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First Full Investigation of Levels of Microplastics on Sandy Beaches in Malta

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Abstract

This paper will report on the first full investigations on the level of occurrence and qualitative/quantitative profiles of microplastics, MP, (1-5mm) in a number of sandy beaches in Malta, (Central Mediterranean). Five popular beaches were investigated, including Għadira Bay, Golden Bay, St. George's Bay, Għajn Tuffieħa Bay and Pretty Bay. Samples for all bays were collected in August 2015, while further detailed sampling was carried out for the last two bays in summer and in winter of 2016. Sampling protocol was adopted from Galgani et al., (2013). For all locations, samples were collected from strandline and then at 10m up shore at surface (top 5cm). For Għajn

Tuffieha and Pretty Bay, samples were also collected from a 40cm depth. MP were extracted from sand through wet sieving, and then sorted and characterized according to size, colour, shape, and polymer type. Several parameters including degree of sea exposure and sand properties were recorded. Full beach profiles for all locations are available. Identification of polymer type was carried out by means of qualitative density tests.

In summer of 2015, the highest levels of MP were reported in Pretty Bay at 10.81 items/1000cm^3 of wet sand with the lowest being in Għajn Tuffieħa, at 0.72 items/1000 cm^3. In general, levels of MP in the dry season were found to be higher than those recorded in the wet season (winter). Higher MP concentration was recorded at 10 m up-shore as opposed to the strandline. Furthermore, surface sands contained a higher concentration of MP when compared with the subsurface sediments, though this was not was not the case at Pretty Bay in winter. These results are interpreted in terms of different beach profiles, beach dynamics, sand properties and potential sources of MP.

The local level of occurrence of MP seems to be lower when compared to other European locations studied so far. The fact that in this study, MP below 1mm were not included in the data, as well as the lack of rivers in the Maltese islands, regular beach clean ups and other factors may explain this. Data on the characterisation of MP found are provided. For example, polyethylene and polypropylene were the most common polymers recorded at Għajn Tuffieħa Bay whereas polyethylene and paint fragments were the most common MP recorded at Pretty Bay. This investigation is a contribution to our knowledge of how levels of MP in sandy beaches may be affected by sand properties and dynamics, beach profiles and other factors.

Introduction

One aspect of marine pollution by litter, which is increasingly receiving research as well as media attention, is that of microplastics (MP). These MP result either from fragmentation and weathering of larger plastic litter items (secondary MP), or from pre-production plastic pellets, industrial abrasives and consumer products (primary MP). MP are generally defined as plastic particles which are smaller than 5 mm (Arthur, 2009; Galgani et al., 2013), For the purpose of the present report, the MP monitored were in the size range of 1 to 5 mm. These MP have been reported to occur in ubiquitously in marine habitats, including surface waters and the water column, biota, marine sediments, and sandy shores (Pedrotti et al., 2014; Sobral et al., 2014). Furthermore, they are known to be bioavailable to a range of marine organisms, as well as a potential source of marine contaminants which may be adsorbed to their surface. In Malta, MP were first reported to occur in sandy beaches in 2007, (Flores Martin, 2008). Recently, Holmes and Turner (2010) reported on plastic pellets in local beaches.

The present paper will report on the first full investigation on the level of occurrence and qualitative/quantitative profiles of microplastics, MP, (1-5mm) in five sandy beaches in Malta, (Central Mediterranean), undertaken between 2015 and 2016, while adopting a monitoring protocol modified from standardized monitoring guidelines proposed by Galgani et al. (2013). These guidelines have been proposed as standardized monitoring for MP within the Marine Strategy Framework Directive. In fact, one major problem in our knowledge of MP in different environmental phases, is the fact that to date, researches had adopted a wide range of monitoring protocols, which create difficulties when trying to compare data on the levels of such MP in different areas (Sobral et al., 2014; Galgani et al., 2013). Furthermore, most reports on MP in sandy beaches tend to restrict the monitoring to the top surface layers. In the present study, at two particular beaches investigated, MP were monitored at surface and subsurface (40cm depths), and the resultant data were interpreted in terms of sand dynamics on such beaches.

Materials and Methods

In the present study, MP ranging from 1mm to 5mm were monitored for. Sampling protocol was adopted from Galgani et al., (2013) and based on guidelines proposed for the Marine Strategy Framework Directive. A total of five sand beaches were monitored in August 2015. These included Għadira Bay, Għajn Tuffieħa Bay, Golden Bay, St. George's Bay and Pretty Bay (see Fig. 1). For each sandy beach a number (3 to 5) of 10 m long transects at right angles to the shoreline were identified so as to represent the whole beach. These were normally equally spaced between themselves. For each transect, samples were collected from top 5 cm at strandline and then at 10m up shore. For Ghajn Tuffieħa and Pretty Bay, samples were also collected from 40cm depth for monitoring undertaken in 2016. At the latter two sites, apart from August 2015, sampling was carried out in July/August 2016 and then December 2016. Sampling was always carried out at a time of day when there were few or no beach users, and several hours after the last beach cleaning operation has been carried out.

In each case, a given volume of wet sand was collected from surface or from 40cm depth. This wet sand was then wet sieved through two stacked copper sieves, with the narrowest mesh size being 1mm. Seawater was used for wet sieving. The material retained by the 1mm sieve, was then transferred for analysis into a metal funnel containing a medical gauze supported by rubber bands at its mouth, which was used to collect the remaining particles which were larger than 1 mm. The gauze was then removed, closed and put in labelled aluminium foil and placed in a plastic bag. All precautions proposed by Galgani et al., (2013) to prevent contamination from clothing of personnel and from utensils used, were followed. A seawater blank was taken during each sampling session to ensure there were no MP introduced to the sample from the seawater itself. Samples were stored at 4^0C until analysis.

MP were sorted and characterized according to size, colour, shape, and polymer type (Galgani, et al., 2013). When needed, MP were photographed under X50 magnification. An air blank was also periodically carried out by placing a Petri dish with a filter paper which was checked after the sampling session to ensure that no plastic particles or fibres were introduced from the air to the sample. Levels of MP are reported in items/1000cm^3 of wet sand. However conversion factors for items/kg of dry sand are available in order to facilitate comparisons of reported data with other reports in literature. Sand properties were also investigated including granulometry, permeability and porosity using standard procedures.

Full beach profiles for all locations are available, including degree of wave exposure (Thomas Exposure Index, Thomas, 1986), beach slope, beach use, beach cleaning and management, any run-off points and the presence of waste bins and a number of anthropogenic factors.

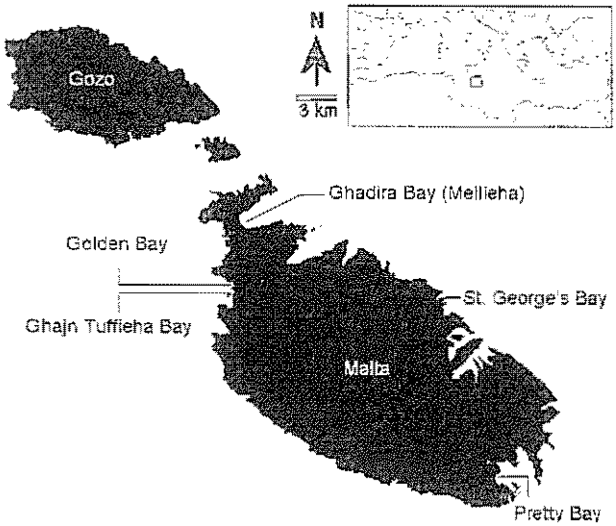

Fig. 1: Location of the five sandy beaches monitored in the present study. Location of the Maltese Islands within the Mediterranean is shown in the top insert.

Attempts to identify plastic types through FT-ATR spectrophotometry did not produce good and reliable results. Therefore, flame tests (copper wire flame test) coupled with density measurements (using buoyancy in fluids including water; 45.5% by volume propan-2-ol, acetone, corn oil) were used to identify the material of MP.

Results and Discussion

Levels of occurrence of MP

The location of the five sandy beaches investigated in the present study are shown in Fig. 1. These sandy beaches are of the pocket type formed between headlands and are relatively small, ranging from approximately 110 to 470m in length, with a width varing from 75 to 10 m. In Malta, sand beaches only represent 2.4% of coastline. Additionally, the level of anthropogenic activities in these areas is very high during summer. Nonetheless, these beaches are exposed to varying grades of anthropogenic disturbance. Għadira Bay, St. George's Bay and Pretty bay are situated next to a major road, whilst Golden Bay and Għajn Tuffieħa Bay are more remote from intense urban development. Golden Bay, Għadira Bay, Pretty Bay, and St. George's Bay are surrounded by numerous commercial outlets (e.g. hotels, restaurants), recreational activities (e.g. water sports), amongst others. However, Għajn Tuffieħa Bay seems less affected by anthropogenic activities, although there is still one food outlet positioned at the right side of the beach. St. George's Bay is a reclaimed sandy beach with sand being made of artificial crushed granite imported from Jordan (ADI, 2014).

Periodic beach cleaning is undertaken during the summer months (May until October). Beach clean ups include: manual cleaning by employees (daily), as well as use of garbage trucks, and mechanical cleaning by using sifting machines to remove natural and artificial debris from the surface up to 15cm deep in the sediment (weekly, or monthly). As already indicated, during the present study, sampling was always carried at least 24-6 hours after any beach cleaning operation. From January to April, removal of natural debris (i.e. seagrass) deposited on the beaches is carried out, except at St. George's Bay where it occurs all throughout the year.

The levels of occurrence of MP (1-5 mm) in items/1000 cm^3 of wet sand, in the various localities, at the various dates of monitoring, are presented in Tables 1 and 2. Furthermore, in order to assist in the comparison of our results with those of other authors, an investigation was carried out to estimate conversion factors from 1000 cm^3 of wet sand to kg of dry sand, for Għajn Tuffieħa and for Pretty Bay. These were estimated to be 1.491 for Għajn Tuffiegha Bay (±0.115 SD at 95% confidence intervals, replicates = 36) and 1.013 for Pretty Bay (±0.163 SD at 95% confidence intervals, replicates = 36). Table 1 also shows wave exposure indices, beach slope, as well as granulometric and other sand parameters. Such information is also available for the monitoring undertaken in 2016, but conld not be presented due to lack of space.

Table 1: Levels of Microplastics (MP: 1-5mm) as found in the five sandy beaches in August 2015 and as expressed in items/1000 cm^3 Also shown are wave exposure indices, beach slope, granulometric and other sand parameters. (For further details, see key at end of table).

	A strandline	At 10m upshore
Għadira Bay (Mellieħa)	Mean /median ,±SD, (max-min), replicates[1]	Mean /median[1] ,±SD, (max-min), replicates
MP/1000cm^3 of wet sediment[2]	**1.56** ± 0.51,(2.2-0 .8), 5	**4.03** ± 0.43, (4.7-3.7),5
Thomas Exposure Index[3]	4.13 ± 0.98 (4.9-2.5),5	
Median Slope[4]	7.6 (10.2-4), 5	1.9 (3.7-0.2),5
Median size of sand grains, (Φ)[5]	(0.212 - 0.5), 5	(0.212 - 0.5), 5
Sediment description[6]	Medium, 5	Medium, 5
Sorting Coefficient[7]	< 0.5, 5	< 0.5, 5
Sorting Description[8]	Good, 5	Good, 5
Sand Porosity (%)[9]	37.4, 1	42.5, 1
Permeability (outflow cm^3/s)[10]	1.4. 1	1.3, 1
Golden Bay		
MP/1000cm^3 of wet sediment	**3.94** ± 2.75 (8.1-1.3), 5	**3.05** ±0.83 (4.16-2.22),5
Thomas Exposure Index	6.26 ±0.17 (6.4-5.97), 5	
Median Slope	10.8 (18.4-7.7),5	1.9 (6.8-0.3), 5
Median size of sand grains, (Φ)	(0.212 - 0.5), 5	(0.212 - 0.5), 5
Sediment description	Medium, 5	Medium, 5
Sorting Coefficient	< 0.5, 5	< 0.5, 5
Sorting Description	Good, 5	Good, 5
Sand Porosity (%)	25.0 , 1	39.0, 1
Permeability (outflow cm^3/s)	2.4, 1	3.7, 1

Ghajn Tuffieha Bay

MP/1000cm³ of wet sediment	**0.72** ±0.42 (1.4-0.33), 5	**4.93** ± 2.32 (7.2-1.8),5
Thomas Exposure Index	5.88 ± 1.90 (7.8-3.3), 5	
Median Slope	4.3, (11.8-2.5), 5	2.5, (4.1-0.6),5
Median size of sand grains, (Φ)	(0.212 - 0.5), 5	(0.212 - 0.5), 5
Sediment description	Medium, 5	Medium, 5
Sorting Coefficient	< 0.5, 5	< 0.5, 5
Sorting Description	Good, 5	Good, 5
Sand Porosity (%)	45.2, 1	40.0, 1
Permeability (outflow cm³/s)	2.5, 1	2.5, 1

St George's Bay	**At strandline** Mean /median ,±SD, (max-min), replicates	**10m upshore** Mean /median ,±SD, (max-min), replicates
MP/1000cm³ of wet sediment	**7.00** ±8.19 (16-0), 3	**3.00** ± 2.65 (6-1), 3
Thomas Exposure Index	1.26 ±0.98 (1.8-0.1), 3	
Median Slope	19.5 (21-8-16.6), 3	2.8, 3
Median size of sand grains, (Φ)	(1.7 - 4.0) ,3	(1.7 - 4.0), 3
Sediment description	Granule, 3	Granule, 3
Sorting Coefficient	< 0.5, 3	0.7, 3
Sorting Description	Good, 3	Moderate, 3
Sand Porosity (%)	38.8, 1	34.0, 1
Permeability (outflow cm³/s)	11.2, 1	5.6, 1

Pretty Bay

MP/1000cm³ of wet sediment	**10.81**±4.4(16.7-5.65), 5	**3.84** ±1.18 (4.98-2.51), 5
Thomas Exposure Index	4.19 ±1.30(5.8-2.8), 5	
Median Slope	9.6, (10.5-8.1), 5	2, (2.8-0.3) , 5
Median size of sand grains, (Φ)	(0.212 - 0.5), 5	(0.212 - 0.5), 5
Sediment description	Medium, 5	Medium, 5
Sorting Coefficient	< 0.5, 5	< 0.5, 5
Sorting Description	Good, 5	Good, 5
Sand Porosity (%)	50.0, 1	47.5, 1
Permeability (outflow cm³/s)	2.0, 1	2.0, 1

Key to Table 1:
[1] Mean or median value as indicated in parameter description, followed by standard deviation and range from maximum to minimum value in brackets, and number of replicates, the latter being underlined;
[2] MP= Microplastics of 5-1mm in size;
[3] Thomas Wave Exposure Index (Thomas, 1986);
[4] Median Slope = Median value of slope angles in degrees at sampling point;
[5] Granulometry: Median sand grain size classified according to the Udden-Wentworth Scale (University of New England, 2005),
[6] Sand description;
[7] Sorting coefficient;
[8] Sorting description;

[9] Sand porosity expressed as %, i.e. volume of water that could be stored within air spaces found between the sand granules (Baron et al, 2012);
[10] Sand permeability, i.e. the ability of a fluid to pass through sand particles (Granlund, 1999).

Table 2: Levels of Microplastics (MP: 1-5mm) in items/1000cm^3 of sand ([A] See footnote to this table), as found in two sandy beaches, Għajn Tuffieħa and Pretty Bay at surface and at 40cm depth, in August and December 2016.

	At strandline	10m upshore
Location, date of sampling, sand depth of sampling	Mean,±SD, (max-min), replicates	Mean,±SD, (max-min), replicates
Għajn Tuffieħa, Aug 2016, 0 cm	**0.43**±0.3 0 (0.83-0),5	**4.47**±4.40(9.33-0.67),5
Għajn Tuffieħa,Aug 2016,40 cm	0, 5	**1.37**±1.31(3.17-0.17),5
Għajn Tuffieħa, Dec 2016 ,0 cm	0.30±0.67(1.5-0),5	**2.07**±3.55(8.33-0),5
Għajn Tuffieħa, Dec 2016,40 cm	**0.27**±0.38(0,83-0),5	0.90±1.20(3-0),5
Pretty Bay, Aug 2016, 0 cm	0.44±0.51(1-0),3	**2.61**±0.26(2.83-2.33),3
Pretty Bay, Aug 2016 , 40 cm	**0.83**±0.60(1.33-.17),3	**2.11**±1.34(3.33-0.67),3
Pretty Bay, Dec 2016 , 0 cm	**0.33**±0 (0.33-0.33),3	0.89±1.02(2-0),3
Pretty Bay, Dec 2016, 40 cm	0.89±0.77(1.33-0),3	**1.33**±1.20(2.33-0),3

[A] In order to assist in the comparison of our results with those of other authors, estimation of conversion factors from 1000 cm^3 of wet sand to kg of dry sand, for Għajn Tuffieħa and Pretty Bay has been carried out. These conversion factors were estimated to be 1.491 for Għajn Tuffiegħa Bay and 1.013 for Pretty Bay. For further details, see text.

From the monitoring surveys undertaken in 2015, it follows that there are statistically significant differences in the levels of occurrences of MP in the different localities (ANOVA, p-value = 0.029), with Pretty Bay and St. George's Bay showing the highest levels. However, levels in Pretty Bay as monitored in 2016, were much lower. This suggests that levels of MP in a locality may vary significantly from year to year probably due to varying sand dynamics. For example, Pretty Bay is within a major harbour and often exposed to significant dredging operations. The latter observation is confirmed by the fact that substantially different sand properties and granulometric parameters were recorded for sands collected in this same area, in 2015 and 2016. On the other hand, levels of occurrences of MP at Għajn Tuffieħa (which is relatively isolated from anthropogenic pressures) have been found to be consistently low at strandline over the two-year period, though levels at 10m upshore and at surface as monitored in summer were comparable to other localities.

Levels of occurrences of MP within the same beach, often changed significantly both between different transects, at strandline and upshore (at upshore, being generally higher than at strandline), as well as with different depths of sand (as monitored in 2016). Higher MP levels recorded at 10 m up-shore as opposed to the strandline, may due to the continuous disturbance via wave action preventing accumulation of MP at strandline. Samples taken from a depth of 40 cm confirmed the presence of MP below the sand surface. MP concentration seemed to be lower at the subsurface at Ghajn Tuffieha Bay during both seasons however, at Pretty Bay subsurface concentration was higher during the wet season. Aeolian transport and the surrounding environment of Pretty Bay and Ghajn Tuffieha (the two localities where subsurface sand was also monitored) might be a reason for such results.

The levels of occurrence of MP at the two localities monitored both in summer and then in winter, indicated seasonal changes, such that levels were higher in summer than in winter (though this difference was not found to be statistically significant). This may be related to intense beach use during the summer months. The amount of MP however, might be more directly linked to the dynamics of sandy beaches. Since waves play an important role in littoral transport, it can cause MP to be deposited and re-deposited in a similar manner to the movement of sediments (Veerasingam, *et al.*, 2016). Furthermore, high-steep waves cause a process by which material is moved offshore with the backwash (destructive waves) whereas low waves having a low steepness, transfer material onshore with the swash (constructive waves). In a study by Sammut *et al.* in 2017 it was shown that high energy waves were recorded during winter. Storm waves have been shown to have an association with the onshore and offshore process. Sediments might be transported to the backshore by storms (Sammut *et al.*, 2017).

In fact, in the present study, a negative correlation was found between the levels of occurrence of MP and the degree of sea exposure (Thomas Exposure Index). The correlation coefficient was estimated to be -0.455, though this was not statistically significant due to the high level of dispersion of data of MP.

Lomax (2017) reviewed these results comparing them with other published data, The author concluded that the locally reported levels were generally less than those reported elsewhere. This was probably due to the fact that other studies included MP less than 1mm in size. Furthermore, the absence of fluvial inputs in Malta, may also partly explain this. Such inputs can be significant sources of plastic litter including MP in some countries such as Italy (Guerranti *et al.*, 2017) and Slovenia (Laglbauer *et al.*, 2014).

Few correlations could be found which are statistically significant between the levels of occurences of MP as reported in this study and the various sand properties monitored. Nonetheless, MP tended to be higher with an elevated slope. More MPs tend to occur with higher sand porosity, but less so with sand permeability.

Characterization of MP found

As already noted, four categories were used for the characterisation of MP items including: colour, size, shape and type. Evidently this produced a huge amount of numerical data which cannot be fully represented here.

As regards sizes of MP monitored, most items were within the range of 1-2mm, making up 50% of the MP recorded in 2015. This suggests that stranded MP tend to fragment into smaller pieces. Nonetheless, both at Pretty Bay and at Ghajn Tuffieha, in 2016, other size ranges were significantly present, though at 40cm depth, smaller fragments of MP tend to be more abundant. No significant seasonal changes in such occurrences were evident.

Many items of MP recorded were often classified as fragments, which form a secondary type of MP resulting from fragmentation and plastic product degradation. For example, at Pretty Bay fragments were the most predominant type during both seasons (61.43 % for summer and 90.32 % for winter). This observation is similar to what was found at Ghajn Tuffieha Bay since there was also an increase in the fragment type during winter. Fragments were also located both at the strandline and 10 m up-shore Moreover, it seems that fragments tend to accumulate at the subsurface during both seasons and at both the strandline and 10 m up-shore.

Nonetheless, primary MP in the form of pellets were also quite abundant especially in Ghajn Tuffieha Bay during summer 2016, where they reached a relative abundance of 69 % of items found. Furthermore, pellets (unlike fragments) were mostly concentrated at 10 m up-shore in both seasons with the highest concentration being found at the surface layer. It is likely that these plastic pellets are not released from local land-based sources, but rather from sea-based sources or at least from abroad. In fact, the abundance of such pellets at Ghajn Tuffieha, which is relatively free from anthropogenic pressures, and remote from industrial activities, confirm this.

In general, during monitoring surveys undertaken in 2015, the main observed MP in all sites were of low density polyethylene (LDPE-29 %) and high density polyethylene (HDPE-21%), followed by polystyrene (PS-20%). The polystyrene MP found are foamed plastic which is referred to as expanded polystyrene (EPS). This high occurrence of polyethylene is similar to that recorded by other studies focusing on the identification of MP. However, polypropylene (PP) was mentioned (Gutow et al., 2012) as another commonly occurring type of MP, which was not enlisted as one of the MP types identified in this study. This is considered as a limitation of the present study, since the identification method used does not provide a high level of accuracy. Ideally, infrared spectroscopy should be used to identify the chemical nature of these MP.

In the surveys undertaken in 2016, for Pretty Bay and Ghajn Tuffieha, HDPE was the most common plastic material observed at both bays and during both seasons (with % relative frequencies exceeding 40%). At Ghajn Tuffieha Bay, this was followed by polypropylene and LDPE which were associated with pellets. On the other hand, at Pretty Bay, paint fragments was the second most frequent material observed. Such fragments may be released from ship hulls during ship maintenance occuring at Marsaxlokk Harbour, where this bay is located. Furthermore, the occurrence of paint increased from summer to winter. In addition, at Pretty Bay, clothing accounted for 19 % of materials collected whereas it was not recorded during the winter. This might be due to the higher number of beachgoers during the summer period.

As regards the colours of MP recorded, blue, white, cream and opaque are the four colours which were mostly observed within the sites sampled (each being recorded in excess of 15% of the total items).

All sea water and air blanks never showed any evidence of MP.

Conclusions

The present study is the first attempt in monitoring MP (1-5mm), in five local sandy beaches in an extensive manner, using standardized MSFD protocols, in Malta. Furthermore, two local beaches were monitored for MP in different seasons and at surface as well as subsurface (-40cm) levels. Most other studies rarely extend over more than one season, and normally focus only on MP at surface.

Land-based anthropogenic factors are most likely to be the major contributors to the occurrence of MP on local sandy beaches. These include: frequency of use of the beach, commercial and industrial activity in the area and sources of waste run off. This is confirmed by the fact that the two bays, which are located in the midst of intense urban activities, had the highest levels of MPs. Most of such MP were of a secondary type resulting from fragmentation of primary plastic products (being mostly composed on polyethylene) and paint fragments. On the other hand, levels of MP in 'urbanized' beaches much depend on operations both on the beach itself (including beach cleaning) as well as out at sea such as dredging activities in port areas. This was well illustrated in Pretty Bay, located within Marsaxlokk Harbour, where sediment properties as well as levels of MP were found to change substantially both seasonally, and annually.

On the other hand, bays which are more remote from urban activities, may often include primary MP such as production pellets, which within the local context are evidently derived from sea-based sources or from transport from other neighbouring countries. At the same time, the more a beach is exposed to open sea conditions the less it usually tends to have secondary MP resulting from fragmentation.

On the two beaches which were monitored at two different seasons, levels of MP tend to decrease from summer to winter probably due to lower levels of anthropogenic factors but also because of erosion and accretion periods as part of the equilibrium coastal profile as well as storms.

MP levels were often higher at 10 m up-shore when compared to the strandline especially in some bays. Samples taken from a depth of 40 cm confirmed the presence of MP below the sand surface. MP concentration seemed to be lower at the subsurface at Għajn Tuffieħa Bay during both seasons however, at Pretty Bay subsurface concentration was higher during the wet season. Aeolian transport and the surrounding environment of both bays may explain such results.

MP levels recorded in the present two year study tend to be lower when compared with other countries. This might be due to a lack of fluvial inputs in the Maltese islands, and to organised and regular beach clean ups. The general profile of the MP found locally (size, colour, shape and type) is similar to that reported elsewhere.

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