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Anthropogenic marine litter on the north coast of Cyprus: Insights into marine pollution in the eastern Mediterranean

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ABSTRACT

The eastern Mediterranean is a region that has been relatively understudied with regards to anthropogenic marine litter despite potential for environmental and social costs. Here, coastal marine litter accumulation was assessed at eight beach locations along the coast of Northern Cyprus. Monthly surveys were performed between January 2017 and January 2019. All items ≥ 2.5 cm in diameter within the same 250 m^2 plot were collected and processed. A total of 59,556 separate items were collected with a total mass of 697 kg. At the worst affected site (Ronnas Bay) litter accumulation averaged 1114 items and 11.9 kg per month. Plastic and polystyrene litter accounted for 82% (622.71 kg) of all litter types by mass and 96% (57,231) by frequency. Plastic bags, plastic pieces, drinks containers, caps/lids were the four most abundant forms of plastic by mass and by frequency. This suggests dumping/poor domestic waste governance as the main driver of marine litter in the region.

1. Introduction

Anthropogenic marine litter has become a global concern and is defined as any processed solid waste material that enters the marine environment from any source (Coe and Rogers, 1997). Ultimately there are two sources of marine litter; maritime or land based. Maritime sources comprise of litter which has directly originated from marine vessels, gas or oil platforms, and aquaculture installations (UNEP, 2005). Land-based sources arise from poor municipal waste disposal, illegal dumping, sewage, and unintentional discards. A considerable amount of the land based litter enters the marine realm through riverine inputs which are directly fed from urban runoff waters following heavy rainfall (Willis et al., 2017). Marine litter has become ubiquitous throughout the world's oceans and seas, appearing in some of the most remote regions of the world (Lavers and Bond, 2017; Walker et al., 1997). Although marine litter is made up from a diversity of materials (metal, glass, wood), plastics are by far the largest single constituent (Barnes et al., 2009; Derraik, 2002; Laglbauer et al., 2014; Pasternak et al., 2017; Schulz et al., 2015). Rapidly increasing use, coupled with low levels of recycling and poor waste management have led to a global pollution problem in both terrestrial and marine environments (Barnes et al., 2009; Eriksen et al., 2014; Geyer et al., 2017). In recent years the levels of marine plastics and its threats to marine ecosystems and human health have become of global concern (Barboza et al., 2019). The spread of plastic litter throughout the oceans of the world has led to distressing physical impacts through entanglement, ingestion and death of large numbers of marine biota (Battisti et al., 2019; De Stephanis et al., 2013; Franco-Trecu et al., 2017; Gregory, 2009). A wide range of marine fauna (including cetaceans, sea turtles, sea birds and fish) have been directly impacted through interactions with marine litter either through entanglement or ingestion (Bernardini et al., 2018; Bravo Rebolledo et al., 2013; Duncan et al., 2019; Laist, 1997; Parton et al., 2019; Schuyler et al., 2014; Sheavly and Register, 2007).

Additionally, the marine litter which accumulates along the shorelines is aesthetically unattractive and potentially dangerous for beach users (Corraini et al., 2018; Williams et al., 2016). Understanding the social, ecological, and economic effects of marine litter will provide us with the necessary tools to mitigate against this escalating problem. Once this is achieved it will reduce the numerous costly initiatives on which NGOs or governments spend their limited resources for beach cleaning activities (Beaumont et al., 2019; Brouwer et al., 2017; Sheavly and Register, 2007).

To understand the scale of the marine litter problem and to develop an effective management strategy, it is necessary to conduct monitoring

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programs that follow trends in the levels of coastal marine litter (Critchell and Lambrechts, 2016; Schulz et al., 2015). Programs such as OSPAR (Oslo Paris Commission) have led to the monitoring 50 indicator beaches in the north-eastern Atlantic using standardised protocol since 1998 (Galgani et al., 2010).

Marine litter in the Mediterranean has been an issue of concern since the 1970s (Shiber, 1979). Barnes and Milner, 2005, highlighted how semi-enclosed seas which are surrounded by developed areas, such as the Mediterranean Sea, are likely to have high concentrations of marine litter. A recent comprehensive review of marine coastal litter in the Mediterranean concluded that >80% of beach litter consisted of plastic items (Vlachogianni, 2019). Much of the focus thus far has been in the western Mediterranean basin, Adriatic and Aegean seas, leaving the eastern Mediterranean and the area of our focus, the Cilician Basin, relatively underrepresented in the scientific literature (Aydın et al., 2016; Gündoğdu, 2017; Portman and Brennan, 2017).

The beaches of Cyprus are important ecologically, socially, and economically. Tourism is one of the major income sources for the country, with most tourists spending a large proportion of their time at the beach. Beaches presenting large quantities of marine litter are unattractive to both tourists and locals alike. Additionally, from an ecological standpoint, the beaches of Cyprus hold internationally significant populations of nesting sea turtles *Caretta caretta* and *Chelonia mydas* (Broderick et al., 2002; Casale et al., 2018).

2. Materials and methods

2.1. Study region and surveys

This study was carried out around the shoreline of Northern Cyprus from January 2017 to January 2019. Cyprus is located in the Eastern Mediterranean Sea, with Asia Minor Current (AMC) flowing in an anticlockwise direction from the southern coastal waters to the northern coastline. Eight beaches were selected to include beaches with easterly, westerly, and northerly aspects (Fig. 1). Five of the eight (A, B, D–F) beaches are within officially designated SEPA's (Special Environmental Protection Areas; Fuller et al., 2011, 2010a, 2010b). Additionally, four (C, D, G & H) and six (A–F) of the eight beaches are touristic and important turtle nesting locations, respectively (Godley and Broderick, 1992). All beaches are of typical Mediterranean nature, usually bordered by rocky outcrops with sparse, low growing shrub like vegetation (for detailed descriptions of protected area beaches see Fuller et al., 2011, 2010a, 2010b). One beach (H) is the only beach which does not fit this description and is surrounded by touristic type infrastructure and buildings. Beaches C, D, F and H receive high numbers of beach users during the summer months, particularly July and August.

Litter surveys followed protocols adapted from the EU MSFD TG10 (Galgani et al., 2013) on transects of area 250 m^2 (5 × 50 m) landward along high water (MHW) (see Fig. 1 Supplemental material). All transect locations were marked and GPS positions recorded. All plots were cleared in January 2017, and then each subsequent month (February 2017–January 2019) all beaches were cleared of all surface macro litter (≥2.5 cm). The collected litter was bagged and labelled and taken to the laboratory for cleaning, counting, weighing and characterization. Cleaning of the beach litter included the provisional removal of sand by shaking, if items required additional cleaning to remove any remaining sand this was either done outside using garden hose (for larger items), or washed under a tap using a sieve (for small items). All items were left to dry naturally before counting and weighing. All marine litter collected was categorised according to established protocols (OSPAR, 2010). The number and weight of each item category was recorded as was any geographical origin suggested by labelling. Weight was ascertained using Ohaus CT200-13U electronic balance (precision: 0.01 g) for small items and larger single items were weighed using a household digital balance (precision: 1.0 g).

To compare this study with others from the region we selected at least one publication from each country in the region which provided the highest estimates of marine debris for that country. Additionally, these studies needed to have comparable methodologies and similar result metrics i.e. beach transects of report dimensions and results showing densities of litter accumulation (Table 1).

3. Results

3.1. Total beach litter density and distribution

During shoreline surveys, a total of 59,563 items, amounting to a total mass of 697.0 kg were collected, sorted, and catalogued. The mean

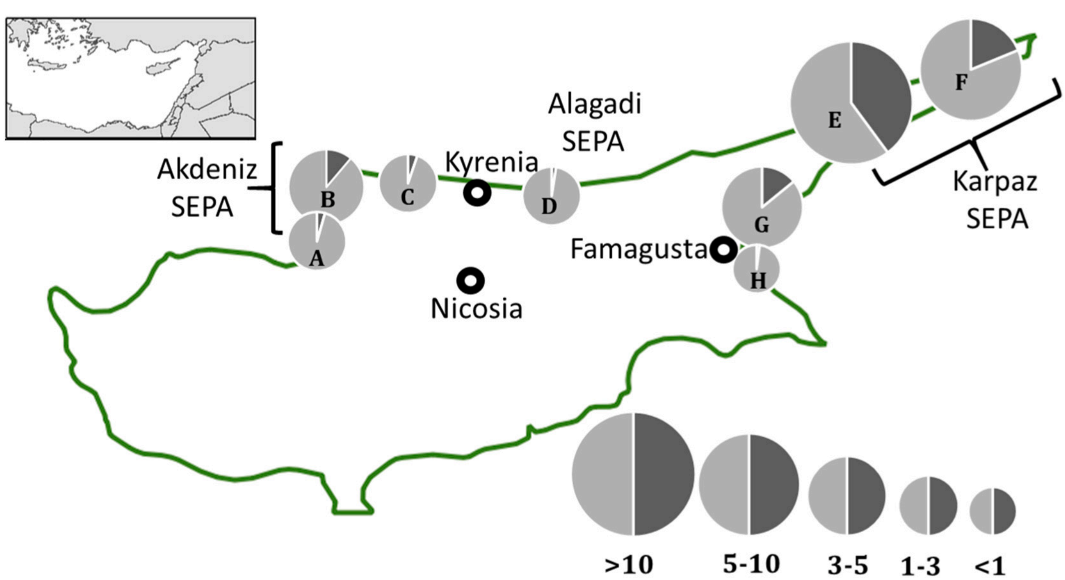

Fig. 1. Map of beach sampling locations (A = Akdeniz II, B = Akdeniz I, C = Güzelyalı, D = Alagadi, E = Ronnas, F = Ayios Philon, G = İskele, H = Kocareis). The diameter of each pie indicates the mean monthly mass (kg) of debris collected at each beach location and dark shaded segment indicates the percentage contribution of that individual beach to the total mass of debris collected. Insert map shows the location of Cyprus in the eastern Mediterranean. SEPA = Special Environmental Protection Area.

Table 1
Comparison of macro beach litter in the Mediterranean region using similar survey protocols. Survey types are divided into two types (M) multiple surveys of the same area and (S) single, one-off survey events. Only the most polluted sites for each country were selected from Vlachogianni et al. (2018). Values of items/m^2 >0.8 are emboldened.

Country	Region	Research period	Area		Coastline		Survey type	Reference
			Items/m^2	Mass (g)/m^2	Items/m	Mass (g)/m		
Italy	Ligurian Sea	2014–15	**1.06**				M	Giovacchini et al., 2018
Croatia	Zaglav (Adriatic)	2014–16	**11.0**		105.5		M	Vlachogianni et al., 2018
Greece	Ipsos (Ionian Sea)	2014–16	**0.91**		4.55		M	"
Slovenia	Strunjan (Adriatic)	2014–16	**0.83**		8.28		M	"
Italy	Foce Bevano (Adriatic Sea)	2014–16	0.55		5.49		M	"
Montenegro	Kamenovo (Adriatic)	2014–16	0.52		5.24		M	"
Slovenia	Bele Skale (Adriatic)	2014–16	0.49		4.90		M	"
Croatia	Neretva (Adriatic)	2014–16	0.48		4.79		M	"
Israel	Jisr-Az-Zarqa (E. Med)	2016	0.52				M	Portman and Brennan, 2017
Turkey	South East Coast (NE. Med)	2014	**0.92**	7.4	15.4		S	Aydın et al., 2016
Turkey	Black Sea Coast	2012–13	0.16	3.4			M	Terzi and Seyhan, 2017
Greece	Corfu	2014–15	0.31				M	Prevenios et al., 2018
Italy	NW Adriatic	2015	0.22				S	Munari et al., 2016
Slovenia	Gulf of Trieste	2012	**1.51**				S	Laglbauer et al., 2014
Israel	E. Mediterranean	2012–2015	0.12				M	Pasternak et al., 2017
Spain	W. Mediterranean	2018	0.05				S	Asensio-Montesinos et al., 2019
Turkey	Black Sea Coast	2008–09	**0.88**		27.5		M	Topçu et al., 2013
Cyprus	North Cyprus	2017–2019	**1.19**	15.1	5.96	75.7	M	This study

Cyprus - Individual beach results

Country	Region	Research period	Area		Coastline		Survey type	Reference
			Items/m^2	Mass (g)/m^2	Items/m	Mass (g)/m		
Cyprus	Akdeniz I	2017–2019	**0.92**	16.0	4.6	80.1	M	This study
Cyprus	Kocareis	2017–2019	0.24	3.1	1.2	15.5	M	"
Cyprus	Iskele	2017–2019	**0.89**	15.8	4.4	79.1	M	"
Cyprus	Ayios Philon	2017–2019	**0.98**	21.6	4.9	108.0	M	"
Cyprus	Ronnas	2017–2019	**4.46**	47.8	22.3	239.4	M	"
Cyprus	Akdeniz II	2017–2019	0.25	5.0	1.3	24.8	M	"
Cyprus	Guzelyali	2017–2019	0.46	6.0	2.3	30.2	M	"
Cyprus	Alagadi	2017–2019	**1.33**	5.7	6.7	28.6	M	"

monthly density levels of anthropogenic litter collected amounted to 1.2 items/m^2 and 13.9 g/m^2 or 69.7 g/m and 6.0 items/m of coastline (Table 1). Individual beach densities ranged from 0.2 to 4.5 items/m^2 and 3.1 to 47.5 g/m^2 or 1.2 to 22.3 items/m and 15.5 to 237.2 g/m (for individual beach details see Table 1). Spatially the location receiving the highest level of marine litter both in mass and number of items was Ronnas Bay (beach E) which averaged 11.9 kg and 1113.8 items each month respectively (Figs. 1, 2a & b). Conversely, Kocareis beach (beach H) received the lowest amount of mean monthly marine litter amounting to 0.8 kg and 59.8 items per month (Figs. 1, 2a & b).

3.1.1. *Monthly rates of litter accumulation*

Following the initial cleaning of anthropogenic litter in January 2017, the mean monthly levels of litter accumulation (February 2017–January 2019) were 27.0 kg by mass and 2204 individual items, which equates to 1.1 items/m^2 and 13.3 g/m^2 or 66.4 g/m and 5.5 items/m of coastline. No significant difference was found between years in the mean monthly levels in both mass (paired *t*-test, $t_{11} = 0.985$, $p = 0.35$ Fig. 3a) and number (paired t-test, $t_{11} = 1.597$, $p = 0.14$. Fig. 3b). There was considerable within and between beach variation in the monthly totals of both litter mass (Figs. 1, 3a & b) and the number items (Fig. 3b). When monthly marine litter accumulation was visually appraised from a seasonal perspective there appeared to be an elevated level of accumulation during the winter months, however, this was not found to be statistically significant (Kruskal-Wallis test, mass $p = 0.21$, the number of items $p = 0.77$. See Fig. 2a & b Supplemental material).

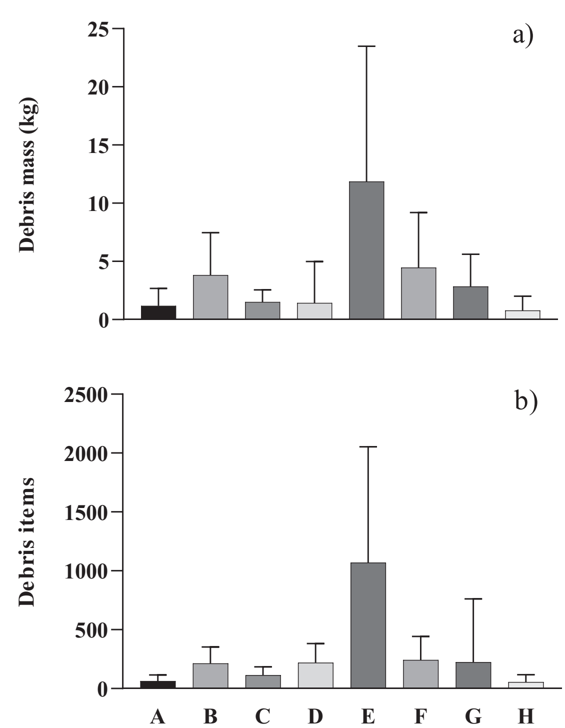

Fig. 2. Provides details of the mean (±1sd) monthly levels of marine litter by (a) mass and (b) the number of items (inclusive of initial beach clearance).

3.2. *Characterization of litter*

The litter type category deposited with the greatest frequency during the two years was that of plastics/polystyrene which accounted for 80%

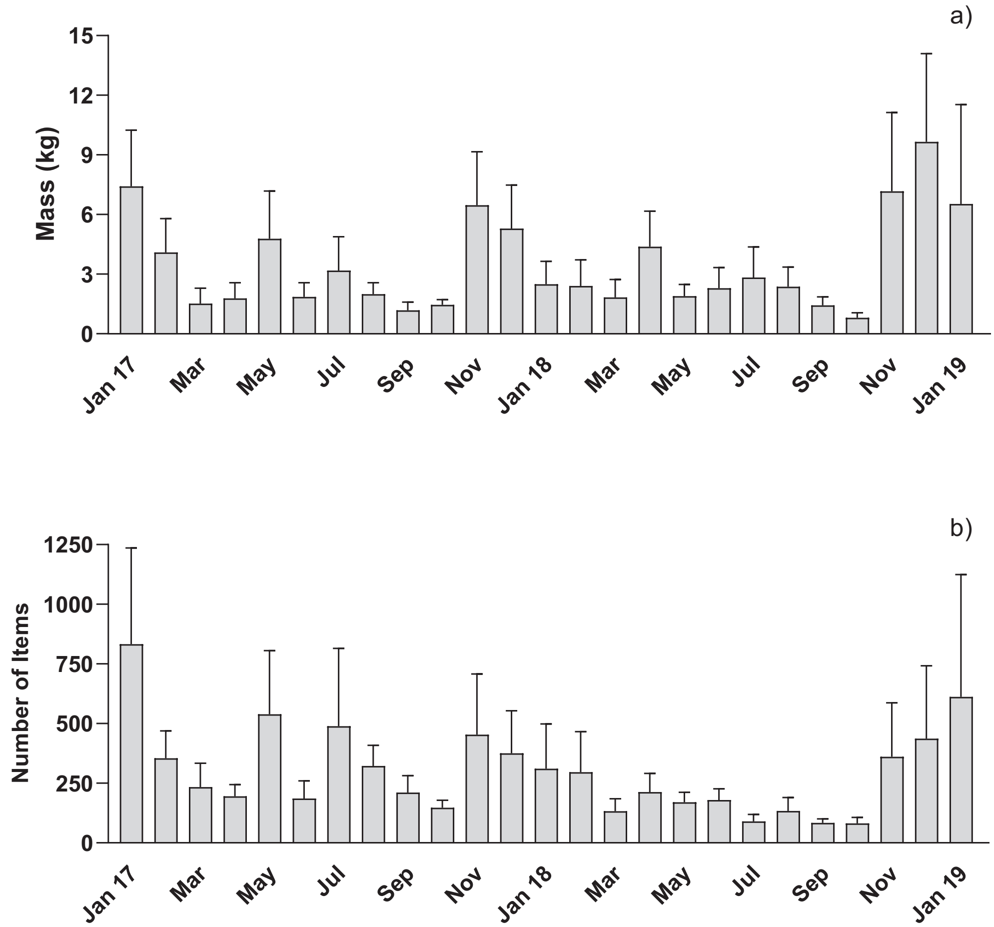

Fig. 3. Annual mean (SEM) monthly comparisons of beach litter mass (a) and the number of items (b).

(561.0 kg) of all litter types by mass (Fig. 4a) and 96% (57,231) by the number of items collected (Fig. 4b). All other categories constituted less than 20% by mass and less than 4% by frequency (Fig. 4). The single category which represented the greatest mass collected was unidentifiable plastic/polystyrene pieces >2.5–50 cm (OSPAR ID No 46) which amounted 107.9 kg and made up 17.3% of all plastic collected, followed by drinks containers (11.0%), plastic shopping bags (8.1%), and caps/lids (7.6%) (Fig. 5a). Although when considered by frequency of items, the order of these four categories changed, they were still some of the most abundant items, totalling 67% of all items (Fig. 5b). Wood, Metal, Glass and Ceramic items appear relatively high in terms of mass (Fig. 4a) due to their relative density in comparison to lighter items such as plastics, cloth, card and paper. However, these items are relatively low in terms of the frequency of items (Fig. 4b).

3.3. Country comparisons within the region

When data from this study are compared with similar studies in the region, Cyprus has some of the most polluted beaches in the Mediterranean region (Table 1). With the north-eastern Karpaz peninsula holding the highest levels of marine coastal litter in Cyprus and the second most polluted in terms of items/m^2 for the region and considering the relatively low level of touristic development in the northern part of Cyprus, when compared to many other Mediterranean countries it is perhaps surprising to see these levels of litter accumulation.

3.4. Litter origin

From January 2018 to January 2019 a total of 86 items of non-Turkish origin were collected and identified through the items labelling addresses or language (items with non-identifiable origins were excluded). The reason for choosing non-Turkish origin is it would be impossible to separate products from the Turkish part of Cyprus from those which originated from mainland Turkey. The countries from which these items originated were Lebanon (55), Syria (26), Israel (3) and Egypt (2). Of these items, 96.5% were plastic and comprised of bottles, bottle tops or food containers. The location which received the most items was beach E on the north Karpaz coast ($n = 51$) nearly 60% of the total, followed by beach F with 12 items (14%). With four additional beaches (Beaches A–D) receiving 8, 5, 6 and 4 of these items, respectively.

4. Discussion

4.1. Beach litter density and distribution

The levels of beach litter found during this study were some of the highest found in the Mediterranean, with only Zaglev, Croatia in the Adriatic providing a greater number of items/m^2 (see Table 1) (Vlachogianni et al., 2018). Between-study comparisons are fraught with difficulties, as methodologies can vary according to the areas surveyed, their periodicity and the beach environment (i.e. topography, geographical aspect, beach usage and oceanic currents). However, we feel using items/m^2 or mass/m^2 provides the best density estimates for between-study comparisons, as using metres of coastline leads to great variability dependent on the transect width. The results of our monthly beach surveys have shown that the beaches of the Karpaz peninsula experience the highest levels of marine anthropogenic marine litter

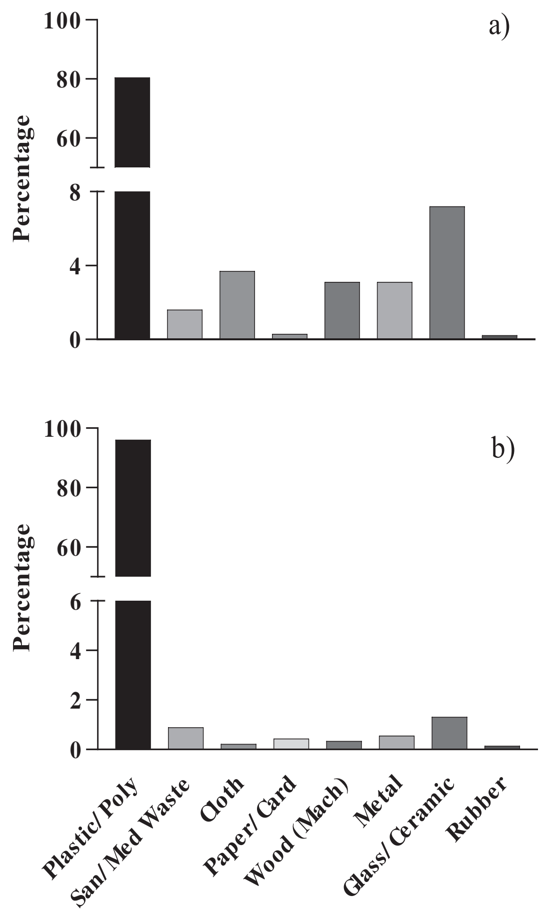

Fig. 4. Percentage levels of eight different categories of marine litter by (a) mass and (b) the number of items deposited on all beaches during the survey period.

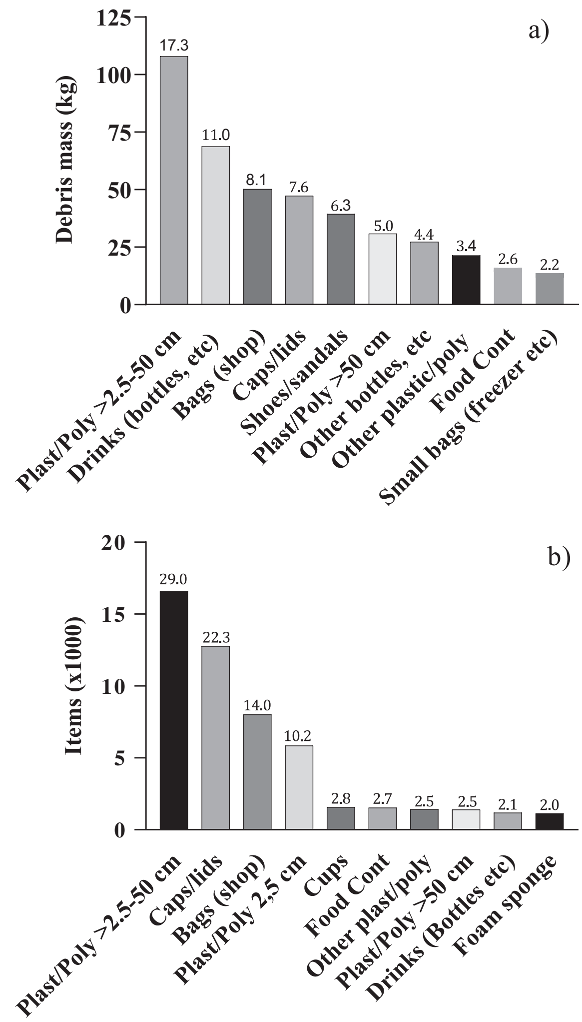

Fig. 5. The top ten individual plastic items in terms of total mass (a) and item counts (b) during the survey period. Figures above each column indicate the percentage that item represents from all the plastic items collected. For OSPAR numbers and individual category description see Table 1 Supplementary data.

accumulation. Beach E received the highest levels both in terms of mass and the number of items collected, receiving approximately double that of any other monitored beach. The reasons for these rates of accumulation are probably related to the hydrodynamic conditions present in the coastal waters of Cyprus (Duncan et al., 2018; Pasternak et al., 2018). Duncan et al. (2018) found similar results when some of the same sites were surveyed for microplastics, where beach E also demonstrated the highest levels of microplastics of all monitored beaches, indeed among the highest globally. Additionally, it must be assumed that most of the litter found on these beaches was ocean-borne as these beaches are remote, with low levels of human usage. Although our data lacked power to detect seasonal trends in the levels of accumulation, there was a suggestion that levels of accumulation during the winter months (Dec–Feb) may be higher, which might be expected given increased winds and the outflowing of seasonal rivers.

4.2. Beach litter composition

Litter types were categorised into 8 different categories using OSPAR's marine litter monitoring guide (OSPAR, 2010). In terms of the number of items collected, plastic and polystyrene constituted 96% of all items collected. The proportional contribution of plastic to marine litter found on the beaches of Northern Cyprus is the highest reported to date in the Mediterranean, although other beaches in the region have reported similar levels of >90% (Battisti et al., 2019; Pasternak et al., 2017; Poeta et al., 2016; Prevenios et al., 2018; Vlachogianni et al., 2018), and between 80 and 90% (Asensio-Montesinos et al., 2019; Aydın et al., 2016; Giovacchini et al., 2018; Munari et al., 2016; Terzi and Seyhan, 2017). The pervasiveness of plastics in coastal locations is related to the characteristics which has led their multipurpose and widespread use, in simple terms they are light, often buoyant, and extremely durable. This facilitates their dispersal over thousands of kilometres from their source of origin to distant and sometimes uninhabited locations (Benton, 1995; Lavers and Bond, 2017).

4.3. Plastic litter composition

Four categories made up of 54% of plastic by mass or 67% by frequency (bags, bottles, lids and smaller pieces of plastic/polystyrene resultant from the breakdown of larger pieces). These point to a pathway of public littering and/or poor domestic waste governance as the principle driver of marine plastic levels rather than maritime industries such as fishing, which is a major driver in some locations (Nelms et al., 2020, 2018), especially when mass is considered. Of the plastic litter collected, the most numerous category, making up nearly 30% of all plastic items collected was plastic/polystyrene pieces of the size class 2.5–50 cm. This category was also the highest in terms of mass. Drinks bottles, plastic bags and bottle tops were also among the highest items collected both in terms of the number and mass of items. These results are comparable to Vlachogianni et al., 2018, who also found plastic/polystyrene pieces of the size class 2.5–50 cm to be the most numerous items deposited on the beaches of the Adriatic and Ionian seas. These results are not unexpected given that most domestic plastic items will either begin life in this size class or fragmented through solar irradiance (photocatalytic oxidation) and or the physical action of the ocean. Additionally, the prevalence of plastic bags, plastic bottles and their associated caps or lids is also of no surprise given their buoyancy and their pervasive use in today's society. These items were also found to be the most numerous items along the Moroccan and Black Sea coastline (Maziane et al., 2018; Topçu et al., 2013). The universal nature of these items in our society and the poor levels of recycling and waste management throughout the region, together with their durability it is of no surprise that they have become ubiquitous and abundant along the Mediterranean shoreline (Maziane et al., 2018; Prevenios et al., 2018; Vlachogianni et al., 2018).

4.4. Litter origin

Attributing trans-boundary litter items to a specific country source is fraught with a high degree of uncertainty. It is difficult to be certain that items have not been imported into the country officially or by visitors from the country of origin. However, given the relative isolation of the beaches where >80% of the items were recovered and identified to a known source we feel that we can be confident in our assumptions. Other than Turkey or Northern Cyprus, the two country sources contributing the highest number of items were Lebanon and Syria. These two nations are the closest down-stream nations to Cyprus. Lebanon has a long history of poor waste management due to a number of civil and economic issues (civil unrest, corruption of government institutions and poor environmental stewardship) these have all contributed to this ongoing problem (El-Fadel et al., 2001; Haase, 2017). For almost a decade the Syrian government has been involved in a long-drawn-out civil war, which has led to mass emigration of its civilians and a breakdown in governance and services.

4.5. Costs of marine litter

4.5.1. Social and business

Tourism is a significant income for the economy of the country, with many tourists spending large parts of their time at the beach. For this reason, litter on beaches leads to a negative impression and ultimately a poor reputation. One way to deal with this issue is to have regular beach cleans. Private or governmental beach cleans tend to only be performed close to touristic establishments, but obviously, incur a financial cost to the cleaner. Alternatively, voluntary beach cleans, which can receive funding from a variety of donors tend to be performed at locations which are considered more ecologically important, however, these at best, are usually only carried out once or twice a year. Again, this has a financial cost both for the donor and participants. It is clear from the monthly litter counts performed during this study that even monthly beach cleans had little or no effect on the levels of beach litter mass, with re-accumulation rates similar between years. However, a commitment to monthly beach cleans would require a huge investment, both in terms of resources and finances, both of which are unlikely in the short term to be provided in the current global financial crisis.

4.5.2. Ecological costs of beach litter

Most of the ecological studies in relation to the effects of litter on the ecology of the supra-littoral zone are related to entanglement, entrapment or obstruction of faunal species (Aguilera et al., 2018; Lavers et al., 2020). Studies have also revealed that plastic litter in the sand column can alter the thermal and hydrological properties of the substrate (Carson et al., 2011). Given that the beaches of northern Cyprus are important nesting locations (Casale et al., 2018) for both loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles, the amount of beach litter present at some of the most important beaches may be impacting the nest environment, plus preventing the hatchlings access to the sea (Aguilera et al., 2018). Changes to the nest environment have two main issues over and above that of physical obstruction to hatchling emergence. Firstly, alterations to the thermal range could alter the sex ratio of the hatchlings produced on those beaches (Fuller et al., 2013). Secondly, changes in the hydrological properties of the sand surrounding the eggs may impact the hatching success of the clutch. To date, there are no published studies related to the effect of litter on beach flora. However, it is clear that beaches with extensive levels of litter will restrict plant growth when the litter is stationary and when it is moved by winds, this, in turn, has the potential to affect the general beach biodiversity and habitat structure.

4.5.3. Entanglement and ingestion

Macroplastic ingestion and entanglement by marine vertebrates has received world-wide attention affecting almost all marine vertebrate taxa (Battisti et al., 2019; Bernardini et al., 2018; Duncan et al., 2019; Laist, 1997; Parton et al., 2019; Wilcox et al., 2018). Entanglement and ingestion events can result in permanent physical damage or death. The ingestion of micro- and nanoplastics is reported in an even wider spectrum of taxa, including many marine invertebrates (Courtene-Jones et al., 2019; Ribeiro et al., 2018). The physical and physiological effects and retention times of micro or nano plastics and their associated contaminants on different organisms is little understood. However, it is possible that they will both bio-accumulate and bio-magnify under different food web scenarios, with currently unknown consequences.

5. Conclusion

This research has the potential to inform marine litter policy across the Mediterranean region, highlighting the downstream impacts which result from poor waste management, both locally and regionally. Now that a baseline has been established, continued ongoing efforts hold the potential to highlight the relative changes in abundance and proportions of key litter categories. This will help link items with sources and origins (i.e. locally deposited or transnational), which will help in assessing the impact of nascent mitigation and control strategies throughout the region. Additionally, any continued monitoring should integrate the enumeration of micro (<5 mm) and meso-plastic (5–25 mm) categories, which due to fragmentation, (Andrady, 2011) will help to provide a more complete picture as to the pervasiveness of the various categories within the marine realm and a thorough assessment of their likely ecological impacts.

CRediT authorship contribution statement

Ozge Ozden - Conceptualization; Funding acquisition; Methodology; Project administration; Data collection, Supervision and writing of drafts.
Wayne Fuller - Data collection, Data curation and analysis; Writing - original draft, review & editing.
Sinem Yildirim - Data collection and recording.
Brendan Godley - Conceptualization, Methodology, Writing and reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.112167.

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