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Title of Thesis **Microplastic pollution along the coast of Cyprus: Occurrence in beach sediments of marine turtle nesting beaches**

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Microplastics (<5mm) have become ubiquitous in marine environments, posing a number of issues to biodiversity, food safety and socioeconomics worldwide. One of the most affected regions is the Mediterranean Sea, with an estimated 250 billion microplastics present across it. This study looked at the island of Cyprus, located in the Levantine basin of the eastern Mediterranean, and particularly at important turtle nesting beaches. These are considered as sensitive habitats due to the endangered listing of marine turtles. Microplastics were found across all 14 sampled locations, at a mean concentration of 20,870 ± 5,968 (mean ± se) particles m^{-3} (range 0-199,600 particles m^{-3} across 14 beaches) at the surface. Microplastic concentrations were lower, deeper down in the sediment at 2.1-10.0cm. The most polluted beach was the worst recorded across the island so far. The majority of microplastics were fragments, broken down from larger debris, followed by sheets and industrial pellets. By examining the circulation patterns and currents of the Mediterranean, it was predicted that the majority of microplastics originated from nearby countries and were deposited on the beaches of Cyprus via the sea. As the microplastic pollution levels in the Mediterranean worsen, sensitive species such as marine turtles are coming under increased threat, with potential impacts on nesting success and hatchling sex ratios. For effective protection to be achieved, it is important that all relevant governments and stakeholders make the best decisions in terms of policy and legislation, offering protection to our oceans and the life within it.

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1. Introduction

With a volume of over 1.3 billion km^3 and covering 71% of the Earth's surface, the global ocean is considered one of the largest and most important ecosystems, supporting an estimated 2.2 million marine species (Mora *et al.*, 2011; Visbeck, 2018). In addition to its rich biodiversity, the ocean plays a vital role in regulating the climate, supplying oxygen and storing carbon dioxide, as well as providing a vast amount of resources to humanity, such as food, transport, materials, energy, recreation and aesthetic value. Due to the doubling of the world population in the last 50 years and the rapid increase in industrial development, demand for resources and pressure exerted on the global ocean have increased dramatically. This has led to a series of threats being posed to the marine environment, including the destruction of marine habitats, non-sustainable exploitation of resources, climate change, and marine pollution (Global Ocean Commission, 2014; Visbeck, 2018).

Prior to the 1950s, marine pollution mostly took the form of human and animal effluent as well as food waste. Most scientists believed that due to their vast size, oceans were immune to the effects of pollution, and had the unlimited ability to dilute all types of waste. Since the accelerated industrial activity in the 1950s, the nature of pollutants has changed dramatically, taking on several forms such as chemical and industrial waste, debris, toxins and underwater noise (Global Ocean Commission, 2014). After several radioactive waste dumping events, oil spills and significant anthropogenic debris accumulation, marine pollution was being recognised as a threat to ocean health. In 1972 it became a major topic of discussion at the United Nations Conference on the Human Environment, bringing attention to the issue globally (United Nations, 1972). In 1991, the United Nations (UN) Sponsored Group of Experts on the Scientific Aspects of Marine Environmental Protection defined marine pollution as (GESAMP, 1991):

"The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".

Although there are a number of pathways which pollutants may enter the marine environment, they can be split into two main categories:

1. **Nonpoint source (NPS) pollution** is the most common type of marine pollution and results from processes such as land runoff, precipitation, atmospheric deposition and drainage, originating from many diffuse sources rather than one known direct source. Fertilizers from agricultural lands, oil and toxic chemicals from industrial practice, sediments from construction sites and heavy metals from abandoned mines are some of the common examples of NPS pollutants that make their way into the marine environment. (NOAA, 2020). Due to their nature, NPS pollution is difficult to regulate through policy and legislation.
2. **Point source (PS) pollution** is defined as pollution that comes directly from a single known source. Examples include but are not limited to industrial waste, waste from ships and urban sewage (European Environment Agency, 2020). Due to their nature, PS pollutants are much easier to regulate through policy and legislation.

Hence, marine pollution can take several different forms, each with its own difficulties and opportunities for mitigation and control. One of the modern and most widespread pollutants affecting oceans globally is that of plastic. A diverse group of synthetic polymers, plastic became a very popular material in the mid twentieth century due to its cheap, lightweight, strong and malleable properties. Today more than 300 million tons of plastic are produced yearly for a wide range of applications such as packaging, construction, household and sports equipment, vehicles and agriculture, with about half of this plastic being used for the production of single-use items such as cups, straws and bags (Boucher and Friot, 2017). Around 8 million tons of plastic yearly end up in marine environments, making up 80% of all marine debris. Sources of plastic pollution include both NPS and PS, originating mostly from land. These include storm and urban runoff, overflowing sewers, mismanagement of waste, construction, industrial activities and illegal dumping. Plastics can also originate from ocean-based sources, most commonly dumping from ships, the fishing industry and aquaculture (Boucher and Friot, 2017). The diverse sources of plastic pollution into the oceans makes regulation through legislation and policy a challenging task. The presence of plastic threatens ocean health, marine biodiversity, food safety, human health, tourism as well as contributing to climate change. Due to the durability and strength of the polymers that make up plastics, decomposition can take decades, if not centuries, meaning that debris accumulates, and is dispersed by water and wind over potentially thousands of kilometres to habitats and coastlines all across the globe (Hopewell, Dvorak and Kosior, 2009; Ryan, 2015).

As well as existing in a larger form, plastics can also take the form of smaller particles known as microplastics, commonly described as < 5mm. First described by scientists in the 1970s, microplastics have since been found in marine environments and coastlines all around the globe. Due to their small size, making it difficult to quantify their effects, microplastics have gained great attention by the scientific community since the late 2000s, with much still remaining unknown (GESAMP, 2015).

This report consists of a literature review to describe the sources, impacts, and legislation associated with marine microplastic pollution, followed by a study to determine the abundance, distribution and composition of microplastics across turtle nesting beaches in Cyprus. This study focuses primarily on turtle nesting sites since marine turtles come under a number of potential threats as a result of beach microplastic pollution in Cyprus. To date, only one study on microplastic abundance and distribution has been undertaken, covering the northern region of the island (Duncan *et al.*, 2018), therefore this study will provide a base-line survey of microplastic pollution in coastal sediments across the western, southern and eastern regions of Cyprus.

2. Literature Review: Marine Microplastic Pollution: Sources, Impacts & Legislation

2.1. Introduction to microplastics

In 2004, the term 'microplastic' was first used in a study to describe very small plastic particles, without specific size dimensions being stated (Thompson, 2004). Since then, the term has been defined differently by various researchers, ranging from 'barely visible plastics', to distinct dimensions between 0.06 and 5mm (Andrady, 2011). In 2009, a workshop by the National Oceanic and Atmospheric Administration (NOAA) defined the upper limit of microplastics as 5mm (Arthur, Baker and Bamford, 2009), and since then this has remained consistent across numerous studies (Li *et al.*, 2015; Waite, Donnelly and Walters, 2018).

Most commonly synthesized from fossil fuels, the global plastic market is dominated by 6 types: Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS), Polyurethane (PUR) and Polyethylene Terephthalate (PET) (GESAMP, 2015), each used for a wide variety of different applications (Table 1). As well as being classified in the same way as larger plastics by the synthetic polymer that they are made of, microplastics are also categorised by the way they in which they are produced.

Table 1 Common applications of the most popular plastic types.
(*adapted from Andrady, 2011)*

Plastic Type	Common Applications
Polyethylene	Plastic bags, containers
Polypropylene	Bottle caps, rope
Polystyrene	Cups, cool boxes, floats
Polyvinyl Chloride	Pipes, films, containers
Polyurethane	Building insulation, furniture
Polyethylene Terephthalate	Bottles, strapping

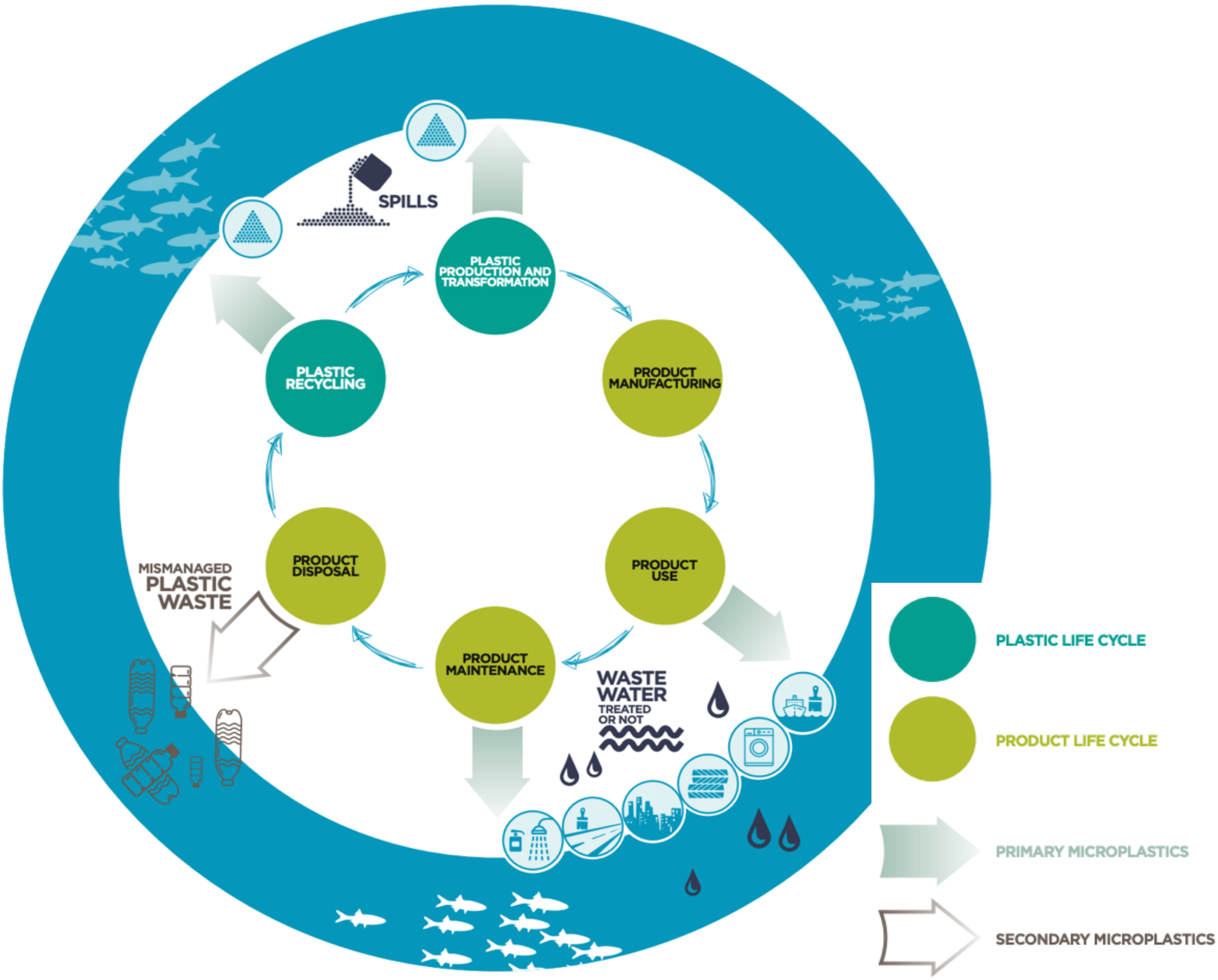
Primary and secondary microplastics

The difference between the two categories of microplastic is whether the particles were intentionally designed to be of that size (primary), or whether the particles are the result of larger plastics breaking down (secondary) (GESAMP, 2015). Common examples of primary microplastics include small particles acting as scrubbing agents in cleaning products, microbeads in cosmetic products, plastic powders used for moulding, and cylindrical or spherical virgin resin pellets, used in the manufacture of larger plastic products (Boucher and Friot, 2017). Secondary microplastics originate from the breakdown of larger plastics either during their use-phase in the case of fishing nets, or once products such as single-use cups and straws have been disposed of. Solar UV radiation is one of the most dominant causes of plastic degradation, accelerating the oxidative degradation of polymers (Gewert, Plassmann and MacLeod, 2015). Physical forces such as wind, waves and human activity are also ways in which plastics can be broken down into smaller fragments (Boucher and Friot, 2017).

2.2. Pathways into the marine environment

Of all floating debris across the global ocean, 80% is estimated to be plastic. 93% of this is estimated to be in the form of microplastics compared to just 7% larger debris (Eriksen *et al.*, 2014). Due to the continuous mass production of plastic products over the past 60 years, and the inadequate management of end-of-life plastics, a substantial volume of debris ends up being deposited in several ecosystems globally, including the marine environment. This phenomenon continues to occur anywhere where humans reside or travel, but also in some of the most remote locations such as the Pacific Ocean and Antarctica (GESAMP, 2015). There are multiple pathways of microplastics into the marine environment, with ocean currents and waves transporting them over large distances to locations all over the world, leading to the global, transboundary issue we face today.

Microplastics can end up in the marine environment via a number of pathways, originating from both point sources (PS) and nonpoint sources (NPS), and can enter as both primary and secondary microplastics. This can happen at various points within the lifecycle of plastic and plastic products (Figure 1). Due to the vast quantity of larger plastics entering the oceans, it is assumed that the majority of microplastics in the environment are secondary (Hidalgo-Ruz *et al.*, 2012; Duis and Coors, 2016). Secondary microplastics most commonly arise from mismanaged waste during the disposal stage of plastic products. In contrary, primary microplastics can be lost during the production, transport and recycling stages, as well as during the use and maintenance of a product (Boucher and Friot, 2017).



(Boucher and Friot, 2017)

Figure 1. The lifecycle of plastic and plastic products with entry points of microplastics into the marine environment.

2.1.1. Primary microplastic pathways

During the production phase, plastics are in the form of powder, or pellets, typically 2-5mm in diameter. It is in this form that plastic is transported and transformed into a variety of products. Throughout the production, processing, transport and recycling, accidents may occur, leading to the unintentional loss of pellets into the oceans and the wider environment (Siegfried *et al.*, 2017). It is estimated that 257,000 kilotons of plastic pellets are consumed globally per year, making them the largest source of primary microplastics (Plastics Europe, 2009).

Primary microplastics can also be discharged via sewage water in the form of fibres. Synthetic fibres tend to shed from clothing during the laundry process in households and in industry, ending up in sewage water, which is commonly discharged into the marine environment (Magnusson *et al.*, 2016). An estimated 42,534 kilotons of plastic in the form of synthetic fibres are thought to be produced every year, making it one of the largest sources of primary microplastics (FAO and ICAC, 2013). Similarly, plastic microbeads used in cosmetic and exfoliating products also end up in sewage waste from households, hotels and hospitals. Microplastics of this nature are the only type that are produced to be lost intentionally. Due to this, many companies have since banned the use of microplastic beads in their products, limiting the amount that is lost through sewage systems (Boucher and Friot, 2017).

Vehicle tyres and roads are also potential sources of primary microplastics, released due to abrasion and weathering. The outside layer of tyres consists of various synthetic polymers that get released as the tyres become eroded with use. Physical forces such as wind and rain can transport such particles into the wider environment, including the oceans (Siegfried *et al.*, 2017). Similarly, paints and thermoplastics applied to roads as markings, are also lost over time due to weathering and vehicle abrasion. In the same way as tyre microplastics, particles can be spread over distances via the wind and rain (Boucher and Friot, 2017).

In addition to land-based sources, primary microplastics can also be ocean-based. Vessels such as cruise ships, transport ships and fishing boats are coated with anticorrosive paints, which includes several types of synthetic polymers (IMO, 2019). During the construction, maintenance and the use of the vessels, synthetic polymers from the coating may be lost directly into the marine environment as result of weathering or faulty application.

2.1.2. Secondary microplastic pathways

Secondary microplastics, originating from larger debris, most commonly end up in the marine environment due to mismanagement of plastic waste. Land-based sources include litter from tourism and recreational use of the coast, harbours, unregulated landfills near the coast and overflows of sewage. Extreme weather events, winds, rivers, and direct dumping are all pathways in which larger plastic debris can enter the ocean, where it can break down over time to form smaller fragments. Ocean-based sources include vessels of all types, including cruise ships and fishing boats, as well as offshore infrastructures such as oil rigs and aquaculture sites, where pollution is usually due to illegal dumping (Galgani, Hanke and Maes, 2015). A study from 2013 identified packaging, fishing nets and polystyrene pieces to be the most common types of secondary plastics floating in the oceans (European Commission, 2013).

2.2. Impacts of microplastics in the marine environment

Microplastics contribute to a wide variety of threats and issues in the marine environment and beyond, including to marine organisms, food and health, and tourism (Andrady, 2011).

2.2.1. Marine wildlife

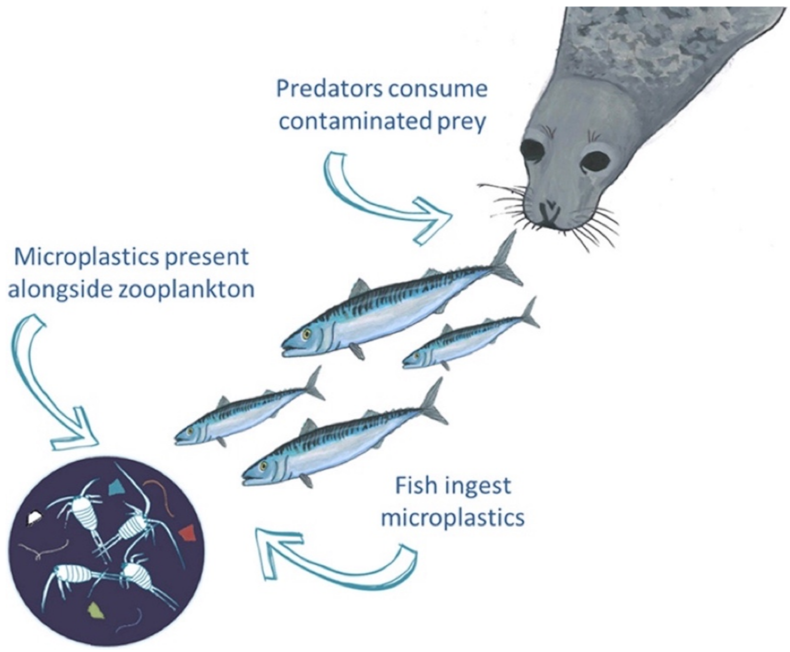
Due to the small size of microplastics, many benthic and pelagic marine organisms are vulnerable to its ingestion. In 2017, a study reported that more than 690 species, including fish, seabirds and turtles, were found to be ingesting microplastics (Provencher *et al.*, 2017). Typically, when larger plastic debris is ingested by organisms, it can lead to external and internal damage, digestive track blockage, causing starvation and physical deterioration. This in turn can result in detrimental effects for animals, such as drowning, decreased reproductive success, exposure to predators and death (Gregory, 2009). These effects can also be observed in smaller animals that ingest microplastics, such as shrimp, zooplankton and marine worms (Li, 2018). Although the effects of microplastic ingestion are not fully understood, studies have reported decreased population numbers, starvation and a lack of nutrition in fish that were found to have ingested microplastics over long term periods (Boerger *et al.*, 2010).

Although not commonly fatal, microplastic ingestion has also affected seabirds all across the globe. A 2015 study estimated that 99% of all seabird species would have microplastics in their gastrointestinal systems by 2050, with 95% of all individual birds of these species being affected by the same year (Wilcox *et al.*, 2015). As well as being mistaken as food and ingested directly from the ocean surface, microplastics can also enter the gastrointestinal tract of a seabird via the ingestion of zooplankton and other prey. Both direct and indirect ingestion have been observed in in several sea bird species and across multiple studies (Avery-Gomm *et al.*, 2013; Desforges, Galbraith and Ross, 2015). Although the effects of microplastic ingestion are not fully understood in seabirds, they are expected to be similar to those seen in fish (Li, 2018).

Studies have found ingestion of microplastics by several sea turtle species, both directly and indirectly via their prey (Tourinho, Ivar do Sul and Fillmann, 2010; Nelms *et al.*, 2016). As sea turtles are visual foragers, it is possible that microplastics could be misidentified as prey and therefore accidentally eaten (Nelms *et al.*, 2016). Another study also suggested that due to microbial film formation on the surface of microplastics, sea turtles are attracted to them due to their sensory cues of taste and smell (Reisser *et al.*, 2014). Potential effects of microplastic ingestion by sea turtles are starvation, nutrient deficiency and internal lacerations.

2.2.2. Human health and food safety

Trophic transfer occurs when microplastics are ingested indirectly by feeding on species that already have microplastic present in their gastrointestinal tract (Figure 2). Although this phenomenon has been observed in a number of studies under laboratory conditions for low



(Nelms et al., 2016)

Figure 2. Example of microplastic trophic transfer along the marine food web.

trophic level organisms (Batel *et al.*, 2016), it is unclear at what extent this occurs for higher trophic organisms in the wild. The potential for this to occur has been highlighted by several studies that have recorded microplastic particles in the gastrointestinal tracts of wild caught fish. A 2016 study found microplastics were present in 11% of mesopelagic fish, and estimated that 436 million microplastic particles could be ingested by dolphins through predation of these contaminated fish species (Lusher *et al.*, 2016). Since trophic transfer may occur through the marine food chain, it is possible that microplastics can be ingested by humans when feeding on different kinds of sea foods. This is particularly likely with smaller fish that are consumed whole, rather than larger ones that have their digestive tracts removed prior to being eaten. Studies carried out on both rats and humans have shown that very fine microplastic particles are capable of passing through cell membranes, the blood-brain barrier, and the placenta in pregnant women. Effects that were observed include damage to cells, inflammation and oxidative stress (Vethaak and Leslie, 2016). Although examples of negative impacts do exist, further research would be required to investigate long term impacts to microplastic exposure, as well as what levels are safe to ingest.

Besides the physical effects of microplastic ingestion, microplastics may also act as vectors for toxic chemicals. A number of toxic pollutants including polycyclic aromatic hydrocarbons (PAHs) and pesticides such as DDT, have been found to adsorb to microplastics, being transported and accumulating over large distances in the oceans (Hirai *et al.*, 2011). This is likely to be due to the large surface-area-to-volume-ratio of microplastic particles, and their hydrophobic properties (Hong, Shim and Hong, 2017). Extensive exposure to such toxic pollutants can lead to endocrine problems as well as liver and kidney damage in species that ingest them (Muirhead *et al.*, 2006). It is possible that through trophic transfer, such toxic pollutants can be passed along the food chain and ingested by humans through different sea foods. The risks to human health through trophic transfer of pollutants adsorbed to microplastics have not been yet reported.

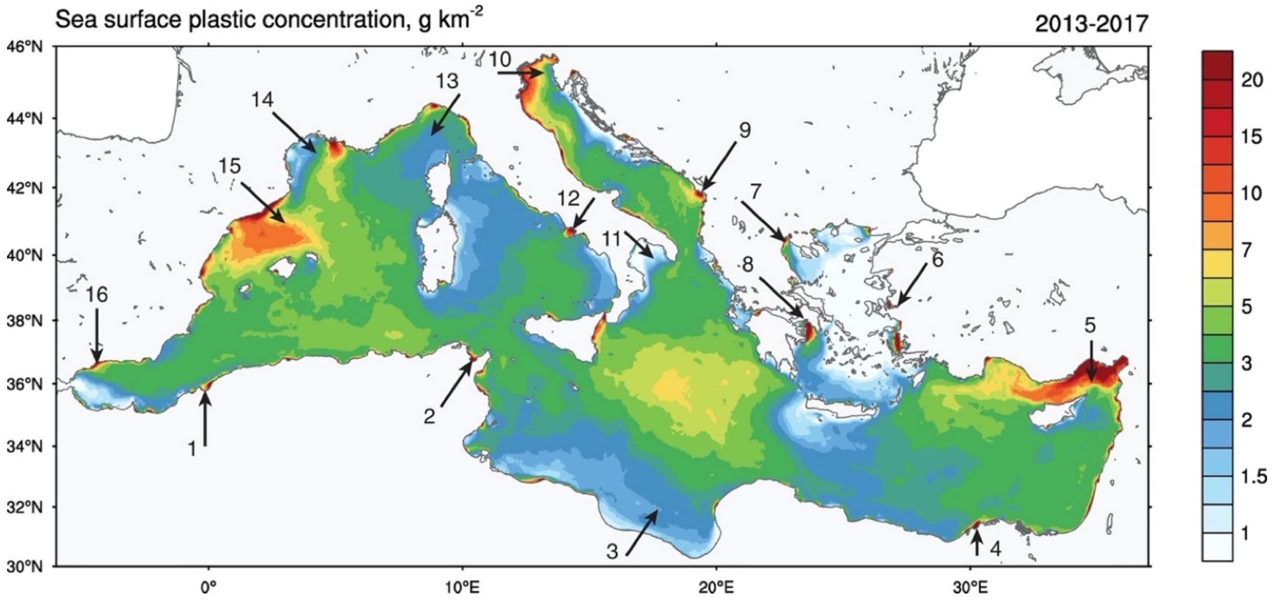
2.2.3. Tourism industry

Since microplastics can be transported over thousands of kilometres through waves and ocean currents, it is not uncommon for them to be washed up onto shorelines and beaches all across the globe (Galgani, Hanke and Maes, 2015). Particularly in popular tourist destinations, high concentrations of microplastics diminish the aesthetic value of the beach, leading to a decreased income from tourist activity. In addition, cleaning and maintaining these sites from microplastics in order to make them more attractive to tourists, has major economic costs (Boucher and Friot, 2017).

2.3. Microplastics in the Mediterranean

The Mediterranean Sea is thought to be one of the worst affected marine environments in regard to plastic pollution, with up to 250,000 items recorded per km^2, of which the majority are microplastics (Avio, Gorbi and Regoli, 2017). Several studies have found plastic marine debris to be present throughout various environmental compartments of the Mediterranean, such as the water, bottom sediments, coastlines and biota (Suaria and Aliani, 2014; Poeta *et al.*, 2016). It is estimated that up to 500,000 tons of larger plastic debris and 130,000 tons of microplastics end up in the Mediterranean Sea every year (Bayo, Del Pozo and Fuertes, 2018). Marine pollution in the Mediterranean is likely to be a result of high-density populations living in the coastal zones (7% of the world's population), the high number of tourists visiting throughout the year (25% of all yearly international tourism), the vast amount of marine traffic, both commercial and leisure (30% of global marine travel passes through the Mediterranean), and the hydrodynamic characteristics associated with being a semi-enclosed basin (Bayo, Del Pozo and Fuertes, 2018).

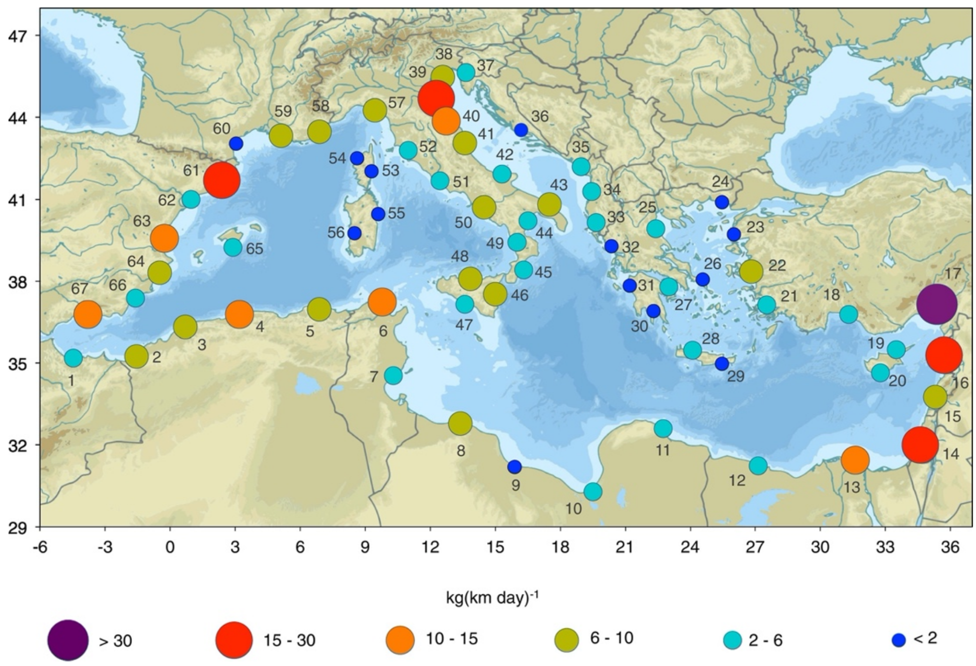
Studies have shown that the accumulation and distribution of plastics within the Mediterranean are not homogeneous, but rather show heterogeneity within the semi-enclosed sea (Figure 3) (Liubartseva *et al.*, 2018). A higher concentration can be seen particularly in the Catalan (Figure 3



(Liubartseva et al., 2018)

Figure 3. Sea surface plastic concentrations across the Mediterranean Sea.
Average plastic concentration found on the surface of the Mediterranean Sea in g/km^2, between 2013-2017. Arrows point to the 16 most polluted areas.

number 15) and the Cilician (Figure 3 number 5) seas compared to the rest of the Mediterranean. Such a varied distribution is likely to be correlated with the high influx of plastic waste from the Barcelona coast in the Catalan sea (26.1kg/km/day) (Figure 4, number 64; Supplemental Table 1), as well as the Turkish and Syrian coasts in the Cilician sea (31.3kg/km/day) (Figure 4, number 17; Supplemental Table 1). These two locations were the highest polluters in terms of plastic recorded in the study compared to the rest of the Mediterranean coast (Figure 4) (Liubartseva *et al.*, 2018). Varying influxes of plastic pollution combined with the oceanic currents and wave paths, means



(*Liubartseva et al., 2018)*

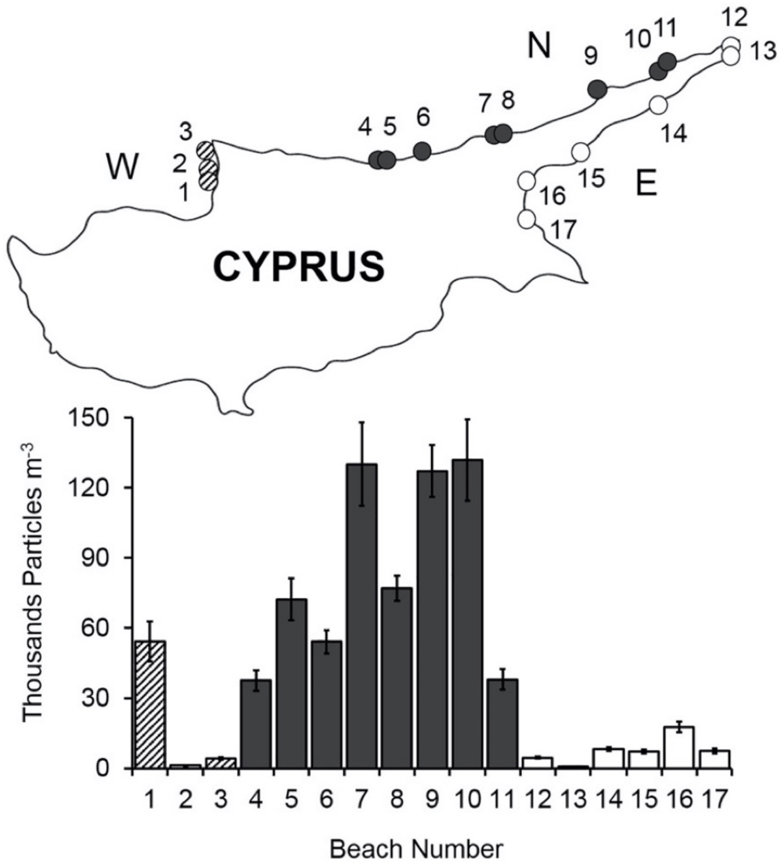
Figure 4. Plastic debris influx into the Mediterranean Sea.
Amount of plastic entering the Mediterranean Sea in kg/km/day from 67 coastal locations.

that plastic debris originating from one coast may not necessarily end up on the same coast. Over extended periods of time, waves and currents can transport plastic debris over thousands of kilometres, leading to the deposition of plastics in locations far away from the source (Millot and Taupier-Letage, 2005). This phenomenon creates a complex transboundary issue, making it difficult for countries to manage plastic waste present on their shores. Despite this, Liubartseva et al. found that the majority of plastic waste located on a country's coastline in the Mediterranean, originated from land-based sources withing the country itself, coining this the 'boomerang effect'. The remaining plastic pathways were identified as land-based sources from other countries, as well as shipping lanes within the sea (Liubartseva *et al.*, 2018).

2.4. Microplastics in Cyprus

Cyprus, the third largest island in the Mediterranean with a 640km-long coastline, is located in the Levantine Basin, 65km south of Turkey and 100km west of Syria (Hunt, 2020). The Levantine Basin has been estimated to be a hotspot of long term plastic accumulation, although further scientific evidence is required to support this claim (Zambianchi, Trani and Falco, 2017).

A study conducted in 2018, shows the extent of microplastic pollution in Cyprus's northern region and specifically on turtle nesting beaches (Duncan *et al.*, 2018). Across 17 sites on the west, north and east coasts, microplastic concentrations in beach sediments were found to be on average 45,497 particles/m^3, with the most polluted beach containing up to 131,939 particles/m^3, the highest recorded across the Mediterranean at the time, and the second highest globally to Hong Kong. The north coast was found to have the most polluted beaches compared to the east and west (Figure 5) (Duncan *et al.*, 2018). Since most of the beaches that were sampled are located far



(Duncan et al., 2018)

Figure 5. Locations and Microplastic concentrations in beaches of Cyprus.
Turtle nesting beaches sampled with the concentration of microplastic of each in thousands of particles/m^3. The colours of the bars and dots represent the orientation of the coast as follows: Black=North, Striped=West, White=East.

from industrial practice and have a low level of use by tourists and locals, it is less likely that microplastics originated from land-based sources within Cyprus. Rather, it is much more likely that the majority of microplastics were deposited by the sea and originated from land-based sources in other neighbouring countries as well as ocean-based sources such as ships and oil rigs. Research by Liubartseva *et al.,* estimates that around 55% of microplastics on the beaches of Cyprus originate from land-based sources within the country, whereas around 45% come from other countires and shipping lanes (Liubartseva *et al.*, 2018). A particle drifter analysis from the Duncan *et al.* study, identified the potential sources where microplastics could have originated from before being deposited on the beaches of Cyprus. The model found most particles originating from within Cyprus, with Turkey and Lebanon being the second and third highest sources respectively (Duncan *et al.*, 2018).

Altough the study by Duncan *et al*. highlights just how vast the microplastic problem may be in the beaches of Cyprus, no data was available from the southern region of the island prior to the completion of this study, therefore it was not possible to get a complete picture of microplastic pollution in Cyprus. Thus, the results presented in this study act as a baseline for the majority of the island, primarily the south coast and parts of the east and west coasts.

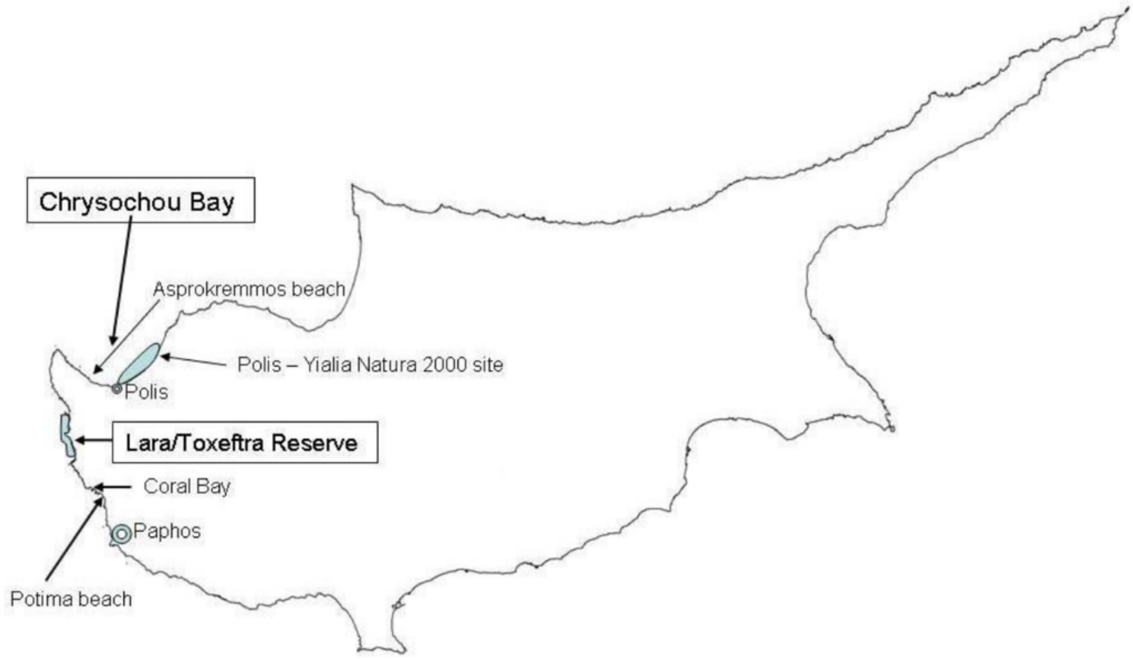
2.5. The major threats of microplastic pollution on Cyprus's beaches

2.5.1. Tourism

Just as in the global oceans, microplastic pollution has the potential to threaten the coasts of Cyprus in similar ways. The island of Cyprus is a popular tourist destination, relying on the cleanliness and attractiveness of its beaches to attract tourists and support the largest source of income to the country. Large amounts of microplastics, particularly on popular beaches, may affect the aesthetic value of the location, making them less attractive for tourists to visit. A study conducted in Zanzibar, Tanzania, a popular destination for tourists due to its beaches, found that the presence of microplastic pollution had a negative impact on people's perception of a beach (Maione, 2019). Removing microplastics from beach sediment is an option but tends to be costly and time consuming, requiring heavy machinery that have additional impacts on the natural landscape and animal habitats.

2.5.2. Marine turtles

The beaches of Cyprus are also important nesting sites for the Green Turtle (*Chelonia mydas*) and the Loggerhead Turtle (*Caretta caretta*), listed by the IUCN on their Red List as endangered and vulnerable respectively (IUCN, 2020). Around 1500-2000 Loggerhead and 200-600 Green Turtles nests are found every year on beaches all across Cyprus, with the majority of nesting of both species occurring on the West coast of the island, in the Lara/Toxeftra region and Chrysochou Bay (Figure 6) (Hochscheid, Kaska and Panagopoulou, 2018). Due to their endangered status since the 1970s, conservation activities have been occurring on the island from 1978 until present. Implemented by the Department of Fisheries and Marine Research (DFMR) and The Cyprus Turtle Conservations Project, all beaches across the island have been monitored, with nests being recorded and protected using metallic cages (Hochscheid, Kaska and Panagopoulou, 2018).



(Hochscheid, Kaska and Panagopoulou, 2018)

Figure 6. The most popular nesting areas for Loggerhead and Green Turtles in Cyprus.

Since the 1970s, marine turtles in Cyprus have come under a number of threats. Coastal developments such as construction and the associated light pollution have led to disturbance of many nesting sites across the island. Activities such as driving and mechanical clean ups have also been responsible for damaging and sometimes completely destroying turtle nests. During the 1970s and 80s, sand extraction was particularly popular, especially in the west of the island, leading to erosion problems up until today. Although most of these threats have been regulated with the establishment of a Natura 2000 site in the Chrysochou Bay and the Protection measures implemented in the Lara/Toxeftra region, much of the rest of the island still suffers from such threats (DFMR Cyprus, 2011). Occasionally, turtle nests become victim to non-human predators such as foxes and ghost crabs, but due to the use of protective cages, such activity has been limited. Within the marine habitat, sea turtles sometimes get caught in fishing nets as incidental bycatch, leading to their mortality. About 15-20 Loggerhead and 20-30 Green Turtles are estimated to be caught accidentally by fishermen per year (Hochscheid, Kaska and Panagopoulou, 2018).

Since the rise of microplastics in the Mediterranean Sea, marine turtles may potentially be exposed to a number of new threats. Although not fully understood, there is evidence that microplastics in beach sediments can cause issues for marine turtles. One threat is the one of microplastic ingestion. A 2019 study looking at 56 necropsies of Loggerhead and Green Turtles in Cyprus, found microplastics to be present in the gastrointestinal tracts of all turtles, with up to 30 particles present in each. Mediterranean turtles had higher concentrations of plastic inside them compared to the Atlantic and Pacific regions, which were also studied (Duncan *et al.*, 2019). Although this study did not find any evident impacts of microplastic ingestion by marine turtles, a study by Wilcox et al. suggests that the ingestion of just a single microplastic may increase the chance of mortality by 22% (Wilcox *et al.*, 2018). This could be due to starvation, lack of nutrition or internal lacerations. Another potential impact that microplastics could have is on the incubation environment of turtle eggs, demonstrated in a study from 2011. Due to the different physical properties of plastic compared to natural beach sediment, high concentrations of microplastics may lead to increased permeability, causing desiccation of eggs and thus a reduced nesting success (Carson *et al.*, 2011). Carson also suggested that high microplastic concentrations could potentially lead to higher sediment temperatures, due to the higher heat capacity of plastic compared to sand. Higher temperatures could potentially skew the sex ratio of turtle offspring, resulting in more females turtles being born, since the sex of the turtle is influenced by the external temperature during nesting (Carson *et al.*, 2011). Although this concept has been suggested by a number of authors (Valenzuela *et al.*, 2019; Tezak *et al.*, 2020), further research is required in order to identify the ability of microplastic to skew turtle sex ratios.

2.6. Policy and legislation regarding Mediterranean plastic pollution

There are a number of existing frameworks in place that aim to reduce plastic pollution in the Mediterranean (Table 2). These include international, EU-wide and Mediterranean-wide policies. Despite the existing frameworks, there are still issues being faced, preventing the best possible outcome from such policy. Several of these directives, such as the Honolulu Strategy, are not legally binding and therefore are not applied by all countries. This greatly reduces the effectiveness achieved. Additionally, a number of frameworks are EU-wide, meaning that several Mediterranean countries such as Turkey, Lebanon and Egypt, who are not EU members, are excluded from following the required measures. Most importantly, in many cases there is a lack of compliance by states to follow such frameworks and guidance. This is mainly due to the lack of strict enforcement and limited financial resources to invest in implementation (Law, 2017).

Table 2. Policy Frameworks regarding plastic pollution in the Mediterranean region.

Policy/Framework	Aim	Region
United Nations Convention on the Law of the Sea (UNCLOS)	Articles 207-211: Call for individual countries to adopt laws regarding reduction, prevention and control of marine pollution from both land and marine-based sources (United Nations, 1994)	International
International Convention of the Prevention of Marine Pollution from Ships (MARPOL)	Annex V: dumping of plastic in the sea is prohibited. States are required to have adequate facilities for the reception of waste (IMO, 2018)	International
Honolulu Strategy	Guidance regarding the monitoring of marine debris and preventative measure (UNEP, 2011)	International
Marine Strategy Framework Directive (MSFD)	Requires member states to monitor marine debris and maintain a 'good environmental status' (European Commission, 2017b)	EU
EU Circular Economy Package	Requires all plastic packaging to be recyclable by the year 2030 (European Commission, 2020)	EU
EU Directive 94/62/EC	Call to reduce plastic packaging waste by reducing, reusing and recycling (European Parliament, 1994)	EU
Barcelona Convention	Call to reduce pollution from land-based sources (European Commission, 2019)	Mediterranean

In addition to falling under the policies listed in Table 2, Cyprus implements further protection, particularly in the western region of the island at the Chrysochou Bay and the Lara/Toxeftra region. The assignment of a Natura 2000 Special Area of Conservation (SAC) in the Chrysochou Bay area since 2017, and the Lara Reserve Protected Area since 1989, have limited a number of threatening activities such as fishing, construction, driving on the beach and littering (European Commission, 2017a) (DFMR Cyprus, 2011). Such regulation will no doubt have limited the amount of plastic pollution entering the marine environment from these locations.

2.7. Conclusion

The dangers and impacts of microplastic pollution are ones that are being faced globally in numerous ecosystems. Several studies since the late 2000s have shown that microplastics are ubiquitous within the marine environment, appearing on surface waters, in beach sediments, as well as the deep sea. Physical forces such as ocean currents, rain and wind have led to the transport of these tiny particles across thousands of kilometres, in various habitats across the globe, threatening marine biodiversity, human health and having negative economic effects (GESAMP, 2015). Although governing bodies around the world have made efforts to reduce plastic pollution, through actions such as legislative frameworks and protected areas, the threats of microplastic pollution still exist today. In order to ensure truly effective and efficient legislation and policy, it is important that more research is undertaken, particularly in areas where no data is present. This would not only help the scientific community to better understand the distribution and impacts that microplastic pollution poses but would also allow for more informed decision to be made by governing bodies regarding policy and regulation.

3. Aims and Objectives

The aim of this study is to establish a base-line survey, determining the extent of microplastic pollution in beach sediments across important turtle nesting beaches in the east, south and west regions of Cyprus.

This will be achieved through the 5 main objectives of the study:

1. To evaluate the abundance, classification, distribution and spatial variation of microplastics across 14 turtle nesting beaches

2. To investigate the significance between beach orientation, geographical location, and microplastic concentration in beach sediment

3. To explore how microplastic abundance is affected by depth in the sediment

4. The justify whether current policy & legislation are effective in controlling microplastic pollution in Cyprus

5. To propose further research priorities and recommendations for policy makers

4. Materials & Methods

4.1. Study area

Data sampling was carried out at 14 locations across the coast of Cyprus, in the Levantine basin of the Mediterranean Sea (Figure 7; Supplemental Table 2). Taking into account the study conducted by Duncan et al. primarily along the north coast of the island (Duncan *et al.*, 2018), the regions of the island considered in this study include the west, south and east, where data has not been collected in the past. The specific beach locations were selected based on their importance as turtle nesting sites and based on spatial distribution. For the purpose of this study, turtle nesting sites were defined as 'any sandy beach where turtles could potentially nest'. Turtle nests were present at all study sites with exception of sites 10, 13 and 14, which were included for geographical and orientational variation of the study. Turtle nesting beaches were prioritised due to being sensitive habitats and thus potentially under threat from microplastic pollution. In total, 5 sites were located in the eastern region, 5 in the southern region and 4 in the western region of the island.

Figure 7. Map of Cyprus with the 14 locations sampled in this study.
White dots = Western region (*n*=5, beach number 1-5)
Grey dots = Southern region (*n*=5, beach number 6-10)
Black dots = Eastern region (*n*=4, beach number 11-14)
Coordinates of each beach can be found in Table 2, appendix.

4.2. Sediment sampling

In order for results to be comparable to the study conducted by Duncan et al. in the northern region of the island, the same sediment sampling methods were followed as much as possible (Duncan *et al.*, 2018). Samples were collected between June and July of 2020. At each site, sediment samples were collected from 10 pairs of sites along two parallel lines to the shore, the "strandline" (SL) and the "turtle nesting line" (TNL) (Figure 8). Samples on the SL and TNL were positioned at equal distances between each other, and the boundaries of each beach were

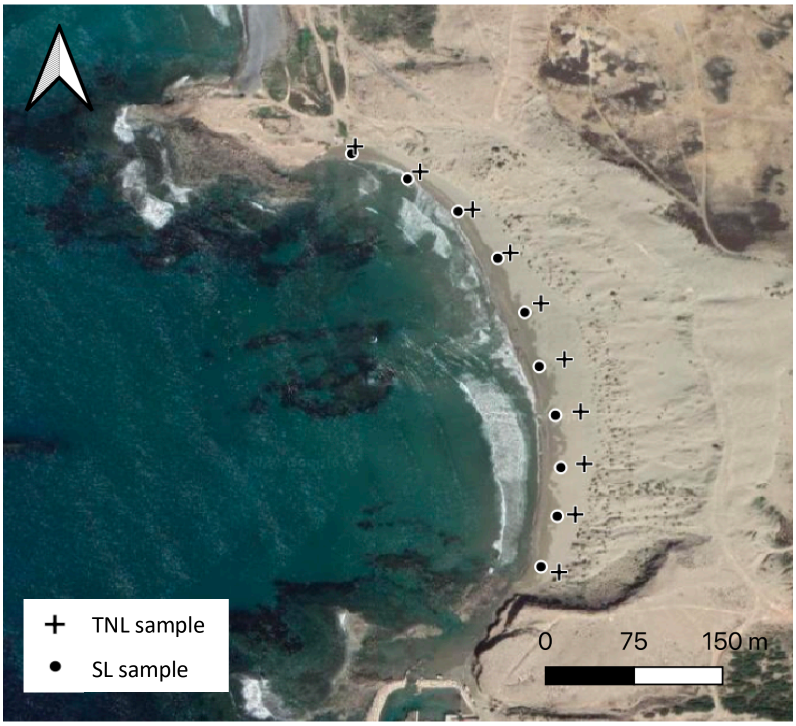


Figure 8. Experimental design of beach sediment sampling.
Sample locations along the strandline (circles) and turtle nesting line (crosses), on beach number 8, plotted using GPS coordinates. Samples are spaced 53m from each other with the first and last samples spaced 26.5m from the rocky edges of the beach.

determined by the rocky edges or cliffs at each location. Total length of each beach was measured initially using Google Earth Pro, and sample distances on field were measured using a measuring tape. The strandline (SL) was defined as the highest point on the beach where debris is deposited by the tide. This was in most cases identified by a line of seaweed or pebbles along the beach, which was affected by incoming waves as well as the force of the wind. The turtle nesting line (TNL) was a transect through the area where turtles usually nest, identified by marked turtle nests (Figure 9a) as well as body pits left by turtles due to attempted but abandoned nesting (Figure 9b). In most cases, the TNL was positioned halfway between the SL and the landward limit of the beach, identified by manmade structures or dense vegetation. Where no marked nests or body pits were present, the TNL was considered at the halfway point between the shore and the landward limit of the beach. Where the landward limit of the beach was very close to the shore and no TNL was clearly present, samples were not recorded. Coordinates at all sample locations were taken (in the format of longitude/latitude: World Geodetic System (WGS) 1984) using a handheld Garmin GPSMAP® 78 device (Supplemental Table 3).

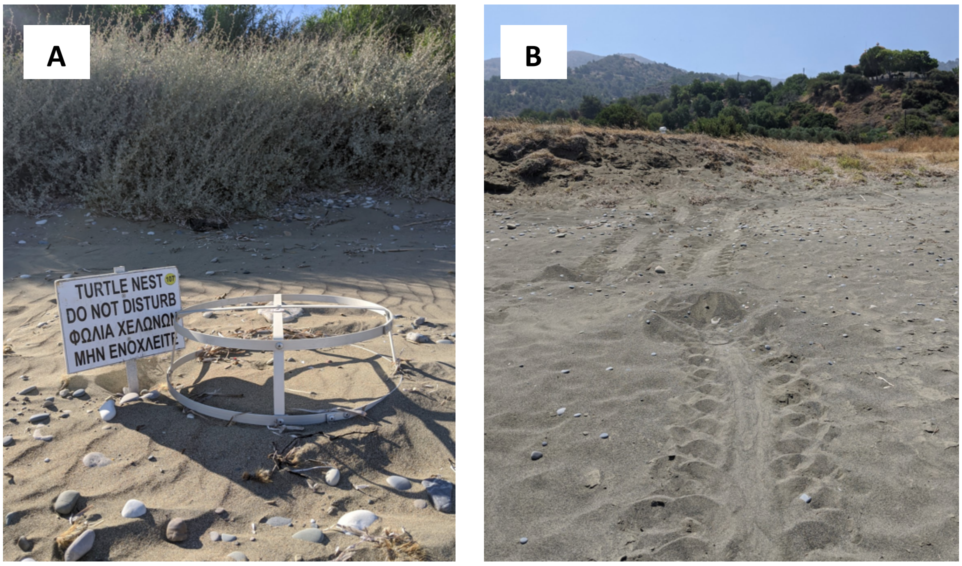


Figure 9. Features that were used to identify the turtle nesting line (TNL)
(A) Marked turtle nest with protective cage, located at beach number 8.
(B) Turtle tracks and body pit left as a result of an abandoned nesting attempt, located at beach number 1.

Each sample was collected using a metallic trowel and stored in covered aluminium foil trays to prevent any type of contamination before being analysed. At the strandline (SL), 250cm^3 samples were collected at a depth of 0-2cm in order to be able to compare results with similar studies (Clunies-Ross *et al.*, 2016; Hengstmann *et al.*, 2018; Atwood *et al.*, 2019). At the turtle nesting line (TNL), 250cm^3 samples were collected at a depth of 0-2cm and at a depth of 2.1-10.0cm. The depth in the beach sediment was measured using a 30cm steel ruler. All samples were left to air dry for 48 hours after collection in a covered area.

4.3. Separation of microplastics and categorisation

Dry weights of sediment samples were recorded to an accuracy of 1.0g. Samples were then passed through 5mm and 1mm sieves to collect microplastics (between 1 and 5mm as defined by Andrady, (2011). Using tweezers, microplastics were then isolated from the remaining sediment and visually sorted into categories using methods presented by van Franeker *et al.*, (2011), used also by Duncan *et al.*, (2018). Where grains in beach sediment were larger than 1mm and microplastic isolation was not possible visually, sediment samples were suspended in water, and due to plastic having a lower density that water in most cases, floating particles could be collected from the surface. The rest of the sunken sediment was visually inspected to make sure no microplastics were missed.

The categories used to sort the microplastics were as follows (van Franeker *et al.*, 2011):

- Industrial (IND): small, often cylindrical or disk-shaped granules. These types of plastic pellets are considered the "raw" plastics, usually melted and mixed with a number of additives to produce several products. They can be found in all sorts of colours but are usually transparent, white, brown or black. These industrial pellets are also known as nurdles, beads or granules.
- Foamed (FOAM): small pieces originating from larger foamed products such as polystyrene packaging and cups, polyurethane from mattresses, or construction foam.
- Fragments (FRAG): originating from larger hard plastic items of various applications such as bottle caps, toys, boxes, lighters, household equipment, etc.
- Sheets (SHE): small pieces originating from sheet-like plastics such as bags, clingfilm etc.
- Threads (THR): remains from ropes, nets, fishing lines etc.

Examples of each microplastic category can be seen in Figure 10.

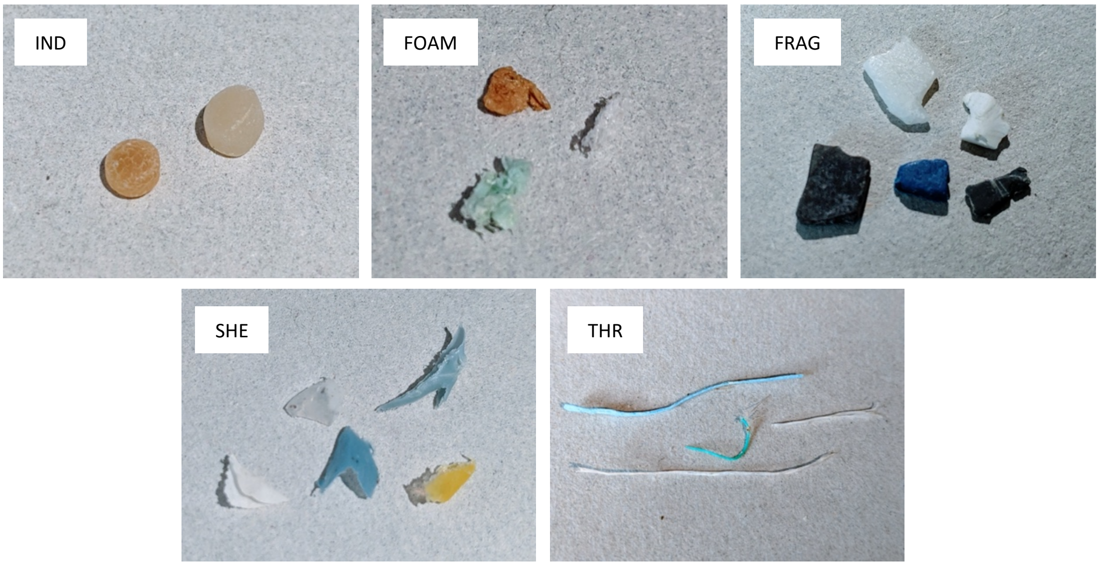


Figure 10. Examples of the 5 types of plastic categories used.
IND – Industrial; FOAM – Foamed; FRAG – Fragments; SHE – Sheets; THR – Threads.

All microplastic particles from each category within each sample were counted and weighed to 0.01g. Since some samples were lighter than 0.01g and therefore could not be measured accurately, their weight was recorded as 0.001g for the purpose of this study. Using the particle numbers, microplastic weights, dry sediments weights and the known volume, data was able to be converted into four different: particles m^{-3}, particles g^{-1}, g m^{-3} and g g^{-1}. These units allowed for the comparison of data with other similar studies.

4.4. Statistical analysis

Strandline (SL) and turtle nesting line (TNL) surface samples were tested for significant difference. Since the paired differences between SL and TNL samples were not normally distributed for both particles m^{-3} and g m^{-3}, the non-parametric Wilcoxon signed rank test was deemed the most appropriate to use.

Variation among the 14 beaches was tested for using TNL surface samples. Since the beaches were selected based on their importance as turtle nesting sites, TNL samples were deemed to be more relevant compared to SL samples for statistical analysis. As the distribution of microplastic abundance in particles m^{-3} and g m^{-3} within each beach was not normally distributed, the non-parametric Kruskal-Wallis test was chosen. This was also the case for data sorted by geographical regions and by beach orientation. In both cases, the non-parametric Kruskal-Wallis test was used to test for significant differences. Where a significant difference was found, a pairwise comparison using the Wilcoxon rank sum test was used to determine which groups were responsible for the significant result.

Variation among different depths was tested for using TNL surface (0.0-2.0cm) and TNL depth (2.1-10.0cm) samples. Due to the paired differences between surface and depth samples not having a normal distribution for both particles m^{-3} and g m^{-3}, the non-parametric Wilcoxon signed rank test was used to test for significant difference.

Variation among microplastic categories was tested for using all sediment samples collected across the study (SL, TNL surface, TNL depth). Due to the distribution of microplastic abundance in particles m^{-3} and g m^{-3} within each category not being normally distributed, the non-parametric Kruskal-Wallis test for used to test for significant difference. Abundance of each category was also calculated in terms of the percentage of the grand total number of particles, and the grand weight of microplastics across all samples.

All statistical analyses were conducted using R studio 1.2.5042. The significance level used across all statistical tests was 5% (α=0.05).

5. Results

5.1. Overview

In total, 416 sediment samples were obtained from the strandline (SL) and turtle nesting lines (TNL) (SL: 140, TNL: 276), across all 14 beaches. Microplastics were found to be present at all beaches, and in most cases, there was a higher abundance in the top 2cm of sediment compared to deeper samples. The grand mean of microplastics in the SL surface samples was 43,420 ± 13,035 (mean ± se) particles m^{-3} (range 0-528,000 particles m^{-3} across 14 beaches) and the grand mean weight was 127.1 ± 42.68 (mean ± se) g m^{-3} (range = 0-4608 g m^{-3} across 14 beaches). The grand mean of microplastics in the TNL surface samples was 20,870 ± 5,968 (mean ± se) particles m^{-3} (range 0-199,600 particles m^{-3} across 14 beaches) and the grand mean weight was 188.1 ± 52.68 (mean ± se) g m^{-3} (range = 0-4364 g m^{-3} across 14 beaches) (results in particles kg^{-1} can be found in Supplemental Table 4) . A Wilcoxon signed rank test revealed no significant difference between SL and TNL mean values, particles m^{-3} n=14, Z=39, p=0.67; g m^{-3} n=14, Z=38, p=0.62 (Supplemental Table 4).

5.2. Variation among beaches

A Kruskal-Wallis test was conducted to test for variation in microplastic abundance across all beaches. Microplastic abundance was found to vary significantly in both particles (particles m^{-3}; χ^2=86.17, df=13, p<0.001) and weight (g m^{-3}; χ^2=82.43, df=13, p<0.001) (Figure 11).

Between the three regions West, South and East, no significant difference was found in microplastic abundance regarding both particles (Kruskal-Wallis test: particles m^{-3}; χ^2=0.20, df=2, p=0.91) and weight (Kruskal-Wallis test: g m^{-3}; χ^2=0.03, df=2, p=0.98).

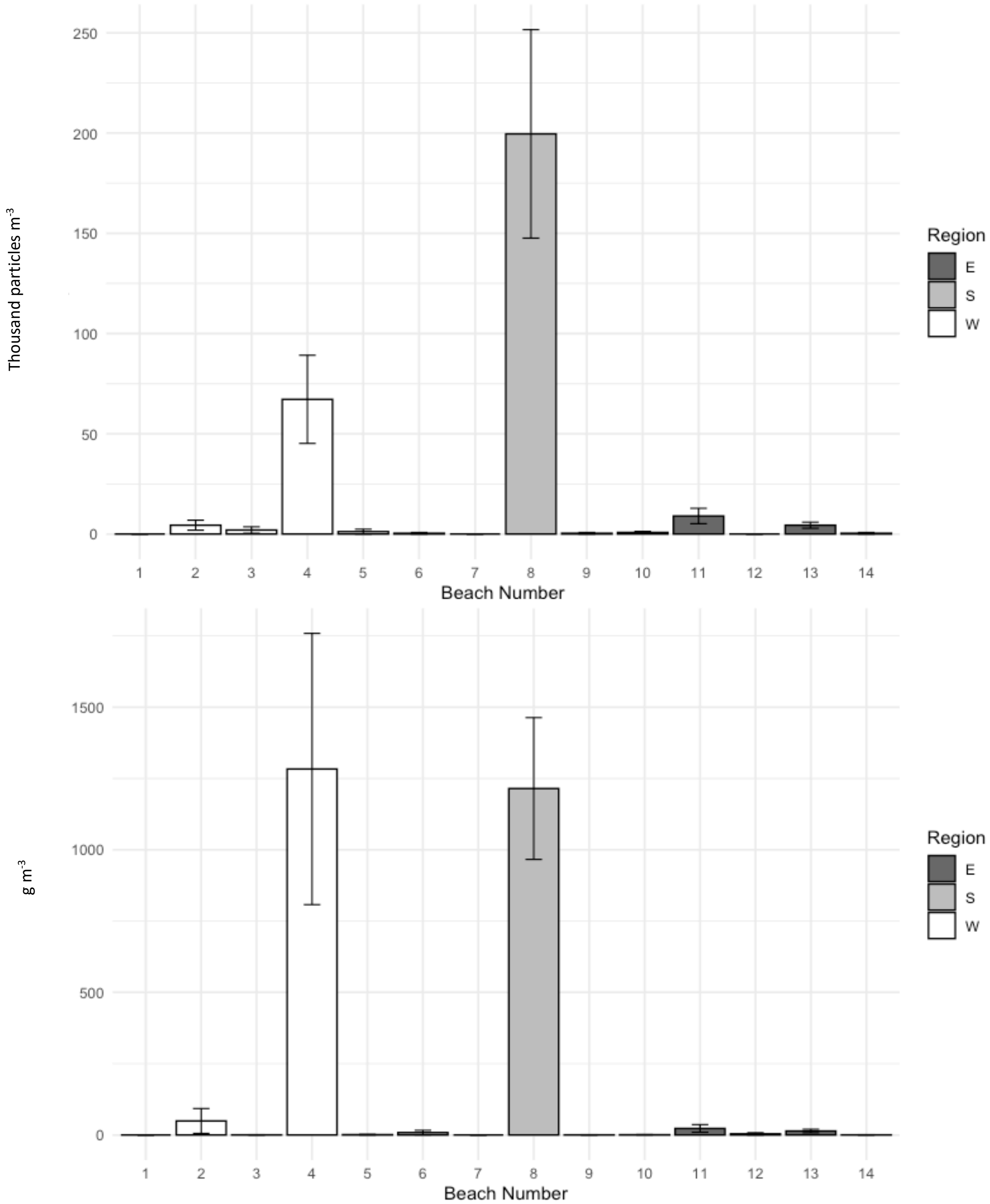


Figure 11. Mean microplastic abundance in TNL surface samples (0.0-2.0cm) across all beaches.
Top: mean number of particles m^{-3} in TNL surface samples per beach with fitted standard error bars.
Bottom: mean weight of microplastics in g m^{-3} in TNL surface samples per beach with fitted standard error bars.
Bar colours represent the region of the island in which the beach is found: White = West (*n*=5, beach number 1-5), Grey = South (*n*=5, beach number 6-10), Black = East (*n*=4, beach number 11-14). Values for mean abundance of microplastics in particles m^{-3} and g m^{-3} can be found in Supplementary Table 3.

Beach orientation was found to have a significant effect on microplastic abundance both in terms of particles (Kruskal-Wallis test: particles m^{-3}; χ^2=46.75, *df*=6, p<0.001) and weight (Kruskal-Wallis test: g m^{-3}; χ^2=43.39, *df*=6, p<0.001) (Figure 12). Pairwise comparisons using Wilcoxon rank sum tests showed that west facing (W) beaches had significantly higher microplastic abundance in both particles m^{-3} and g m^{-3} compared to all other orientations (Table 3, Table 4), except with south-east facing (SE) beaches (particles m^{-3} p=0.13; g m^{-3} p=0.14). Excluding west facing (W) beaches, regarding particles m^{-3}, south-east (SE) facing beaches had a significantly higher abundance than the rest of the orientations except for north-west facing (W) (p=0.13). Excluding west facing (W) beaches, regarding g m^{-3}, south-east (SE) facing beaches had a significantly higher abundance than east facing (E) (p=0.009) and north facing (N) (p=0.02), but no significant difference was found with other orientations. All other beach orientations showed no significant difference between them.

The highest abundance of microplastic in terms of particles m^{-3} was 199,600 ± 51,991 (mean ± se) particles m^{-3}, on beach 8 (west facing). The highest abundance of microplastic in terms of g m^{-3} was 1,283 ± 475.5 (mean ± se) g m^{-3}, on beach 4 (west facing) (Supplemental Table 4).

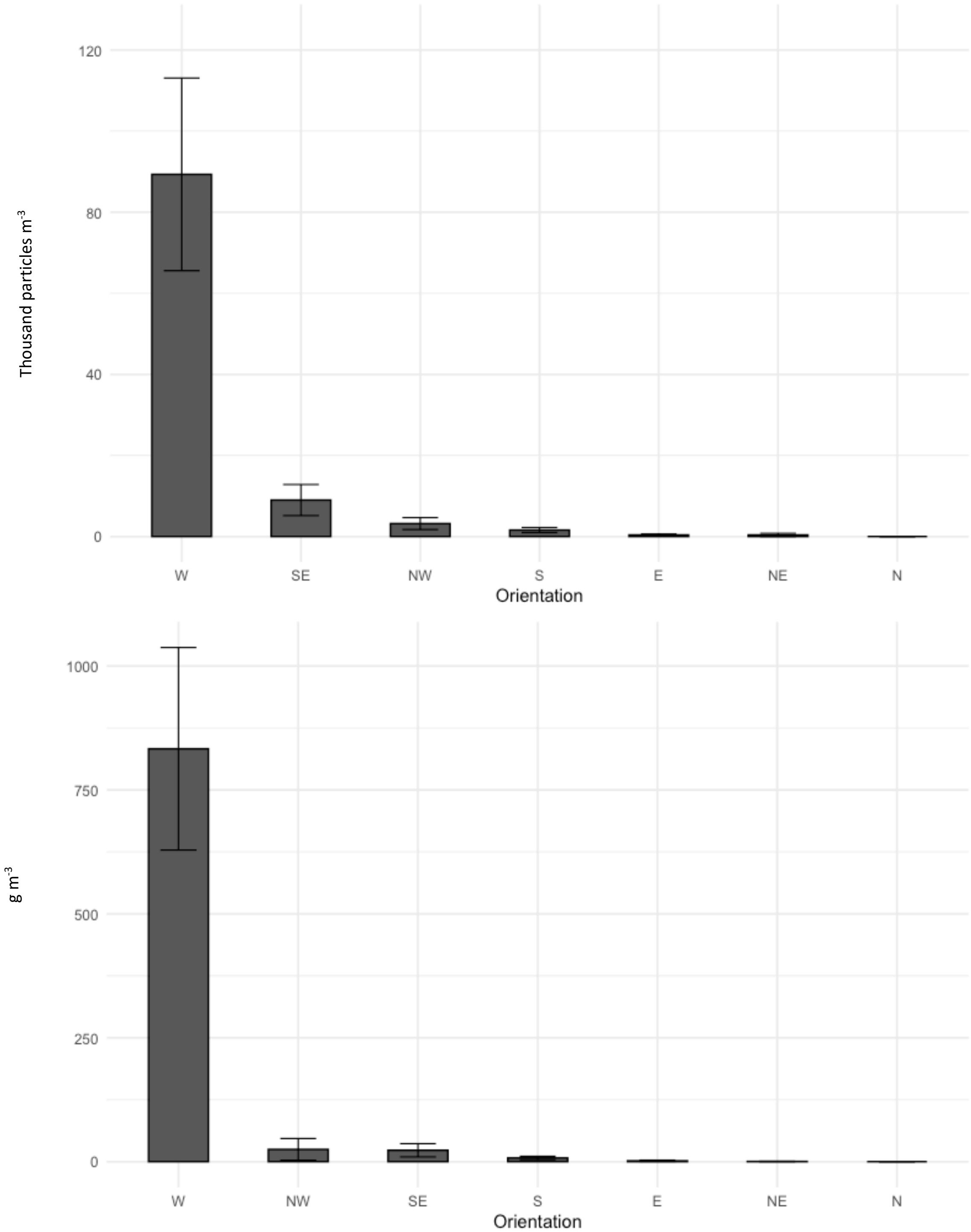


Figure 12. Mean microplastic abundance in TNL surface samples among different beach orientations.
Top: mean number of particles m^{-3} in TNL surface samples per beach orientation with fitted standard error bars.
Bottom: mean weight of microplastics in g m^{-3} in TNL surface samples per beach orientation with fitter standard error bars.
W = West, NW = North West, SE = South East, S = South, E = East, NE = North East and N = North.
In both bar plots, bars are sorted in order of highest to lowest. Orientation of individual beaches can be found in Supplementary Table 1.

Table 3. Pairwise comparison results of microplastic abundance (particles m^{-3}) within each beach orientations using Wilcoxon rank sum test.

P-values of Wilcoxon rank sum tests between each beach orientation. Highlighted green values are below α-value (0.05) and therefore show a significant difference is present.

	E	N	NE	NW	S	SE
N	0.40	-	-	-	-	-
NE	1.00	0.41	-	-	-	-
NW	0.12	0.12	0.28	-	-	-
S	0.20	0.15	0.40	0.55	-	-
SE	0.003	0.02	0.03	0.13	0.03	-
W	<0.001	0.004	0.01	0.003	<0.001	0.13

Table 4. Pairwise comparison results of microplastic abundance (g m^{-3}) within each beach orientations using Wilcoxon rank sum test.

P-values of Wilcoxon rank sum tests between each beach orientation. Highlighted green values are below α-value (0.05) and therefore show a significant difference is present.

	E	N	NE	NW	S	SE
N	0.32	-	-	-	-	-
NE	0.82	0.41	-	-	-	-
NW	0.32	0.16	0.37	-	-	-
S	0.25	0.14	0.32	0.92	-	-
SE	0.009	0.02	0.05	0.14	0.12	-
W	<0.001	0.005	0.008	0.003	<0.001	0.14

5.3. Variation among depths

276 paired samples were taken from the TNL at a depth of up to 10cm (n=138 at TNL 0.0-2.0cm depth, n=138 at TNL 2.1-10.0cm depth). Microplastics were present at both depths with a mean level of 5,014 ± 1,335 (mean ± se) particles m^{-3} (range 0-42,000 particles m^{-3} across 14 beaches), and 27.97 ± 8.76 (mean ± se) g m^{-3} (range 0-189.2 g m^{-3} across 14 beaches). The difference in depths was found to be significant in terms of microplastic numbers (Wilcoxon signed rank test: particles m^{-3}; n=14, Z=57, p=0.04) but not in terms of weight (Wilcoxon signed rank test: g m^{-3}; n=14, Z=52, p=0.01). A greater number of microplastics as found in surface sediment samples (0.0-2.0cm) (Figure 13).

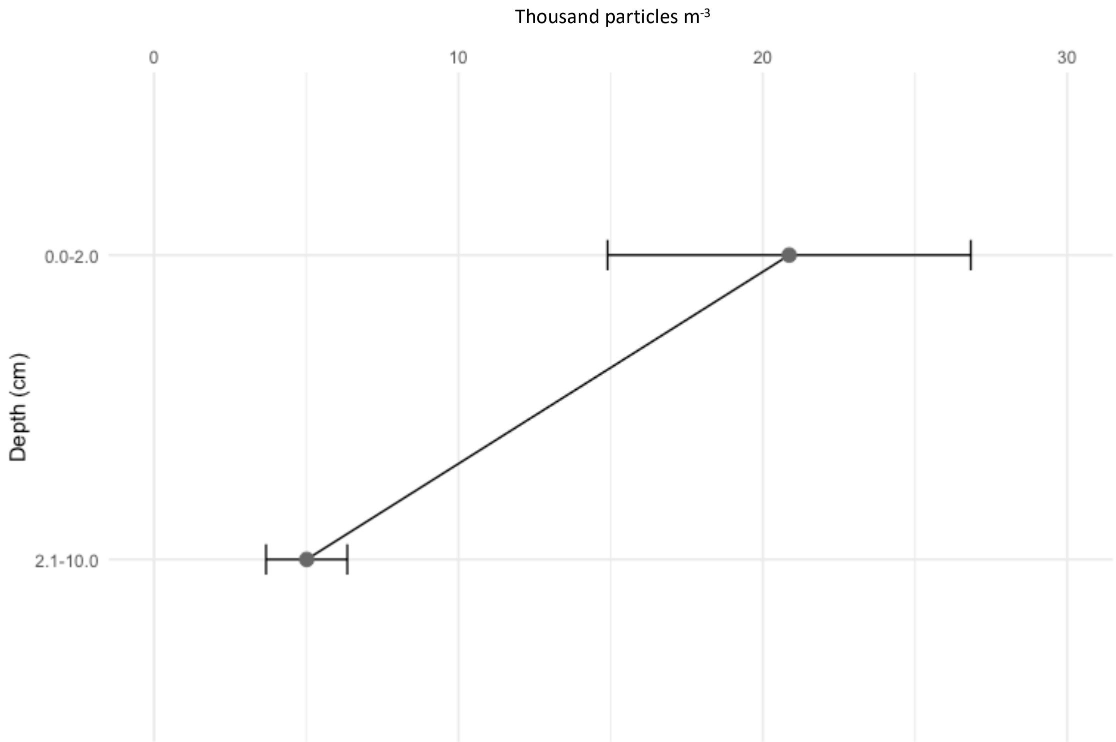


Figure 13. Grand mean microplastic abundance in thousand particles m^{-3} from TNL samples across 14 beaches at different depths.
Grand mean microplastics abundance at 0.0-2.0cm and 2.1-10.0cm with fitted standard error bars.

5.4. Variation among microplastic categories

Across all sediment samples (n=416) from the SL and TNL at all depths, there was a significant difference among the microplastic categories in terms of particle numbers (Kruskal-Wallis test: particles m^{-3}; χ^2=81.01 df=4, p<0.001) and weight (Kruskal-Wallis test: particles m^{-3}; χ^2=83.10, df=4, p<0.001) (Figure 14). Among all microplastic particles identified (n=2,391) across all sediment samples, the majority were fragments (FRAG) (56%), followed by sheet-like (SHE) (33%), industrial (IND) (8%), threads (THR) (2%) and foams (FOAM) (1%). In terms of weight (*total weight* = 11.8g) across all sediment samples, the majority was fragments (FRAG) (61%), followed by industrial (IND) (27%), sheet-like (SHE) (12%), threads (THR) (<1%) and foams (FOAM) (<1%).

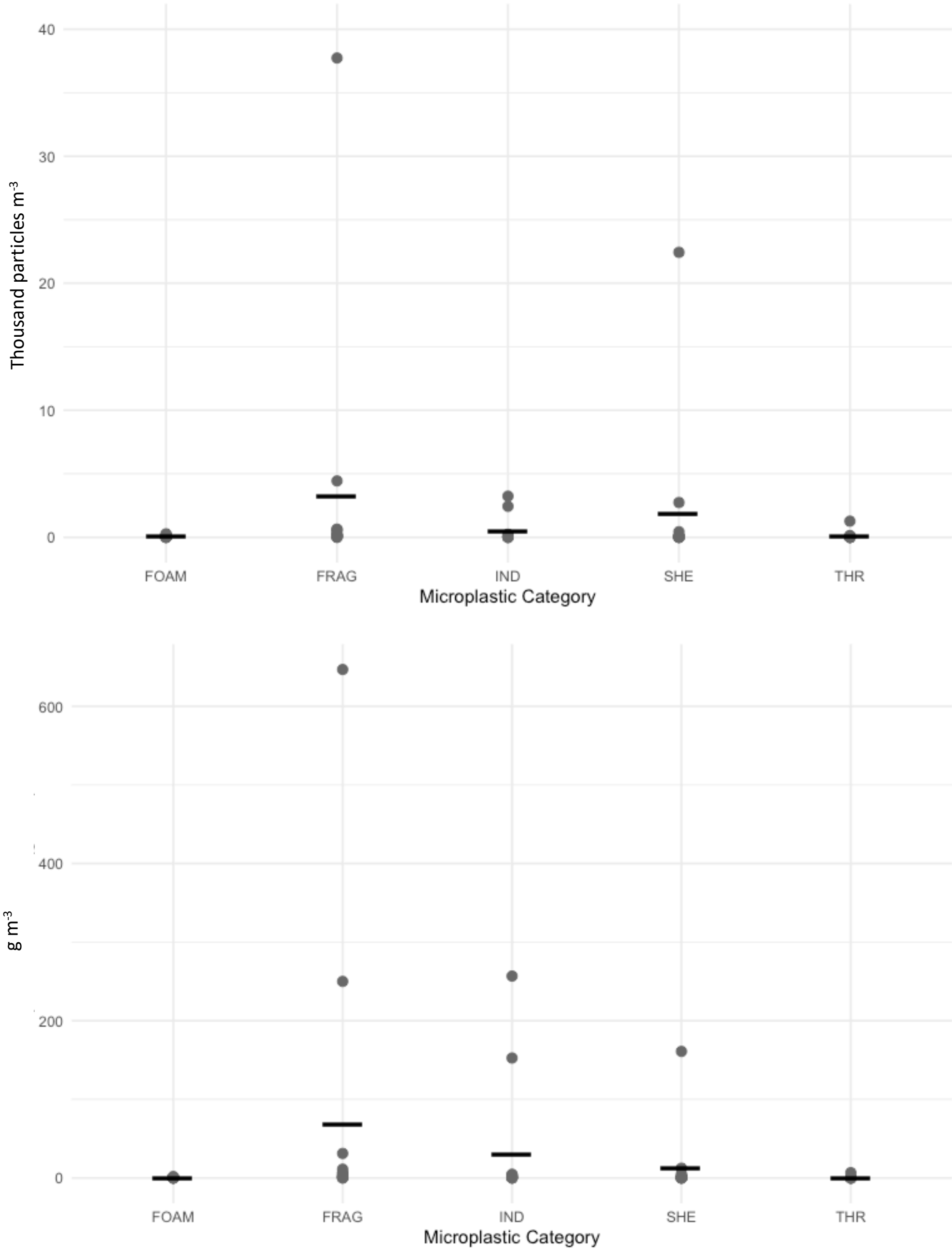


Figure 14. Microplastic abundance per category.
Top: Microplastic abundance in thousand particles m^{-3} of each category on each beach (black dots). Black lines represent the mean particles m^{-3} of each category across all samples. **Bottom:** Microplastic abundance in g m^{-3} of each category on each beach (black dots). Black lines represent the g m^{-3} of each category across all samples.

6. Discussion

6.1. Cyprus in the scope of the Mediterranean

Microplastics were found across all sampled locations, showing that microplastic pollution is ubiquitous among turtle nesting beaches on the coast of Cyprus. This finding is consistent with the wider literature, which supports the idea that beaches act as sinks for floating microplastics in the ocean (Barnes *et al.*, 2009; Browne *et al.*, 2011). The units of the results were converted to particles kg^{-1} (Supplemental Table 4), to allow for the comparison with various other studies, which report using these units. The mean value of surface samples (0.0-2.0cm) across both the SL and TNL was 24.1 ± 20.0 (mean ± se) particles kg^{-1} (range = 0.1–282.7 particles kg^{-1}). The beaches considered in this study were found to have a lower mean microplastic concentration in particles kg^{-1}, compared to several other beaches looked at in a variety of studies across the Mediterranean. For example, in the Spanish Mediterranean continental shelf, the mean concentration was found to be 45.9 ± 23.9 particles kg^{-1} (Filgueiras *et al.*, 2019), in the Eastern Adriatic Sea between 32.3 and 377.8 particles kg^{-1} (Blašković *et al.*, 2017), in the coasts of south Tuscany between 62 and 466 particles kg^{-1} (Cannas *et al.*, 2017), and along the coast of Lebanon 2433 ± 2000 particles kg^{-1} (Kazour *et al.*, 2019). Although it appears that microplastic abundance is on average lower in Cyprus than other regions of the Mediterranean, a direct comparison cannot dictate whether this is true. This is due to the differences in methodology amongst the different studies, with the majority of studies using a wider range of dimensions when isolating microplastics from beach sediment. In many cases, reported results included microplastics with a lower-size limit down to 63µm (Blašković *et al.*, 2017; Cannas *et al.*, 2017; Filgueiras *et al.*, 2019; Kazour *et al.*, 2019), whereas this study used a lower limit of 1mm when isolating microplastics. Since a large portion of the microplastics within the Mediterranean are predicted to be smaller in diameter than 1mm (Cózar *et al.*, 2015), it is likely that if such dimensions (<1mm) were considered for this study, mean microplastic numbers would be higher and more appropriate for comparison with the wider literature.

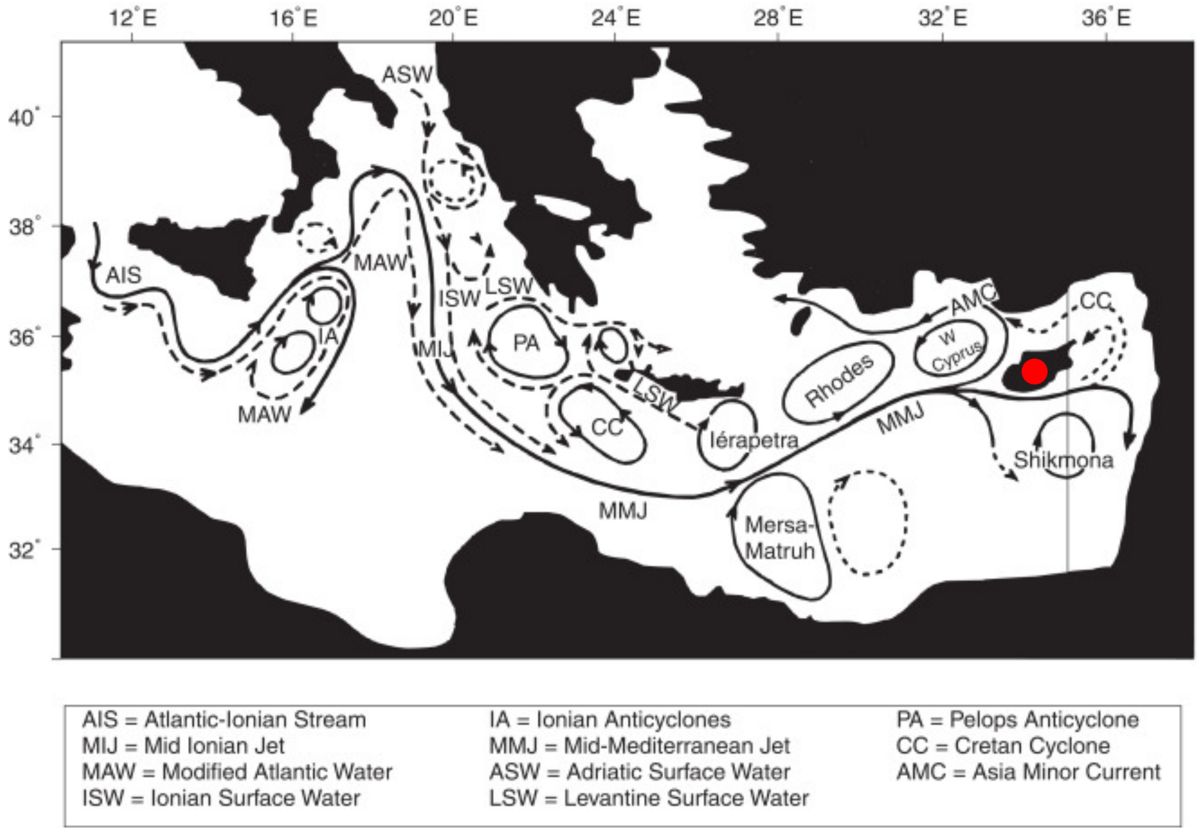
In order to understand where microplastics on the beaches of Cyprus may originate from, it is important to look at plastic production, as well as waste management and recycling across the Mediterranean. Turkey, in the Easter Mediterranean, produces 9 million tonnes of plastic, making them one of the top producers worldwide. Spain, in the Western Mediterranean, is also one of the leading producers and consumers or raw plastic internationally, with over 3.84 million tonnes processed yearly for the production of various products (IUCN, 2018). In addition to being key producers and consumers of plastic, Turkey and Spain are also the two top polluters in regards to plastic debris influx into the ocean, closely followed by Israel (Figure 4, number 16) and Syria (Figure 4, number 14), also located in the Eastern Mediterranean (Liubartseva *et al.*, 2018). Since the influx of plastic debris into the sea originating from Cyprus is around 10 times less than that of Turkey and Spain, and due to many of the sampled beaches being far from industrial practices with low levels of human usage, it is likely that a high amount of microplastics on Cyprus's coasts originate from nearby countries in the Eastern Mediterranean. In addition to the Eastern Mediterranean being host to some of the worst plastic polluters, a study from 2014 that modelled the transport and accumulation of floating debris in the Mediterranean basin, found that the Levantine basin is a hotspot for beaching events, due to the nature of the currents in the region (Mansui, Molcard and Ourmières, 2015). Although most microplastics are likely to be coming in from the highly polluted Levantine basin, Cyprus is ranked as one of the worst in Europe in terms of plastic recycling, and one of the top countries in terms of landfill plastic dumping (Plastics Europe, 2019). Due to this, the pathway from land-based sources within Cyprus cannot be completely ruled out and is likely to also contribute to a certain extent to the microplastic pollution seen in beach sediments across the island.

6.2. Variation among beaches across Cyprus

The abundance of microplastics varied significantly among sampled beaches, but no significant difference was observed between east, south and west regions (section 5.2.). In comparison with the northern region of Cyprus, this study reported a grand mean abundance of 20,870 ± 5,968 (mean ± se) particles m^{-3} (range 0-199,600 particles m^{-3} across 14 beaches) among TNL surface samples, compared to a higher mean level of 45,497 ± 11,456 (mean ± se) particles m^{-3} (range across 17 beaches: 637–131,939 particles m^{-3}) in the north (Duncan *et al.*, 2018). Despite the lower levels of microplastic pollution overall, the most polluted beach observed in this study surpassed the most polluted beach previously recorded in the northern coast, in terms of particle numbers. Beach 8 (west facing) had a mean TNL surface level of 199,600 particles m^{-3}, compared to 131,939 particles m^{-3} observed in the most polluted beach on the north coast.

Beach orientation was shown to be a significant factor in regard to microplastic pollution, with west facing beaches having the highest levels in terms of particle numbers and weight. The fact that beach orientation in both the northern region of the island (Duncan *et al.*, 2018), and in this study of the eastern, southern and western regions, had a significant role in microplastic abundance, suggests that the key pathway of microplastics to the shore is via ocean currents rather than internal land-based sources. This is also further supported by the fact that industrial practice and heavy use are both largely absent from all regions studied across the island (Duncan *et al.*, 2018). By examining the circulation features and currents of the eastern Mediterranean, the origins and pathways of microplastic can be predicted for the different locations on the island, explaining the differences in microplastics abundance among beach orientations.

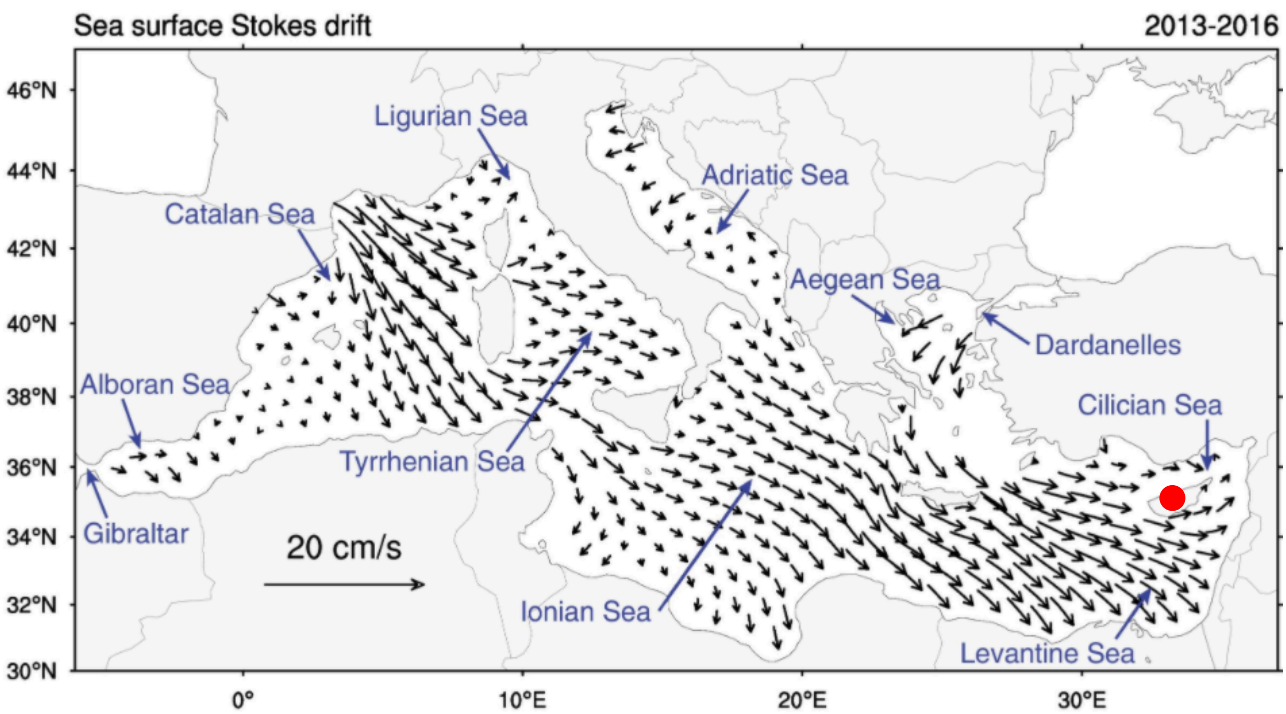
A number of features exist that may bring sea surface microplastics towards Cyprus (Figure 15; Figure 16). The Mid-Mediterranean Jet (MMJ) originating from the central Mediterranean, travels



(Robinson et al., 2001)

Figure 15. Circulation features in the eastern Mediterranean.
Cyprus marked by the red dot.

from west to east, passing next to several gyres such as Ierapetra, Rhodes, Mera-Mutrah and W Cyprus, where microplastics could potentially accumulate over time. As the MMJ passes next to these gyres, microplastics could get caught and travel via the MMJ towards Cyprus, being deposited on a number of beaches. Since west-facing beaches are perpendicular to the incoming currents from the MMJ, they are likely to experience higher levels of deposition compared to other orientations, by acting as traps. Although this phenomenon is likely to explain the high levels of microplastic pollution observed on west-facing beaches across the eastern, southern and western regions of the island, the high abundance of microplastics on the north-facing beaches of the north coast are likely to be affected by different circulation features. Microplastics are likely to accumulate in the Shikmona gyre, off the south-east coast of Cyprus. Strong north-east bound currents can potentially carry these particles towards the northern coast, and through the Cretan Cyclone (CC) can become deposited on the northern coast of the island (Duncan *et al.*, 2018). The general direction of particle travel within the Mediterranean can also be predicted by looking at sea surface Stokes drift (Figure 16). Stokes drift is defined as the motion of a floating particle due to the action of waves (Dobler *et al.*, 2019). The general easterly direction observed in Figure 16, may cause the accumulation of microplastic debris from across the entire Mediterranean, in the eastern region and the Levantine basin, where Cyprus is located. The natural circulation patterns and pathways mentioned above are likely to explain the variation of microplastic pollution among beaches, and specifically the high abundance of microplastics on west-facing beaches as reported in this study and north-facing beaches as reported in the study by Duncan et al. (2018).



(Liubartseva et al., 2018)

Figure 16. Average sea surface Stokes drifts in the Mediterranean Sea.
Main subbasins labelled with arrows. Cyprus marked by the red dot. Data was averaged between 2013 and 2016.

6.3. Microplastics and sediment depth

At most sampled locations, microplastics were present at depths down to 10cm at the TNL (section 5.3.). The ability of microplastics to travel downwards through the sediment has been studied in the past and is likely to be caused by natural forces such as wind and rain, as well as anthropogenic factors such as people walking over the microplastics on the surface (Turra *et al.*, 2015). The presence of microplastics below the surface can be considered more significant than surface microplastics in regard to turtle nesting, as green turtles (*Chelonia mydas)* lay their eggs at depths of around 65cm and loggerhead turtles (*Caretta caretta*) at depths of around 50cm (Duncan *et al.*, 2018). One of the biggest potential threats as a result is an altered incubation environment for the eggs, since microplastics have different physical properties compared to the natural sediment. A 2011 study showed that high microplastic abundance within beach sediment led to an increased permeability under experimental conditions (Carson *et al.*, 2011). Since turtle eggs are reliant on water uptake during their development stage, an increase in permeability could potentially cause desiccation and therefore decrease nesting success. It is not clear whether this is likely to occur on the beaches of Cyprus, since the levels of microplastic used under experimental conditions were much higher than the levels found within this study. Additionally, a number of studies have also explored the possibility of microplastics affecting the sediment temperature (Andrady, 2011; Beckwith and Fuentes, 2018). Since plastic has a higher heat capacity than sand, particularly the darker coloured plastics, they could lead to an increased sediment temperature, skewing hatchling sex ratios. The sex of the turtle is dependent on the incubation temperature of the eggs, with higher temperatures producing female hatchlings and lower temperatures producing male hatchlings (Tezak *et al.*, 2020). Although such impacts due to microplastic presence among the sediment have the potential to affect nesting success and skew sex ratios, it is important that further research is conducted in order to better understand the plastic concentrations that are significant.

6.4. Microplastic categories

Across all samples, fragments (FRAG) made up the majority of microplastic particles followed by sheets (SHE) and industrial pellets (IND). Fragments and pellets also made up the majority of microplastics observed by Duncan et al. (2018) along the northern region of the island. The variability in microplastic types observed can be explained by the differences in physical features and can also help identify the potential sources of microplastic pollution. Due to the lightweight nature of sheets (SHE), foams (FOAM) and threads (THR), they are likely to travel faster through ocean currents, but are also more likely to be affected by natural forces such as wind. As a result, it is possible that once deposited on the beach, the force of the wind could transport them over long distances, and therefore they do not remain within the beach sediment. This could be a possible explanation as to why foams and threads were observed at a much lower frequency than the rest of the categories among the sampled locations. Sheet-like plastics were also shown to be more likely affected by bio-fouling, causing them to sink, compared to other categories (Chubarenko *et al.*, 2016). It is therefore likely that the high amounts of sheet-like plastic observed, could have mostly originated from land-based sources within Cyprus rather than via currents. The higher number of industrial pellets observed in the norther region compared to the rest of the island, may suggest that microplastic pollution originates from different sources for each region. Industrial pellets, a primary microplastic, are likely to enter the eastern Mediterranean through accidental spills from the coast of Turkey, one of the largest plastic producers in the region and worldwide (IUCN, 2018). Due to the close proximity and through natural currents, these are then deposited on the norther coast of Cyprus as described in section 6.2. Regarding the rest of the island, the high number of fragments, secondary plastics originating from the breakdown of larger debris, could be originating from sources in the eastern Mediterranean as well as sources from the western and central Mediterranean, ending up on the east, south and west regions of the island through the circulation features described in section 6.2.

6.5. An evaluation of the existing policy and legislation

The current policies and legislation already in place, whether at an international, EU or Mediterranean scale, aim to reduce plastic pollution in the oceans from both land-based sources and ocean-based sources (section 2.6.). Although it is difficult to assess whether these are effective or not in reducing microplastic pollution in the beaches of Cyprus due to the lack of past data, it is possible to assess the effectiveness of local scale protection and suggest where improvements could be made. As described in section 2.6. there are two regions of the island that are protected under local law, the Natura 2000 site at Chrysochou Bay, and the Lara/Toxeftra protected area. These two areas are also considered the most important in terms of turtle nesting, with the highest numbers of turtle nests being observed here ever year. With the most polluted beach in terms of particles g^{-1} (beach 4), located in Lara Bay, it is clear that local protective measures are not sufficient in preventing microplastic pollution from accumulating on beaches. This not only shows that beach microplastic pollution in Cyprus is hugely a transboundary issue, originating and being transported over large distances across the Mediterranean, but could also suggest that local protection is not implemented at the standard that it should, to achieve the appropriate protection. Cyprus has in the past been accused by the European Commission of failing to protect Natura 2000 sites, by allowing hotels, motorways and energy projects to be constructed within them (BirdLife, 2019). These all could be potential sources of local microplastic pollution to the nearby sensitive habitats such as turtle nesting beaches. Another key issue, is the lack of compliance and lack of enforcement by countries of a number of frameworks, as well as some being non-legally binding, giving countries less of an incentive to implement them (Law, 2017). Due to the transboundary nature of the microplastic pollution problem, unless all countries of the Mediterranean were to strictly adhere by the relevant policies, then the detrimental effects will continue to be seen throughout the entire region, as they are currently.

6.6. Recommendations for future policy

It is clear that in order to improve the plastic pollution problem that exists in the Mediterranean, an effort is to be made by all countries within the region to reduce the production, consumption and the dumping of plastic products. This can be achieved through a series of continuous, short-term and long-term actions and investments applied throughout the region:

Continuous actions: In order to better understand the depth of the microplastic issue, in terms of the distribution as well as the impacts, it is important that continuous research and monitoring is carried out. By constantly updating the scientific evidence, policy makers can make up to date and relevant decisions as well as being able to accurately review progress. This can be encouraged by the EU or by each country's government by offering financial support to scientific research teams, as well as investing in technology and long-term monitoring programs to observe the health of the oceans and the species that live within it.

Short-term actions: In order to reduce the production of single-use plastics such as cups and straws, financial incentives can be offered from the EU and governments, to producers who meet specified targets on production and waste. This could also eventually be achieved through the implementation of strict policies and measure across the entire Mediterranean, with fines being imposed on companies that fail to meet the requirements. Financial incentive could also be offered to the consumer, for recycling items such as plastic bags and bottles, similar to a successful scheme implemented in Germany (Oltermann, 2018). Such methods would not only motivate large producers to produce less plastic but would also motivate the general public to recycle their waste rather than dispose of it in a way that could potentially harm the environment.

Long-term actions: On a yearly basis, the progress of each country could be monitored, and countries that fail to achieve goals set by conventions such as the Barcelona Convention or EU standards can be fined. By introducing strict measures across the entire region, governments across the Mediterranean would be more likely to impose stricter local laws, in order to meet the required standards and avoid dealing with consequences. In addition, setting up a network to improve communication between Mediterranean countries could potentially lead to the sharing of information and good practice, such as effective policies or technologies for better waste management. Collaboration and effective communication would no doubt lead to better results and progress for all parties affected by the threats of microplastic pollution.

6.7. Limitations and recommendations for future research

There are a number of limitations that exist within this study that can be improved on in further future research.

Microplastics were isolated based on their dimensions (between 1 and 5mm) using sieves and visual assessment. Due to the lack of access to laboratory equipment such as precision microscopes, it was not possible to consider microplastics smaller than 1mm. Therefore, the results reported in this study appeared to be lower than many similar studies conducted in other regions that included microplastics as small as 63µm in length (Poeta *et al.*, 2016; Cannas *et al.*, 2017; Filgueiras *et al.*, 2019). By considering microplastics of smaller dimensions in future research, the comparison between different studies would be possible, giving more insight into microplastic distribution, transport pathways and potential impacts.

Microplastics isolated from sediment samples were measure to an accuracy of 0.01g. Due to not having access to a high precision measuring scale, some samples could not be measured accurately as they were lighter than 0.01g. For the purpose of this study these were still included in the results with a weight of 0.001g. It is suggested that future studies use more precise measuring equipment in order to achieve more accurate results.

In order to get a better representation of microplastic concentrations and their impacts at turtle nesting depths, it is recommended that future studies consider sampling at lower depths, down to 60cm, as this is where Loggerhead and Green Turtles tend to lay their eggs. Sampling at this depth would give a much clearer picture on microplastic abundance and potential impacts on nesting success and skewed sex rations.

For a better understanding on microplastic particle sources and pathways within the sea, it is recommended that a particle drifter analysis is carried out for the beaches that were considered in this study, such as in the study by Duncan et al. (2018). By modelling plastic particle trajectories at sea, researchers can gather important information that could answer question such as whether pollution is likely to be originating from the country itself or from other countries, and if so which ones. Such information would be extremely useful in shaping local policy as well as regional policy, making it more targeted towards the biggest polluters.

Sampling across a larger number of beaches would also make results more representative and give a better understanding of microplastic pollution across the beaches of Cyprus. Due to time constraints, only 14 locations were selected in this study based on their region, orientation and importance as turtle nesting beaches. There are still a vast number of important turtle nesting sites across the island that remain unstudied. By collecting data from these, scientist can better understand patterns and associations regarding microplastics and therefore better target protection efforts towards the sensitive habitats that are most vulnerable.

Finally, the standardization of units is strongly recommended among studies that sample microplastics from beach sediment. Across several studies that were looked at, a variety of units were used to present the results, including: particles m^{-2}, particles m^{-3}, particles g^{-1}, g m^{-3}, g g^{-3} and as a % of total sediment weight. The use of different units makes comparison of studies difficult and sometimes not possible. As most studies reported in particles g^{-1} or particles kg^{-1}, it is proposed that these units are preferred, or that sufficient data is provided to allow for the conversion into these units.

7. Conclusion

Microplastic pollution was shown to be ubiquitous across beach sediments on the island of Cyprus. Microplastics were found at all sampled locations and were present at depths down to 10cm. Although no significant difference was observed among the different regions (east, south, west), the orientation of the beach was a significant factor in regard to microplastic abundance. West facing beaches were found to have the highest concentrations of microplastic among the beach sediment, with beach number 8 being recorded as the most polluted on the island, presenting mean levels of 199,600 particles m^{-3}.

By examining Mediterranean circulation patterns and currents, it was predicted that the vast majority of microplastics originated from nearby countries such as Turkey, Israel and Syria, as well as the central Mediterranean. Due to the lack of industrial practice in close proximity to the sampled sites, land-based sources from within the country were not considered to be the key source of pollution, but further research would be required to investigate this.

An evaluation of the current policies and legislation concluded that stricter measures and better implementation by countries would be required in order to effectively fight the plastic pollution problem of the Mediterranean. Due to the transboundary nature of the issue, and the detrimental biodiversity, socioeconomic and health impacts associated with it, it is important that further research is conducted, not only to help scientists better understand the distribution and the impacts, but to also help governments and policy makers make the most informed and effective decision for the health of the oceans.

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Appendix

Supplemental Table 1. Plastic influx kg^{-1} km^{-1} day^{-1} for 67 coastal locations within the Mediterranean. ***(adapted from** Liubartseva et al., 2018)*

Number	Location	Plastic influx (kg/km/day)
1	Morocco El Hoceima	5.6
2	Morocco, Algeria, Oran Bay	9
3	Algeria Mostaganem	8.7
4	Algiers	12.2
5	Algeria Skikda	7.5
6	Tunisia Bizerte	11.9
7	Tunisia Hammamet, Gabes	5
8	Libya Tripoli	6.9
9	Libya Sirte	1.7
10	Libya Al Wahat	2
11	Libya Darnah	4.8
12	Egypt Mersa-Mutruh	3
13	Alexandria, Nile, North Sinai	12.7
14	Israel	21
15	Lebanon	9.9
16	Syria	19.4
17	Turkey Cilicia	31.3
18	Turkey Antalya	4.6
19	Northern Cyprus	5
20	Cyprus	2.1
21	Turkey Mugla	3.2
22	Turkey Izmir	7.2
23	Turkey Canakkale	0.6
24	Greece Thrace	1.6
25	Thermaic Gulf	2.1
26	Greece Myrtoan	0.6
27	Saronic Gulf	5.5
28	Crete North	2.2
29	Crete South	0.5
30	Peloponnese Ionian	1.2
31	Gulf of Patras	1.3
32	Greece Epirus, Corfu	1.3
33	Albania Vlore	2.1
34	Albania Durres	4
35	Montenegro	3
36	Croatia and B&H	0.9
37	Slovenia, Trieste Gulf	5.3
38	Venice Lagoon	9
39	Po Delta, Emilia Romagna	18.2
40	Italy Marche North	12.5
41	Italy Abruzzo	7.4
42	Italy Apulia North	3.2
43	Italy Apulia South	7.9
44	Taranto Gulf	2.3
45	Italy Calabria Ionian	3.2

46	Sicily East	9.6
47	Sicily Southwest	2.6
48	Sicily North	6.1
49	Italy Calabria Tyrhhenian	2.6
50	Italy Campania	8.2
51	Italy Lazio	4.8
52	Italy Tuscany	3.3
53	Corsica East	1.3
54	Corsica West	1.6
55	Sardinia East	1.5
56	Sardinia West	2
57	Italy Liguria	8
58	French Riviera	9.4
59	Bay of Marseille	9
60	France Languedoc	1.2
61	Barcelona	26.1
62	Spain Terragona	5.3
63	Valencia Gulf	12.9
64	Spain Costa Blanca	9.8
65	Balearic Islands	4.6
66	Mazarron Bay	4.2
67	Spain Malaga	10.8

Supplemental Table 2. Information on beaches sampled in the study.
Coordinates are presented in DMS (Degrees, Minutes, Seconds). Orientation refers to the direction the beach is facing.

Beach number	Latitude	Longitude	Length (m)	Orientation	Region
1	35 10.440' N	032 34.103' E	700	N	West
2	35 05.982' N	032 30.000' E	8500	NW	West
3	35 02.875' N	032 26.121' N	1400	NW	West
4	34 57.481' N	032 18.627' E	520	W	West
5	34 55.333' N	032 19.576' E	840	W	West
6	34 39.454' N	032 46.071' E	1300	S	South
7	34 39.918' N	032 50.205' E	1320	S	South
8	34 35.444' N	032 56.271' E	530	W	South
9	34 37.281' N	033 00.363' E	5160	E	South
10	34 42.758' N	033 16.301' E	388	E	South
11	34 48.713' N	033 32.325' E	550	SE	East
12	34 49.174' N	033 36.285' E	770	E	East
13	34 59.052' N	033 00.520' E	840	S	East
14	35 01.076' N	034 03.191' E	840	NE	East

Supplemental Table 3. Coordinates of every point sampled across all beaches. Coordinates are presented in DMS (Degrees, Minutes, Seconds).

Beach number	Sample	Latitude	Longitude
1	1 SL	35 10.598' N	032 35.082' E
	TNL	35 10.562' N	032 35.066' E
	2 SL	35 10.393' N	032 34.981' E
	TNL	35 10.386' N	032 34.985' E
	3 SL	35 10.408' N	032 34.023' E
	TNL	35 10.403' N	032 34.025' E
	4 SL	35 10.425' N	032 34.064' E
	TNL	35 10.419' N	032 34.068' E
	5 SL	35 10.440' N	032 34.103' E
	TNL	35 10.436' N	032 34.107' E
	6 SL	35 10.459' N	032 34.144' E
	TNL	35 10.457' N	032 34.147' E
	7 SL	35 10.481' N	032 34.182' E
	TNL	35 10.476' N	032 34.186' E
	8 SL	35 10.504' N	032 34.217' E
	TNL	35 10.501' N	032 34.221' E
	9 SL	35 10.531' N	032 34.248' E
	TNL	35 10.528' N	032 34.251' E
	10 SL	35 10.560' N	032 34.275' E
	TNL	35 10.556' N	032 34.283' E
2	1 SL	35 07.715' N	032 30.985' E
	TNL	35 07.716' N	032 30.987' E
	2 SL	35 07.338' N	032 30.793' E
	TNL	35 07.332' N	032 30.804' E
	3 SL	35 06.964' N	032 30.573' E
	TNL	35 06.962' N	032 30.578' E
	4 SL	35 06.548' N	032 30.341' E
	TNL	35 06.545' N	032 30.345' E
	5 SL	35 05.982' N	032 30.000' E
	TNL	35 05.981' N	032 30.002' E
	6 SL	35 05.517' N	032 29.662' E
	TNL	35 05.516' N	032 29.668' E
	7 SL	35 05.097' N	032 29.329' E
	TNL	35 05.094' N	032 29.335' E
	8 SL	35 04.732' N	032 28.995' E
	TNL	35 04.729' N	032 29.000' E
	9 SL	35 04.360' N	032 28.601' E
	TNL	35 04.358' N	032 28.604' E
	10 SL	35 04.148' N	032 28.344' E
	TNL	35 04.147' N	032 28.346' E
3	1 SL	35 03.041' N	032 26.427' N
	TNL	35 03.038' N	032 26.427' N
	2 SL	35 02.995' N	032 26.352' N
	TNL	35 02.993' N	032 26.353' N
	3 SL	35 02.954' N	032 26.276' N
	TNL	35 02.951' N	032 26.277' N
	4 SL	35 02.914' N	032 26.197' N
	TNL	35 02.913' N	032 26.201' N
	5 SL	35 02.875' N	032 26.121' N

	TNL	35 02.872' N	032 26.123' N
	6 SL	35 02.834' N	032 26.042' N
	TNL	35 02.831' N	032 26.046' N
	7 SL	35 02.796' N	032 25.965' N
	TNL	35 02.794' N	032 25.966' N
	8 SL	35 02.759' N	032 25.883' N
	TNL	35 02.755' N	032 25.885' N
	9 SL	35 02.725' N	032 25.804' N
	TNL	35 02.720' N	032 25.806' N
	10 SL	35 02.693' N	032 25.719' N
	TNL	35 02.691' N	032 25.719' N
4	1 SL	34 57.561' N	032 18.710' E
	TNL	34 57.557' N	032 18.715' E
	2 SL	34 57.540' N	032 18.693' E
	TNL	34 57.537' N	032 18.696' E
	3 SL	34 57.522' N	032 18.672' E
	TNL	34 57.518' N	032 18.676' E
	4 SL	34 57.499' N	032 18.655' E
	TNL	34 57.496' N	032 18.658' E
	5 SL	34 57.481' N	032 18.627' E
	TNL	34 57.477' N	032 18.632' E
	6 SL	34 57.465' N	032 18.604' E
	TNL	34 57.461' N	032 18.607' E
	7 SL	34 57.450' N	032 18.584' E
	TNL	34 57.447' N	032 18.586' E
	8 SL	34 57.436' N	032 18.559' E
	TNL	34 57.434' N	032 18.563' E
	9 SL	34 57.426' N	032 18.535' E
	TNL	34 57.424' N	032 18.540' E
	10 SL	34 57.412' N	032 18.505' E
	TNL	34 57.409' N	032 18.506' E
5	1 SL	34 55.505' N	032 19.535' E
	TNL	34 55.506' N	032 19.546' E
	2 SL	34 55.465' N	032 19.542' E
	TNL	34 55.465' N	032 19.550' E
	3 SL	34 55.421' N	032 19.553' E
	TNL	34 55.420' N	032 19.559' E
	4 SL	34 55.378' N	032 19.566' E
	TNL	34 55.379' N	032 19.569' E
	5 SL	34 55.333' N	032 19.576' E
	TNL	34 55.333' N	032 19.579' E
	6 SL	34 55.289' N	032 19.585' E
	TNL	34 55.289' N	032 19.589' E
	7 SL	34 55.245' N	032 19.594' E
	TNL	34 55.245' N	032 19.598' E
	8 SL	34 55.202' N	032 19.597' E
	TNL	34 55.202' N	032 19.603' E
	9 SL	34 55.161' N	032 19.599' E
	TNL	34 55.162' N	032 19.603' E
	10 SL	34 55.120' N	032 19.604' E
	TNL	34 55.123' N	032 19.609' E
6	1 SL	34 39.385' N	032 46.379' E
	TNL	34 39.387' N	032 46.385' E
	2 SL	34 39.415' N	032 46.308' E

	TNL	34 39.421' N	032 46.311' E
	3 SL	34 39.419' N	032 46.225' E
	TNL	34 39.430' N	032 46.229' E
	4 SL	34 39.439' N	032 46.145' E
	TNL	34 39.448' N	032 46.142' E
	5 SL	34 39.454' N	032 46.071' E
	TNL	34 39.462' N	032 46.069' E
	6 SL	34 39.462' N	032 45.986' E
	TNL	34 39.472' N	032 45.988' E
	7 SL	34 39.465' N	032 45.910' E
	TNL	34 39.470' N	032 45.909' E
	8 SL	34 39.463' N	032 45.817' E
	TNL	34 39.468' N	032 45.815' E
	9 SL	34 39.453' N	032 45.734' E
	TNL	34 39.465' N	032 45.725' E
	10 SL	34 39.421' N	032 45.652' E
	TNL	34 39.432' N	032 45.645' E
7	1 SL	34 39.830' N	032 50.523' E
	TNL	34 39.843' N	032 50.524' E
	2 SL	34 39.854' N	032 50.452' E
	TNL	34 39.867' N	032 50.457' E
	3 SL	34 39.877' N	032 50.372' E
	TNL	34 39.888' N	032 50.376' E
	4 SL	34 39.897' N	032 50.289' E
	TNL	34 39.910' N	032 50.288' E
	5 SL	34 39.918' N	032 50.205' E
	TNL	34 39.927' N	032 50.210' E
	6 SL	34 39.941' N	032 50.121' E
	TNL	34 39.950' N	032 50.124' E
	7 SL	34 39.963' N	032 50.033' E
	TNL	34 39.972' N	032 50.038' E
	8 SL	34 39.982' N	032 49.959' E
	TNL	34 39.985' N	032 49.960' E
	9 SL	34 39.996' N	032 49.883' E
	TNL	34 40.000' N	032 49.885' E
	10 SL	34 40.009' N	032 49.810' E
	TNL	34 40.016' N	032 49.808' E
8	1 SL	34 35.532' N	032 56.175' E
	TNL	34 35.536' N	032 56.177' E
	2 SL	34 35.518' N	032 56.206' E
	TNL	34 35.522' N	032 56.213' E
	3 SL	34 35.500' N	032 56.234' E
	TNL	34 35.501' N	032 56.242' E
	4 SL	34 35.474' N	032 56.256' E
	TNL	34 35.477' N	032 56.263' E
	5 SL	34 35.444' N	032 56.271' E
	TNL	34 35.449' N	032 56.280' E
	6 SL	34 35.414' N	032 56.279' E
	TNL	34 35.418' N	032 56.293' E
	7 SL	34 35.387' N	032 56.288' E
	TNL	34 35.389' N	032 56.302' E
	8 SL	34 35.358' N	032 56.291' E
	TNL	34 35.360' N	032 56.304' E
	9 SL	34 35.331' N	032 56.289' E

	TNL	34 35.332' N	032 56.299' E
	10 SL	34 35.303' N	032 56.280' E
	TNL	34 35.300' N	032 56.290' E
9	1 SL	34 38.294' N	033 00.581' E
	TNL	34 38.295' N	033 00.572' E
	2 SL	34 38.055' N	033 00.507' E
	TNL	34 38.056' N	033 00.505' E
	3 SL	34 37.782' N	033 00.439' E
	TNL	34 37.783' N	033 00.436' E
	4 SL	34 37.558' N	033 00.398' E
	TNL	34 37.562' N	033 00.386' E
	5 SL	34 37.281' N	033 00.363' E
	TNL	34 37.283' N	033 00.357' E
	6 SL	34 36.972' N	033 00.346' E
	TNL	34 36.973' N	033 00.336' E
	7 SL	34 36.710' N	033 00.347' E
	TNL	34 36.711' N	033 00.334' E
	8 SL	34 36.461' N	033 00.361' E
	TNL	34 36.452' N	033 00.345' E
	9 SL	34 36.180' N	033 00.396' E
	TNL	34 36.180' N	033 00.382' E
	10 SL	34 35.960' N	033 00.435' E
	TNL	34 35.960' N	033 00.431' E
10	1 SL	34 42.808' N	033 16.377' E
	TNL	34 42.810' N	033 16.374' E
	2 SL	34 42.790' N	033 16.363' E
	TNL	34 42.797' N	033 16.358' E
	3 SL	34 42.781' N	033 16.339' E
	TNL	34 42.786' N	033 16.336' E
	4 SL	34 42.771' N	033 16.320' E
	TNL	34 42.775' N	033 16.313' E
	5 SL	34 42.758' N	033 16.301' E
	TNL	34 42.760' N	033 16.295' E
	6 SL	34 42.741' N	033 16.283' E
	TNL	34 42.743' N	033 16.280' E
	7 SL	34 42.724' N	033 16.270' E
	TNL	34 42.726' N	033 16.265' E
	8 SL	34 42.707' N	033 16.257' E
	TNL	34 42.707' N	033 16.253' E
	9 SL	34 42.687' N	033 16.252' E
	TNL	34 42.686' N	033 16.248' E
	10 SL	34 42.666' N	033 16.251' E
	TNL	34 42.666' N	033 16.247' E
11	1 SL	34 48.587' N	033 32.189' E
	TNL	na	na
	2 SL	34 48.622' N	033 32.230' E
	TNL	na	na
	3 SL	34 48.647' N	033 32.267' E
	TNL	34 48.649' N	033 32.264' E
	4 SL	34 48.680' N	033 32.292' E
	TNL	34 48.682' N	033 32.291' E
	5 SL	34 48.713' N	033 32.325' E
	TNL	34 48.718' N	033 32.325' E
	6 SL	34 48.738' N	033 32.361' E

	TNL	34 48.742' N	033 32.358' E
	7 SL	34 48.761' N	033 32.405' E
	TNL	34 48.769' N	033 32.400' E
	8 SL	34 48.792' N	033 32.438' E
	TNL	34 48.796' N	033 32.432' E
	9 SL	34 48.821' N	033 32.469' E
	TNL	34 48.822' N	033 32.468' E
	10 SL	34 48.852' N	033 32.493' E
	TNL	34 48.853' N	033 32.493' E
12	1 SL	34 49.011' N	033 36.207' E
	TNL	34 49.013' N	033 36.202' E
	2 SL	34 49.056' N	033 36.231' E
	TNL	34 49.056' N	033 36.228' E
	3 SL	34 49.099' N	033 36.248' E
	TNL	34 49.100' N	033 36.244' E
	4 SL	34 49.135' N	033 36.270' E
	TNL	34 49.136' N	033 36.267' E
	5 SL	34 49.174' N	033 36.285' E
	TNL	34 49.174' N	033 36.278' E
	6 SL	34 49.219' N	033 36.287' E
	TNL	34 49.217' N	033 36.270' E
	7 SL	34 49.262' N	033 36.288' E
	TNL	34 49.264' N	033 36.263' E
	8 SL	34 49.303' N	033 36.262' E
	TNL	34 49.301' N	033 36.252' E
	9 SL	34 49.338' N	033 36.238' E
	TNL	34 49.336' N	033 36.234' E
	10 SL	34 49.380' N	033 36.237' E
	TNL	34 49.381' N	033 36.233' E
13	1 SL	34 59.044' N	033 00.738' E
	TNL	34 59.049' N	033 00.737' E
	2 SL	34 59.028' N	033 00.681' E
	TNL	34 59.033' N	033 00.680' E
	3 SL	34 59.041' N	033 00.633' E
	TNL	34 59.046' N	033 00.633' E
	4 SL	34 59.048' N	033 00.580' E
	TNL	34 59.055' N	033 00.579' E
	5 SL	34 59.052' N	033 00.520' E
	TNL	34 59.056' N	033 00.522' E
	6 SL	34 59.050' N	033 00.469' E
	TNL	34 59.059' N	033 00.468' E
	7 SL	34 59.043' N	033 00.410' E
	TNL	34 59.051' N	033 00.407' E
	8 SL	34 59.032' N	033 00.356' E
	TNL	34 59.041' N	033 00.351' E
	9 SL	34 59.014' N	033 00.304' E
	TNL	34 59.021' N	033 00.299' E
	10 SL	34 58.988' N	033 00.261' E
	TNL	34 58.991' N	033 00.255' E
14	1 SL	35 00.923' N	034 03.333' E
	TNL	35 00.917' N	034 03.327' E
	2 SL	35 00.946' N	034 03.289' E
	TNL	35 00.943' N	034 03.282' E
	3 SL	35 00.986' N	034 03.254' E

TNL	35 00.981' N	034 03.249' E
4 SL	35 01.027' N	034 03.218' E
TNL	35 01.026' N	034 03.213' E
5 SL	35 01.076' N	034 03.191' E
TNL	35 01.072' N	034 03.184' E
6 SL	35 01.116' N	034 03.158' E
TNL	35 01.111' N	034 03.149' E
7 SL	35 01.157' N	034 03.121' E
TNL	35 01.153' N	034 03.111' E
8 SL	35 01.187' N	034 03.099' E
TNL	35 01.183' N	034 03.085' E
9 SL	35 01.216' N	034 03.080' E
TNL	35 01.210' N	034 03.067' E
10 SL	35 01.258' N	034 03.061' E
TNL	35 01.248' N	034 03.053' E

Supplemental Table 4. Mean microplastic abundance per beach for SL and TNL surface and depth samples
Mean microplastic abundance reported in particles m^{-3} and g m^{-3}.

Beach number	SL 0.0-2.0 cm			TNL 0.0-2.0 cm			TNL 2.1-10.0 cm	
	mean particles m^{-3}	mean g m^{-3}	mean particles kg^{-1}	mean particles m^{-3}	mean g m^{-3}	mean particles kg^{-1}	mean particles m^{-3}	mean g m^{-3}
1	1600	8.4	1.1	0	0	0	0	0
2	6000	64.8	3.8	4400	49.2	2.7	0	0
3	0	0	0	2000	0.4	1.2	400	9.2
4	11600	62.8	8.6	67200	1283.2	44.4	19600	189.2
5	4400	18	3.2	1200	1.2	0.8	400	0.4
6	0	0	0	400	8.4	0.2	800	0.4
7	1200	0.4	0.7	0	0	0	0	0
8	528000	1533.2	411.4	199600	1214.8	154.0	42000	155.2
9	400	0.4	0.3	400	0.4	0.3	800	0.8
10	2800	16.8	2.2	800	0.8	0.5	0	0
11	1500	1	0.9	9000	23	6.3	500	5
12	400	0.4	0.2	0	0	0	2400	0.8
13	1200	1.2	0.9	4400	14	2.9	2000	25.6
14	40400	47.2	28.2	400	0.4	0.3	400	0.4