian rivers, Italy (Central Mediterranean). *Environmental Pollution*, *302*, 119073. https://doi.org/10.1016/j.envpol.2022.119073

Pama, J. C., Quinto-Tecson, L. M., Malto, M. A. D., Siladan, M. G., & Baleta, F. N. (2026). Physical characterization and spatial distribution of macroplastics along the Mangrove areas of Suyac Island, Sagay, Negros Occidental, Philippines. *Regional Studies in Marine Science*, *96*, 104928. https://doi.org/10.1016/j.rsma.2026.104928

Parolini, M., De Felice, B., Lamonica, C., Cioccarelli, S., Crosta, A., Diolaiuti, G., Ortenzi, M. A., & Ambrosini, R. (2021). Macroplastics contamination on glaciers from Italian Central-Western Alps. *Environmental Advances*, *5*, 100084. https://doi.org/10.1016/j.envadv.2021.100084

Parsa, S., Yousefi, M., Ansarizadeh, M., Moein, H., Delavari Heravi, M., Nejadsadeghi, E., Ghasemi, A., & Habibi Dowlatabad, A. (2025). The first using developed clean environment index for assessment of the environment pollution caused by littering behavior. *Scientific Reports*, *15*(1), 19102. https://doi.org/10.1038/s41598-025-04145-7

Pasanisi, E., Galasso, G., Panti, C., Baini, M., Galli, M., Giani, D., Limonta, G., Tepsich, P., Delaney, E., Fossi, M.C., & Pojana, G. (2023). Monitoring the composition, sources and spatial distribution of seafloor litter in the Adriatic Sea (Mediterranean Sea) through Fishing for Litter initiatives. *Environmental Science and Pollution Research, 30*, 90858–90874. https://doi.org/10.1007/s11356-023-28557-y

Pasquini, G., Ronchi, F., Strafella, P., Scarcella, G., & Fortibuoni, T. (2016). Seabed litter composition, distribution and sources in the Northern and Central Adriatic Sea (Mediterranean). *Waste Management*, *58*, 41-51. https://doi.org/10.1016/j.wasman.2016.08.038

Pasternak, G. (2024). Marine litter on the coasts of Eilat (Israel) in the Gulf of Aqaba, Red Sea. *Marine Pollution Bulletin*, *205*, 116641. https://doi.org/10.1016/j.marpolbul.2024.116641

Pasternak, G., Ribic, C.A., Spanier, E., & Zviely, D. (2021). Stormwater systems as a source of marine debris: a case study from the Mediterranean coast of Israel. *Journal of Coastal Conservation, 25*, 27. https://doi.org/10.1007/s11852-021-00818-3

Pasternak, G., Zviely, D., Ribic, C. A., Ariel, A., & Spanier, E. (2017). Sources, composition and spatial distribution of marine debris along the Mediterranean coast of Israel. *Marine Pollution Bulletin*, *114*(2), 1036-1045. https://doi.org/10.1016/j.marpolbul.2016.11.023

Peng, X., Dasgupta, S., Zhong, G., Du, M., Xu, H., Chen, M., Chen, S., Ta, K., & Li, J. (2019). Large debris dumps in the northern South China Sea. *Marine Pollution Bulletin*, *142*, 164-168. https://doi.org/10.1016/j.marpolbul.2019.03.041

Perroca, J.F., Giarizzo, T., Azzurro, E., Rodrigues-Filho, J.L., Silva, C.V., Arcifa, M.S., & Azevedo-Santos, V.M. (2024). Negative effects of ghost nets on Mediterranean biodiversity. *Aquatic Ecology,* 58, 131-137. https://doi.org/10.1007/s10452-022-09985-3

Perumal, K., Boopathi, V., Chellaiyan, S., Muthuramalingam, S., & Raja, P. (2021). Sources, spatial distribution, and abundance of marine debris on Thondi coast, Palk Bay, Southeast coast of India. *Environmental Sciences Europe,* 33, 136. https://doi.org/10.1186/s12302-021-00576-x

Pervez, R., Wang, Y., Ali, I., Ali, J., & Ahmed, S. (2020). The analysis of the accumulation of solid waste debris in the summer season along the Shilaoren Beach Qingdao, China. *Regional Studies in Marine Science*, *34*, 101041. https://doi.org/10.1016/j.rsma.2020.101041

Petroleum Economist. (November 15, 2019). Oil demand for plastics production worldwide in 2019, 2050, and 2060 (in million barrels per day) [Graph]. In *Statista*. Retrieved June 17, 2026, from https://www.statista.com/statistics/664933/oil-demand-plastics-production-globally/

Piehl, S., Leibner, A., Löder, M. G., Dris, R., Bogner, C., & Laforsch, C. (2018). Identification and quantification of macro- and microplastics on an agricultural farmland. *Scientific Reports*, *8*(1), 17950. https://doi.org/10.1038/s41598-018-36172-y

PlasticsEurope. (2025). *Annual production of plastics worldwide from 1950 to 2024 (in million metric tons)*. *Statista*. Statista Inc.. Accessed: June 17, 2026. https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/?srsltid=AfmBOoohJpfUb2HCzBjLOOYmsokxQdHzCUt6kMOh_yVcL2djmsG2W2bV

Poeta, G., Battisti, C., Bazzichetto, M., & Acosta, A. T. (2016). The cotton buds beach: Marine litter assessment along the Tyrrhenian coast of central Italy following the marine strategy framework directive criteria. *Marine Pollution Bulletin*, *113*(1-2), 266-270. https://doi.org/10.1016/j.marpolbul.2016.09.035

Poeta, G., Bazzichetto, M., Gallitelli, L., Garzia, M., Aprea, F., Bartoli, F., Battisti, C., Cascone, S., Corradi, A., D'Amelia, D., D'Amico, E., De Luca, J., Del Grosso, F., Iacobelli, L., Langone, S., Lembo Fazio, C., Locchi, G., Perrone, M., Petroni, F., . . . Malavasi, M. (2022). One year after on Tyrrhenian coasts: The ban of cotton buds does not reduce their dominance in beach litter composition. *Marine Policy*, *143*, 105195. https://doi.org/10.1016/j.marpol.2022.105195

Polasek, L., Bering, J., Kim, H., Neitlich, P., Pister, B., Terwilliger, M., Nicolato, K., Turner, C., & Jones, T. (2017). Marine debris in five national parks in Alaska. *Marine Pollution Bulletin*, *117*(1-2), 371-379. https://doi.org/10.1016/j.marpolbul.2017.01.085

Ponmani, M., Padmavathy, P., Manimekalai, D., Shalini, R., Ravikumar, T., Hariharan, G., & Manickavasagam, S. (2024). Vulnerability of mangrove ecosystems to anthropogenic marine litter along the southeast coast of India. *Science of The Total Environment*, *956*, 177224. https://doi.org/10.1016/j.scitotenv.2024.177224

Portz, L., Manzolli, R. P., Villate-Daza, D. A., & Fontán-Bouzas, Á. (2022). Where does marine litter hide? The Providencia and Santa Catalina Island problem, SEAFLOWER Reserve (Colombia). *Science of The Total Environment*, *813*, 151878. https://doi.org/10.1016/j.scitotenv.2021.151878

Pradhan, U., Naik, S., Panda, U. S., Mishra, P., & Murthy, M. (2024). Abundance and transport of macro-litter at sea turtle nesting beach: A case study for sustainable habitat management. *Regional Studies in Marine Science*, *70*, 103353. https://doi.org/10.1016/j.rsma.2023.103353

Qari, R., & Shaffat, M. (2015). Distribution and Abundance of Marine Debris Along the Coast of Karachi (Arabian Sea), Pakistan: Marine Debris Along the Karachi Coast. (2015). *Biological Sciences - PJSIR*, *58*(2), 98-103. https://doi.org/10.52763/PJSIR.BIOL.SCI.58.2.2015.98.103

Raharinaivo, L. R., Todinanahary, G. B. G., Delroisse, J., Raquez, J., Bittencourt, C., Maherizo, T. G. F., Lavitra, T., & Eeckhaut, I. (2025). Quantification of anthropogenic debris from small-scale fisheries and community-based aquaculture in marine and coastal ecosystems of Southwestern Madagascar. *Marine Pollution Bulletin*, *213*, 117631. https://doi.org/10.1016/j.marpolbul.2025.117631

Rahimi Hezarvand, S., Morovati, M., Parsa, S., & Torkashvand, J. (2025). A case study on litter management and clean environment index in small tourism cities. *Scientific Reports, 15*, 36727. https://doi.org/10.1038/s41598-025-20688-1

Ramilo-Henry, M., Umbelina, B., Matilde, E., & Duncan, E. M. (2023). Plastic pollution on remote islands: A baseline study of Príncipe, Gulf of Guinea. *Marine Environmental Research*, *191*, 106181. https://doi.org/10.1016/j.marenvres.2023.106181

Rangel-Buitrago, N. (2025). Coastal processes and human drivers of ocean-derived plastic pollution: insights from remote beaches of the Colombian Caribbean. *Anthropocene Coasts, 8,* 41. https://doi.org/10.1007/s44218-025-00112-x

Rangel-Buitrago, N., Vergara-Cortés, H., Barría-Herrera, J., Contreras-López, M., & Agredano, R. (2019). Marine debris occurrence along Las Salinas beach, Viña Del Mar (Chile): Magnitudes, impacts and management. *Ocean & Coastal Management*, *178*, 104842. https://doi.org/10.1016/j.ocecoaman.2019.104842

Ramos, J. A., & Pessoa, W. V. (2019). Fishing marine debris in a northeast Brazilian beach: Composition, abundance and tidal changes. *Marine Pollution Bulletin*, *142*, 428-432. https://doi.org/10.1016/j.marpolbul.2019.04.002

Rashid, S., Majeed, L.R., Mehta, N., Radu, T., Martín-Fabiani, I., & Bhat, M.A. (2025). Microplastics in terrestrial ecosystems: sources, transport, fate, mitigation, and remediation strategies. *Euro-Mediterranean Journal for Environmental Integration, 10,* 2633-2659. https://doi.org/10.1007/s41207-025-00766-6

Read, F., & Turner, A. (2025). Presence and characteristics of plastics and microplastics on the seabed of the western English Channel. *Marine Pollution Bulletin*, *222*, 118779. https://doi.org/10.1016/j.marpolbul.2025.118779

Rech, S., Macaya-Caquilpán, V., Pantoja, J.F., Rivadeneira, M.M., Campodónico, C.K., & Thiel, M. (2015). Sampling of riverine litter with citizen scientists — findings and recommendations. *Environmental Monitoring and Assessment, 187*, 335. https://doi.org/10.1007/s10661-015-4473-y

Ribeiro, V. V., Garcia, Y., Dos Reis Cavalcante, E., & Castro, I. B. (2024). Marine macrolitter and cigarette butts hazard multiple-use marine protected area and fishing community at Brazil. *Marine Pollution Bulletin*, *208*, 117031. https://doi.org/10.1016/j.marpolbul.2024.117031

Ribeiro, C. I. R., Mendes, G., Cardozo, A. L. P., Gentil, E., & Dantas, D. V. (2025). From isolation to impact: Spatiotemporal assessment of marine litter on a non-urbanized beach in Southern Brazil. *Marine Pollution Bulletin*, *222*, 118706. https://doi.org/10.1016/j.marpolbul.2025.118706

Ribic, C. A., Sheavly, S. B., Rugg, D. J., & Erdmann, E. S. (2012). Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007. *Marine Pollution Bulletin*, *64*(5), 994-1004. https://doi.org/10.1016/j.marpolbul.2012.02.008

Ribic, C. A., Sheavly, S. B., & Klavitter, J. (2012). Baseline for beached marine debris on Sand Island, Midway Atoll. *Marine Pollution Bulletin*, *64*(8), 1726-1729. https://doi.org/10.1016/j.marpolbul.2012.04.001

Ribic, C. A., Sheavly, S. B., Rugg, D. J., & Erdmann, E. S. (2010). Trends and drivers of marine debris on the Atlantic coast of the United States 1997–2007. *Marine Pollution Bulletin*, *60*(8), 1231-1242. https://doi.org/10.1016/j.marpolbul.2010.03.021

Richardson, K., Hardesty, B. D., Vince, J. Z., & Wilcox, C. (2021). Global Causes, Drivers, and Prevention Measures for Lost Fishing Gear. *Frontiers in Marine Science*, *8*, 690447. https://doi.org/10.3389/fmars.2021.690447

Richardson, K., Hardesty, B. D., Vince, J., & Wilcox, C. (2022). Global estimates of fishing gear lost to the ocean each year. *Science Advances*. https://doi.org/abq0135

Rillig, M. C., Lehmann, A., Machado, S., & Yang, G. (2019). Microplastic effects on plants. *New Phytologist*, *223*(3), 1066-1070. https://doi.org/10.1111/nph.15794

Rimmaudo, A., Cundill, A., Singleton, I., Morrison, D., & Blaud, A. (2026). Quantification and Characterisation of Microplastics in Organic Waste-Derived Soil Amendments. *Water, Air, & Soil Pollution,* 237, 450. https://doi.org/10.1007/s11270-026-09145-5

Rizzo, A., Rangel-Buitrago, N., Impedovo, A., Mastronuzzi, G., Scardino, G., & Scicchitano, G. (2021). A rapid assessment of litter magnitudes and impacts along the Torre Guaceto marine protected area (Brindisi, Italy). *Marine Pollution Bulletin*, *173*, 112987. https://doi.org/10.1016/j.marpolbul.2021.112987

Robbe, E., Abdallah, L. B., Fels, L. E., Houda Chaher, N. E., Haseler, M., Mhiri, F., & Schernewski, G. (2024). Towards Solving the Beach Litter Problem: Ecosystem Service Assessments at North African Coasts. *Sustainability*, *16*(14). https://doi.org/10.3390/su16145911

Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Sci. Rep. 3 (1), 1–7. https://doi.org/ 10.1038/srep03263

Rochman, C.M., Lewison, R.L., Eriksen, M., Allen, H., Cook, A., Teh, S.J., 2014. Polybrominated diphenyl ethers (PBDEs) in fish tissue may be an indicator of plastic contamination in marine habitats. Sci. Total Environ. 476–477, 622–633. https:// doi.org/10.1016/j.scitotenv.2014.01.058

Roman, L., Kong, M., Barilli, E., Chanrout, R., Lawson, T., Schuyler, Q., & Hardesty, B. D. (2024). Plastic pollution in a rapidly developing nation: A comprehensive assessment of litter and marine debris surrounding coastal Cambodia. *Marine Pollution Bulletin*, *208*, 116872. https://doi.org/10.1016/j.marpolbul.2024.116872

Roman, L., Warmbrunn, A., Lawson, T., Willis, K., Wilcox, C., & Hardesty, B. D. (2021). Comparing marine anthropogenic debris on inhabited mainland beaches, coastal islands, and uninhabited offshore islands: A case study from Queensland and the Coral Sea, Australia. *Marine Pollution Bulletin*, *172*, 112919. https://doi.org/10.1016/j.marpolbul.2021.112919

Rosevelt, C., Los Huertos, M., Garza, C., & Nevins, H. (2013). Marine debris in central California: Quantifying type and abundance of beach litter in Monterey Bay, CA. *Marine Pollution Bulletin*, *71*(1-2), 299-306. https://doi.org/10.1016/j.marpolbul.2013.01.015

Rupasinghe, H., Perera, I., Sandaruwan, R., Jayapala, H., Bellanthudawa, B., & Tennakoon, A. (2025). Marine litter pollution impacts the sustainability of coastal mangrove ecosystems; an assessment via index-based approach. *Regional Studies in Marine Science*, *93*, 104717. https://doi.org/10.1016/j.rsma.2025.104717

Ryan, P. G. (1988). Effects of ingested plastic on seabird feeding: evidence from chickens. Marine Pollution Bulletin, 19, 125– 128

Rynek, R., Tekman, M.B., Veit-Köhler, G., Wagner, S., Reemtsma, T. & Jahnke, A. (2025). Plastics from Surface to Seabed: Vertical Distribution of (Micro)plastic Particles in the North Pacific Ocean. *Environmental Science & Technology*, 59 (48), 26145-26156. DOI: 10.1021/acs.est.5c11358

Sahai, H., Aguilera del Real, A. M., Alcayde, A., Bueno, M. M., Wang, C., Hernando, M. D., & Fernández-Alba, A. R. (2025). Key insights into microplastic pollution in agricultural soils: A comprehensive review of worldwide trends, sources, distribution, characteristics and analytical approaches. *TrAC Trends in Analytical Chemistry*, *185*, 118176. https://doi.org/10.1016/j.trac.2025.118176

Salazar, J. A., González, R., Navarrete, A. L., Calle, P., Alava, J. J., & Domínguez, G. A. (2022). A temporal assessment of anthropogenic marine debris on sandy beaches from Ecuador's southern coast. *Frontiers in Marine Science*, *9*, 977650. https://doi.org/10.3389/fmars.2022.977650

Salinas, C. X., Palacios, E., Pozo, K., Torres, M., Rebolledo, L., Gómez, V., Rondón, R., De la Maza, I., & Galbán, C. (2024). Marine litter pollution in a subantarctic beach of the Strait of Magellan, Punta Arenas, Chile. *Marine Pollution Bulletin*, *202*, 116313. https://doi.org/10.1016/j.marpolbul.2024.116313

Sánchez, P., Masó, M., Sáez, R., de Juan, S., Muntadas, A., Demestre, M. (2013). Baseline study of the distribution of marine debris on soft-bottom habitats associated with trawling grounds in the northern Mediterranean. *Scientia Marina*,77(2):247-55. https://doi.org/10.3989/scimar03702.10A

Santodomingo, N., Perry, C., Waheed, Z., Syed Hussein, M. A. B., Rosedy, A., & Johnson, K. G. (2021). Marine litter pollution on coral reefs of Darvel Bay (East Sabah, Malaysia). *Marine Pollution Bulletin*, *173*, 112998. https://doi.org/10.1016/j.marpolbul.2021.112998

Santos, I.R., Friedrich, A.C. & Ivar do Sul, J.A. (2009). Marine debris contamination along undeveloped tropical beaches from northeast Brazil. *Environmental Monitoring and Assessment,* 148, 455–462. https://doi.org/10.1007/s10661-008-0175-z

Santos, S. P., Rodrigues, F. L., Santos, A. C. D. A., & Moraes, L. E. (2024). Spatial and temporal patterns of floating litter in shallow habitats: Insights from high-tourism tropical areas in Northeastern Brazil. *Regional Studies in Marine Science*, *78*, 103782. https://doi.org/10.1016/j.rsma.2024.103782

Savva, I., Cai, L. L., Marcou, M., & Angel, D. (2026). The untold story of Sea Caves: Lost and found anthropogenic debris in confined marine environments. *Marine Pollution Bulletin*, *223*, 119065. https://doi.org/10.1016/j.marpolbul.2025.119065

Savva, I., Kola, M., Ioannou, N., & Angel D.L. (2025). Charting plastic shores: environmental NGOs bridging historical data gaps for coastal litter management in Cyprus. *Environmenatl Research Communications,* 7, 075005. DOI: 10.1088/2515-7620/ade7d7

Scheld, A. M., Bilkovic, D. M., & Havens, K. J. (2016). The Dilemma of Derelict Gear. *Scientific Reports*, *6*(1), 19671. https://doi.org/10.1038/srep19671

Schirinzi, G. F., Köck-Schulmeyer, M., Cabrera, M., González-Fernández, D., Hanke, G., Farré, M., & Barceló, D. (2020). Riverine anthropogenic litter load to the Mediterranean Sea near the metropolitan area of Barcelona, Spain. *Science of The Total Environment*, *714*, 136807. https://doi.org/10.1016/j.scitotenv.2020.136807

Schmidt, P. M., Leibig, L., Meyer, L., Roth, C., Bolduan, P., Battagliarin, G., Künkel, A., Harrison, S., Uluseker, C., & Wohlleben, W. (2025). Soil-biodegradable mulch film: Distinguishing between persistent microplastics and fragments released from certified soil-biodegradable products. *Science of The Total Environment*, *1009*, 181048. https://doi.org/10.1016/j.scitotenv.2025.181048

Schneider, F., Kunz, A., Hu, C. S., Yen, N., & Lin, H. T. (2021). Rapid-Survey Methodology to Assess Litter Volumes along Large River Systems—A Case Study of the Tamsui River in Taiwan. *Sustainability*, *13*(16). https://doi.org/10.3390/su13168765

Schneider, F., Lin, H., Hu, C., Hsu, C., & Yen, N. (2022). Volume-based assessment of coastal litter reveals a significant underestimation of marine litter from ocean-based activities in East Asia. *Regional Studies in Marine Science*, *51*, 102214. https://doi.org/10.1016/j.rsma.2022.102214

Schreyers, L., Erismann, R., Erismann, S., Ludwig, C., Patel, B., Filella, M., & Van Emmerik, T. (2024). Revealing the role of land-use features on macrolitter distribution in Swiss freshwaters. *Environmental Pollution*, *362*, 124911. https://doi.org/10.1016/j.envpol.2024.124911

Sciutteri, V., Pedà, C., Longo, F., Calogero, R., Cangemi, G., Pagano, L., Battaglia, P., Nannini, M., Romeo, T., & Consoli, P. (2023). Integrated approach for marine litter pollution assessment in the southern Tyrrhenian Sea: Information from bottom-trawl fishing and plastic ingestion in deep-sea fish. *Marine Pollution Bulletin*, *188*, 114661. https://doi.org/10.1016/j.marpolbul.2023.114661

Seco Pon, J. P., & Becherucci, M. E. (2012). Spatial and temporal variations of urban litter in Mar del Plata, the major coastal city of Argentina. *Waste Management*, *32*(2), 343-348. https://doi.org/10.1016/j.wasman.2011.10.012

Segal, Y., & Lubinevsky, H. (2023). Spatiotemporal distribution of seabed litter in the SE Levantine Basin during 2012–2021. *Marine Pollution Bulletin*, *188*, 114714. https://doi.org/10.1016/j.marpolbul.2023.114714

Selvakumar, U., Wijesinghe, R.D.N. & Arulananthan, A. (2024). Abundance of Marine Macrodebris on the Northern Coast of Jaffna Peninsula, Sri Lanka. *Environmental Science and Pollution Research, 31*, 54534–54545. https://doi.org/10.1007/s11356-024-34771-z

Selvam, K., Xavier, K. M., Shivakrishna, A., Bhutia, T. P., Kamat, S., & Shenoy, L. (2021). Abundance, composition and sources of marine debris trawled-up in the fishing grounds along the north-east Arabian coast. *Science of The Total Environment*, *751*, 141771. https://doi.org/10.1016/j.scitotenv.2020.141771

Sharma, D., Dhanker, R., Bhawna, Tomar, A., Raza, S., Sharma, A. (2024). Fishing Gears and Nets as a Source of Microplastic. In: Shahnawaz, M., Adetunji, C.O., Dar, M.A., Zhu, D. (eds) Microplastic Pollution. Springer, Singapore. https://doi.org/10.1007/978-981-99-8357-5_8

Sherrington, C. (2016). *Plastics in the Marine Environment*, Eunomia.

Sherrington, C., Darrah, C., Cole, G., Corbin, M., & Hann, S. (2016). *Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment*, EUNOMIA, 429 pp.

Šilc, U., Küzmič, F., Caković, D., & Stešević, D. (2018). Beach litter along various sand dune habitats in the southern Adriatic (E Mediterranean). *Marine Pollution Bulletin*, *128*, 353-360. https://doi.org/10.1016/j.marpolbul.2018.01.045

Silva, M. L. D., Castro, R. O., Sales, A. S., & Araújo, F. V. D. (2018). Marine debris on beaches of Arraial do Cabo, RJ, Brazil: An important coastal tourist destination. *Marine Pollution Bulletin*, *130*, 153-158. https://doi.org/10.1016/j.marpolbul.2018.03.026

Singh, R.P., Mishra, S., Das, A.P., 2020. Synthetic microfibers: pollution toxicity and remediation. Chemosphere 257, 127199. https://doi.org/10.1016/j. chemosphere.2020.127199

Skirtun, M., Sandra, M., Strietman, W. J., Van den Burg, S. W., De Raedemaecker, F., & Devriese, L. I. (2021). Plastic pollution pathways from marine aquaculture practices and potential solutions for the North-East Atlantic region. *Marine Pollution Bulletin*, *174*, 113178. https://doi.org/10.1016/j.marpolbul.2021.113178

Soliveres, S., Casado-Coy, N., Martínez, J. E., & Sanz-Lázaro, C. (2024). Anthropogenic and environmental factors partly co-determine the level, composition and temporal variation of beach debris. *Journal of Hazardous Materials*, *468*, 133843. https://doi.org/10.1016/j.jhazmat.2024.133843

Song, S. H., Lee, H. W., Kim, J. N., Jeong, J. M., Ji, H. S., Jo, H., Kim, D. H., & Park, C. (2021). First observation and effect of fishery of seabed litter on sea bed by trawl survey Korea waters. *Marine Pollution Bulletin*, *170*, 112228. https://doi.org/10.1016/j.marpolbul.2021.112228

Spear, L. B., Ainley, D. G., & Ribic, C. A. (1995). Incidence of plastic in seabirds from the tropical Pacific, 1984–91: relation with distribution of species, sex, age, season, year and body weight. Marine Environmental Research, 40, 123–146.

Stagličić, N., Bojanić Varezić, D., Kurtović Mrčelić, J., Pavičić, M., & Tutman, P. (2021). Marine litter on the shallow seafloor at Natura 2000 sites of the Central Eastern Adriatic Sea. *Marine Pollution Bulletin*, *168*, 112432. https://doi.org/10.1016/j.marpolbul.2021.112432

Stefano, N., & Pleissner, D., (2022). Quantification and analysis of surface macroplastic contamination on arable areas. *J Soils Sediments* **22**, 757–768. https://doi.org/10.1007/s11368-021-03114-7

Strafella, P., Fabi, G., Despalatovic, M., Cvitković, I., Fortibuoni, T., Gomiero, A., Guicciardi, S., Marceta, B., Raicevich, S., Tassetti, A., Spagnolo, A., & Scarcella, G. (2019). Assessment of seabed litter in the

Northern and Central Adriatic Sea (Mediterranean) over six years. *Marine Pollution Bulletin*, *141*, 24-35. https://doi.org/10.1016/j.marpolbul.2018.12.054

Strafella, P., Fabi, G., Spagnolo, A., Grati, F., Polidori, P., Punzo, E., Fortibuoni, T., Marceta, B., Raicevich, S., Cvitkovic, I., Despalatovic, M., & Scarcella, G. (2015). Spatial pattern and weight of seabed marine litter in the northern and central Adriatic Sea. *Marine Pollution Bulletin*, *91*(1), 120-127. https://doi.org/10.1016/j.marpolbul.2014.12.018

Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O., & Schaumann, G. E. (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? *Science of The Total Environment*, *550*, 690-705. https://doi.org/10.1016/j.scitotenv.2016.01.153

Suhail, B., Kanwal, H. & Arsalan, M. (2024). Composition and relative abundance of plastic debris along Manora and Sandspit beaches, Karachi, Pakistan. *Journal of Coastal Conservation* 28 (9). https://doi.org/10.1007/s11852-023-01006-1

Sulochanan, B., Veena, S., Ratheesh, L., Padua, S., Rohit, P., Kaladharan, P., & Kripa, V. (2019). Temporal and spatial variability of beach litter in Mangaluru, India. *Marine Pollution Bulletin*, *149*, 110541. https://doi.org/10.1016/j.marpolbul.2019.110541

Sundan, S. M. B., Michelsen, O., Rasmussen, F. N., Aas, B., & Bohne, R. A. (2025). Dynamic material flow analysis of microplastics lost from artificial turfs: A case study from Norway. *Science of The Total Environment*, *973*, 179159. https://doi.org/10.1016/j.scitotenv.2025.179159

Sundaram, B. P., Kulandaisamy, P., Velmayil, P., Thangaraj, K., Rajendran, M., Senapathi, V., Karthikeyan, S., & Krishnamoorthy, R. (2026). Marine litter distribution and environmental impacts along the south-eastern coast of India. *Regional Studies in Marine Science*, *96*, 104921. https://doi.org/10.1016/j.rsma.2026.104921

Suteja, Y., Atmadipoera, A. S., Riani, E., Nurjaya, I. W., Nugroho, D., & Purwiyanto, A. I. S. (2021). Stranded marine debris on the touristic beaches in the south of Bali Island, Indonesia: The spatiotemporal abundance and characteristic. *Marine Pollution Bulletin*, *173*, 113026. https://doi.org/10.1016/j.marpolbul.2021.113026

Suteja, Y., Parwati, E., Budhiman, S., Radjawane, I. M., Hartuti, M., Afgatiani, P. M., Ulfa, A., Dewi, E. K., & Purwiyanto, A. I. S. (2024). Spatial patterns and types of marine anthropogenic debris on touristic

beaches along the Eastern Indian Ocean: A preliminary study from Southern Sumatera Island, Indonesia. *Regional Studies in Marine Science*, *81*, 103970. https://doi.org/10.1016/j.rsma.2024.103970

Syamsuddin, M. F. D., Nevandra, A. P. A., Yona, D., Yamindago, A., Sari, S. H. J., and Yanuar, A. T. (2025). Beach Cleanliness and Marine Debris Characteristics for Sustainable Coastal Tourism in Prigi Bay, Indonesia. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences, [Online] Volume 30(3), pp. 329-344*. https://doi.org/10.14710/ik.ijms.30.3.329-344

Tanaka, K., Watanuki, Y., Takada, H., Ishizuka, M., Yamashita, R., Kazama, M., Hiki, N., Kashiwada, F., Mizukawa, K., Mizukawa, H., Hyrenbach, D., Hester, M., Ikenaka, Y., Nakayama, S.M., 2020. In vivo accumulation of plastic-derived chemicals into seabird tissues. Curr. Biol. 30 (4), 723–728.e3. https://doi.org/10.1016/j. cub.2019.12.037

Tavares, D. C., Moura, J. F., Ceesay, A., & Merico, A. (2020). Density and composition of surface and buried plastic debris in beaches of Senegal. *Science of The Total Environment*, *737*, 139633. https://doi.org/10.1016/j.scitotenv.2020.139633

Tekman, M. B., Krumpen, T., & Bergmann, M. (2017). Marine litter on deep Arctic seafloor continues to increase and spreads to the North at the HAUSGARTEN observatory. *Deep Sea Research Part I: Oceanographic Research Papers*, *120*, 88-99. https://doi.org/10.1016/j.dsr.2016.12.011

Terzi, Y., Gündoğdu, S., Yandi, İ., Altinpinar, İ., Öztürk, R. Ç., & Gedik, K. (2025). Marine litter on the Turkish Black Sea shoreline: Abundance, composition, and sources. *Waste Management*, *205*, 115027. https://doi.org/10.1016/j.wasman.2025.115027

Terzi, Y., & Seyhan, K. (2017). Seasonal and spatial variations of marine litter on the south-eastern Black Sea coast. *Marine Pollution Bulletin*, *120*(1-2), 154-158. https://doi.org/10.1016/j.marpolbul.2017.04.041

Tramoy, R., Blin, E., Poitou, I., Noûs, C., Tassin, B., & Gasperi, J. (2022). Riverine litter in a small urban river in Marseille, France: Plastic load and management challenges. *Waste Management*, *140*, 154-163. https://doi.org/10.1016/j.wasman.2022.01.015

Tubau, X., Canals, M., Lastras, G., Rayo, X., Rivera, J., & Amblas, D. (2015). Marine litter on the floor of deep submarine canyons of the Northwestern Mediterranean Sea: The role of hydrodynamic processes. *Progress in Oceanography*, *134*, 379-403. https://doi.org/10.1016/j.pocean.2015.03.013

UNEP. (2009). Marine litter: a global challenge. Nairobi: UNEP.

Unger, A., & Harrison, N. (2016). Fisheries as a source of marine debris on beaches in the United Kingdom. *Marine Pollution Bulletin*, *107*(1), 52-58. https://doi.org/10.1016/j.marpolbul.2016.04.024

US Department of Agriculture in Frontier Technology Quarterly (2019). *Frontier Technologies for Addressing Plastic Pollution*. United Nations Department of Economic and Social Affairs. Available from: https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/FTU_3rdQtr_2019.pdf. Accessed on: 18 June 2026.

Van Calgar, C.J., & van Emmerik, T.H.M. (2019). Abundance of plastic debris across European and Asian Rivers. *Environmental Research Letters*, 14 (12). DOI 10.1088/1748-9326/ab5468

Van Caneghem, J., Vanstockem, J., & Verstegen, A. (2024). Functional classification and material characterization of plastic packaging in Flemish land litter to support effective reduction policies. *Environmental Advances*, *15*, 100505. https://doi.org/10.1016/j.envadv.2024.100505

Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environ. Pollut. 193, 65–70. https://doi.org/10.1016/j. envpol.2014.06.010

Van den Beld, I. M., Guillaumont, B., Menot, L., Bayle, C., Arnaud-Haond, S., & Bourillet, J. (2017). Marine litter in submarine canyons of the Bay of Biscay. *Deep Sea Research Part II: Topical Studies in Oceanography*, *145*, 142-152. https://doi.org/10.1016/j.dsr2.2016.04.013

Van Gool, E., Campbell, M., Wallace, P., & Hewitt, C. L. (2021). Marine Debris on New Zealand Beaches - Baseline Data to Evaluate Regional Variances. *Frontiers in Environmental Science*, *9*, 700415. https://doi.org/10.3389/fenvs.2021.700415

Van Hoytema, N., Bullimore, R. D., Al Adhoobi, A. S., Al-Khanbashi, M. H., Whomersley, P., & Le Quesne, W. J. (2020). Fishing gear dominates marine litter in the Wetlands Reserve in Al Wusta Governorate, Oman. *Marine Pollution Bulletin*, *159*, 111503. https://doi.org/10.1016/j.marpolbul.2020.111503

Veerasingam, S., Al-Khayat, J. A., Aboobacker, V., Hamza, S., & Vethamony, P. (2020). Sources, spatial distribution and characteristics of marine litter along the west coast of Qatar. *Marine Pollution Bulletin*, *159*, 111478. https://doi.org/10.1016/j.marpolbul.2020.111478

Vesman, A., Moulin, E., Egorova, A., & Zaikov, K. (2019). Marine litter pollution on the Northern Island of the Novaya Zemlya archipelago. *Marine Pollution Bulletin*, *150*, 110671. https://doi.org/10.1016/j.marpolbul.2019.110671

Viejo, J., Cózar, A., Quintana, R., Martí, E., Markelain, G., Cabrera-Castro, R., Arroyo, G. M., Montero, E., & Morales-Caselles, C. (2023). Artisanal trawl fisheries as a sentinel of marine litter pollution. *Marine Pollution Bulletin*, *191*, 114882. https://doi.org/10.1016/j.marpolbul.2023.114882

Vlachogianni, T., Fortibuoni, T., Ronchi, F., Zeri, C., Mazziotti, C., Tutman, P., Varezić, D. B., Palatinus, A., Trdan, Š., Peterlin, M., Mandić, M., Markovic, O., Prvan, M., Kaberi, H., Prevenios, M., Kolitari, J., Kroqi, G., Fusco, M., Kalampokis, E., . . . Scoullos, M. (2018). Marine litter on the beaches of the Adriatic and Ionian Seas: An assessment of their abundance, composition and sources. *Marine Pollution Bulletin*, *131*, 745-756. https://doi.org/10.1016/j.marpolbul.2018.05.006

Vlachogianni, T., Skocir, M., Constantin, P., Labbe, C., Orthodoxou, D., Pesmatzoglou, I., Scannella, D., Spika, M., Zissimopoulos, V., & Scoullos, M. (2020). Plastic pollution on the Mediterranean coastline: Generating fit-for-purpose data to support decision-making via a participatory-science initiative. *Science of The Total Environment*, *711*, 135058. https://doi.org/10.1016/j.scitotenv.2019.135058

Vorsatz, L. D., So, M. W. K., Not, C., & Cannicci, S. (2023). Anthropogenic debris pollution in peri-urban mangroves of South China: Spatial, seasonal, and environmental drivers in Hong Kong. Marine Pollution Bulletin, 195, 115495. https://doi.org/10.1016/j.marpolbul.2023.115495

Vriend, P., Schoor, M., Rus, M., Oswald, S. B., & Collas, F. P. (2023). Macroplastic concentrations in the water column of the river Rhine increase with higher discharge. *Science of The Total Environment*, *900*, 165716. https://doi.org/10.1016/j.scitotenv.2023.165716

Walther, B. A., Kunz, A., & Hu, C. (2018). Type and quantity of coastal debris pollution in Taiwan: A 12-year nationwide assessment using citizen science data. *Marine Pollution Bulletin*, *135*, 862-872. https://doi.org/10.1016/j.marpolbul.2018.08.025

Waluda, C. M., Staniland, I. J., Dunn, M. J., Thorpe, S. E., Grilly, E., Whitelaw, M., & Hughes, K. A. (2020). Thirty years of marine debris in the Southern Ocean: Annual surveys of two island shores in the Scotia Sea. *Environment International*, *136*, 105460. https://doi.org/10.1016/j.envint.2020.105460

Wang, K., Chen, W., Tian, J., Niu, F., Xing, Y., Wu, Y., Zhang, R., Zheng, J., & Xu, L. (2022a). Accumulation of microplastics in greenhouse soil after long-term plastic film mulching in Beijing, China. *Science of The Total Environment*, *828*, 154544. https://doi.org/10.1016/j.scitotenv.2022.154544

Wang, S., Fan, T., Cheng, W., Wang, L., Zhao, G., Li, S., Dang, Y., & Zhang, J. (2022b). Occurrence of macroplastic debris in the long-term plastic film-mulched agricultural soil: A case study of Northwest China. *Science of The Total Environment*, *831*, 154881. https://doi.org/10.1016/j.scitotenv.2022.154881

WBCSD - World Business Council for Sustainable Development. (2019). Global ELT management: a global state of knowledge on regulation, management systems, impacts of recovery and technologies. Available at: https://docs.wbcsd.org/2019/12/Global_ELT_Management%E2%80%93A_global_state_of_knowledge_on_regulation_management_systems_impacts_of_recovery_and_technologies.pdf Accessed on: 18 June 2026.

Weideman, E. A., Perold, V., Omardien, A., Smyth, L. K., & Ryan, P. G. (2020). Quantifying temporal trends in anthropogenic litter in a rocky intertidal habitat. Marine Pollution Bulletin, 160, 111543. https://doi.org/10.1016/j.marpolbul.2020.111543

Weinstein, J. E., Dekle, J. L., Leads, R. R., & Hunter, R. A. (2020). Degradation of bio-based and biodegradable plastics in a salt marsh habitat: Another potential source of microplastics in coastal waters. *Marine Pollution Bulletin*, *160*, 111518. https://doi.org/10.1016/j.marpolbul.2020.111518

Woodall, L. C., Robinson, L. F., Rogers, A. D., Narayanaswamy, B. E., & Paterson, G. L. (2015). Deep-sea litter: A comparison of seamounts, banks and a ridge in the Atlantic and Indian Oceans reveals both environmental and anthropogenic factors impact accumulation and composition. *Frontiers in Marine Science*, *2*, 128166. https://doi.org/10.3389/fmars.2015.00003

Wright, S.L., Rowe, D., Thompson, R.C., Galloway, T.S., 2013. Microplastic ingestion decreases energy reserves in marine worms. Curr. Biol. 23 (23), R1031–R1033. https://doi.org/10.1016/j.cub.2013.10.068

Wulan, F. N., Iskandar, I., Arief, M. C. W. & Zahidah, Z. (2025). Composition and Distribution of Waste in The Jatigede Reservoir. Polish Journal of Environmental Studies, 34(2), 1363–1374. https://doi.org/10.15244/pjoes/187066

Yang, HT., Chao, HR. & Cheng, YF. (2023). Inferences of waste management policy and reduction of marine debris in Southern Taiwan. *Int. J. Environ. Sci. Technol.* 20, 1597–1606. https://doi.org/10.1007/s13762-022-04082-2

Yen, N., Hu, C., Chiu, C., & Walther, B. A. (2022). Quantity and type of coastal debris pollution in Taiwan: A rapid assessment with trained citizen scientists using a visual estimation method. *Science of The Total Environment*, *822*, 153584. https://doi.org/10.1016/j.scitotenv.2022.153584

Yenici, E., & Turkoglu, M. (2023). Abundance and composition of marine litter on the coasts of the Dardanelles (Canakkale Strait, Turkey). *Environ Monit Assess* 195, 4. https://doi.org/10.1007/s10661-022-10511-z

Yona, D., Nooraini, P., Putri, S. E., Sari, S. H., Lestariadi, R. A., & Amirudin, A. (2023). Spatial distribution and composition of marine litter on sandy beaches along the Indian Ocean coastline in the south Java region, Indonesia. *Frontiers in Marine Science*, *10*, 1220650. https://doi.org/10.3389/fmars.2023.1220650

Youngblood, K., Brooks, A., Das, N., Singh, A., Sultana, M., Verma, G., Zakir, T., Chowdhury, G.W., Duncan, E., Khatton, H., Maddalene, T., Napper, I., Nelms, S., Patel, S., Sturges, V., & Jambeck, J.R. (2022). Rapid Characterization of Macroplastic Input and Leakage in the Ganges River Basin. *Environmental Science & Technology*, *56* (7), 4029-4038 DOI: 10.1021/acs.est.1c04781

Yousefi, M., Torkashvand, J., Yousefi, M., Zeinalpour, A., Ansarizadeh, M., & Sheikhmohammadi, A. (2025). Spatial variation of litter density and associated PAHs leakage on Aras River bank. *Scientific Reports*, *16*(1), 1151. https://doi.org/10.1038/s41598-025-30927-0

Yünlü, M.Z. (2025). Assessment of macro litter pollution and potential sources in the shorelines of two Mediterranean lakes in Isparta, Turkey: a first report. *Environmental Monitoring and Assessment,* 197, 335. https://doi.org/10.1007/s10661-025-13798-w

Zbyszewski, M., & Corcoran, P.L. (2011). Distribution and Degradation of Fresh Water Plastic Particles Along the Beaches of Lake Huron, Canada. *Water, Air, & Soil Pollution,* 220, 365–372. https://doi.org/10.1007/s11270-011-0760-6

Zbyszewski, M., Corcoran, P. L., & Hockin, A. (2014). Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America. *Journal of Great Lakes Research*, *40*(2), 288-299. https://doi.org/10.1016/j.jglr.2014.02.012

Zhang, Q.Q., Ma, Z.R., Cai, Y.Y,, Li, H.R., & Ying, G.G. (2021). Agricultural Plastic Pollution in China: Generation of Plastic Debris and Emission of Phthalic Acid Esters from Agricultural Films. *Environmental Science & Technology*, *55* (18), 12459-12470 DOI: 10.1021/acs.est.1c04369

Zhou, B., Wang, J., Zhang, H., Shi, H., Fei, Y., Huang, S., Tong, Y., Wen, D., Luo, Y., & Barceló, D. (2020). Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. *Journal of Hazardous Materials*, *388*, 121814. https://doi.org/10.1016/j.jhazmat.2019.121814

Zylstra, E. (2013). Accumulation of wind-dispersed trash in desert environments. *Journal of Arid Environments*, *89*, 13-15. https://doi.org/10.1016/j.jaridenv.2012.10.004