Selective accumulation of plastic debris at the breaking wave area of coastal waters

Ngai Hei Ernest Ho[a] and Christelle Not [a,b]*

[a] Department of Earth Sciences, University of Hong Kong, Pokfulam, Hong Kong

[b] Swire Institute of Marine Science, University of Hong Kong, Cape d'Aguilar Road, Shek O, Hong Kong

*Corresponding author. Email address: cnot@hku.hk

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Abstract

Over the last decades, plastic debris has been identified and quantified in the marine environment. Coastal and riverine input have been recognized as sources of plastic debris, whereas oceanic gyres and sediments are understood to be sinks. However, we have a limited understanding of the fate of plastic debris in the nearshore environment. To investigate the movement and distribution of plastic debris in the nearshore environment, we collected samples at three distinct locations: below the high tide line, the turbulent zone created by the combination of breaking wave and backflush (defined as the boundary), and the outer nearshore. We estimated the abundance and physical characteristics (e.g. density, hardness, etc.) of macroplastic and microplastics. Four times and 15 times more macroplastics and microplastics are observed, respectively, at the boundary than in the outer nearshore waters, which suggests an accumulation driven by the physical properties of the plastic particles such as density, buoyancy and surface area. We further report that highly energetic conditions characteristic of the boundary area promote the long-term suspension and/or degradation of low density, highly buoyant or large surface area plastic debris, leading to their preferential accumulation at the boundary. Contrastingly, denser and low surface area plastic pieces were transported to the outer nearshore. These results emphasize the role of selective plastic movement at the nearshore driven by physical properties, but also by the combined effects of several hydrodynamics forces like wave action, wind or tide in the resuspension, as well as degradation and transport of plastic debris out of the nearshore environment.

Capsule

A higher abundance of plastic litter has been found in the breaking wave area of nearshore marine environments. This is attributed to wave dynamics responsible for selective transport of plastic litter based on their physical characteristics.

Introduction

Since the mid 1950s, plastic has been a cheap and convenient material used for a variety of societal purposes. The widespread adoption of plastic technology is largely due to its stability, malleability and durability, which is achieved by adjusting the type and quantity of additives incorporated into the resin. However, this convenience results in high material heterogeneity, which limits the degradability and lowers the recyclability of plastic compared to other materials such as paper, metal, and glass (Beaman and Bergeron, 2016). This combination of high stability, low recyclability and inadequate waste management leads to a plastic leak into the environment. Globally, between 2 to 5 % of the plastic producted is estimated to be discarded into the ocean (Jambeck et al., 2015). The accumulation of plastic debris in the aquatic environment has received wide attention owing to the increase awareness of their abundance and potential ecological impacts (Barnes et al., 2009; Koelmans et al., 2017; Lebreton et al., 2018; So et al., 2018; van Sebille et al., 2015; Wright et al., 2013). Ingestion of macroplastics (plastic pieces > 5 mm; Cole et al., 2011) can result in a variety of new stressors on aquatic organisms and water-feeding birds, including a reduction in the organism’s energy budget (Spear et al., 1995) and toxicity-induced reproductive impairment (Gregory, 2009). Furthermore, microplastics (plastic pieces <5 mm; Cole et al., 2011), produced by either the physical breakdown of macroplastics or specifically manufactured small pellets or microbeads, are suspected to cause additional biological impacts such as false-satiation amid excessive ingestion (Wright et al., 2013) and internal abrasion (Eriksson and Burton, 2003).

In recent years, a wealth of studies has described the abundance and spatial distribution of plastic debris using both land surface-sampling techniques (mostly on beaches) (Cheung et al., 2016; Fok et al., 2017; Ivar do Sul et al., 2013; Lee et al., 2015; Widmer and Hennemann, 2010; Zhao et al., 2018), and vessel-based surface trawling approaches (Aytan et al., 2016; Eriksen et al., 2013a; Lechner et al., 2014; So et al., 2018; Tsang et al., 2017). In offshore waters, the majority of studies only quantified microplastics, as there is limited data on macroplastics available. Further, the variable mesh size used in different studies limits an unequivocal comparison of the quantity of plastic pieces. Regardless, Asia consistently appears to be a hotspot of plastic pollution with microplastic content an order of magnitude higher than other regions (Cheung et al., 2016; Fok et al., 2017; Heo et al., 2013; Kang et al., 2015; Lee et al., 2015; Zhao et al., 2015). Lebreton et al. (2018) estimated that 67% of the plastic entering the ocean originates from Asian rivers, with over 74% of the total plastic release occurring between May and October (wet season). Such seasonal variability is also observed in the abundance of plastic debris in Hong Kong's coastal waters (Fok and Cheung, 2015). Once plastic debris reached the coastal area, they might be retained there for years up to decades (e.g.Lebreton et al., 2012).

In the nearshore environment, plastic debris are affected by beaching, sinking, degradation, fragmentation prior to transportation to the open ocean, but these processes remain poorly understood (Zhang, 2017). Beach sediments have been shown to accumulate plastic debris (Critchell and Lambrechts, 2016; Liebezeit and Dubaish, 2012; Mathalon and Hill, 2014) and the hydrodynamic conditions, the depositional features (shoreline, coast geomorphology) and physical characteristics of plastic debris are known to affect the transport/deposition of plastic debris within the nearshore area (Zhang, 2017). However, few studies have investigated these different factors and their impact on the abundance and distribution of plastic debris limiting our understanding of their transport and fate. Thus, in order to gain a better understanding of the effect of shoreline hydrodynamics and their impact on the abundance of debris in the nearshore area, we quantified and characterized macroplastic and microplastic debris on the beach and in the nearshore waters (boundary and outer nearshore). Investigating the abundance and physical composition of both macroplastic and microplastic debris in the nearshore area will help elucidate the role of turbulent conditions in plastic transport and degradation. Further, our work can help to identify specific locations within the nearshore region for targeted plastic removal efforts.

2. Material and Methods

2.1. Description of the study site

Hong Kong is a city located to the east of the Pearl River Estuary (Figure 1a), with its western part significantly affected by Pearl River water during the summer (Harrison et al., 2008). Our study was conducted at Lung Kwu Tan (LKT), a fine-sand beach located at the north-western coast of Hong Kong. It is located 7 km distant from the nearest town, which has minimal recreational activities. LKT is a reflective beach, characterized as having a steep narrow beach face, coarse sand and a narrow surf zone, which is exposed to persistent ocean swells and waves. During high tide (>0.7 m), waves break close to the shore, resulting in significant uprush followed by backflush (Figure 1b). Here, we define the nearshore area as the region between the strandline and the seaward limit of the littoral zone (Figure 1b; Mangor et al., 2017). We further define the “boundary zone” as the turbulence zone formed from the combination of the backflush of a breaking wave reaching the swash zone and the next breaking wave. The boundary separates the outer nearshore and the inner nearshore. The outer nearshore area is the zone extending seaward from the boundary, where waves can be disrupted by the seafloor contact (Figure 1b; Mangor et al., 2017). The inner nearshore, the zone between the boundary and the strandline, is subdivided into the swash zone, where the backflush is formed, and the surf zone, where hydraulic jump that receives the backflush (Figure 1b). Since the direction of water movement in the hydraulic jump is the same as the orbital motion of the wave, the jump acts to reinforce the breaking wave, giving the zone very high turbulence. Because tides and wind will affect wave dynamics and therefore the location of the boundary zone over the time, we adjusted the sampling location to follow the turbulent area defining the boundary zone.

2.2. Sample collection

All samples were collected under high tide scenario on seven days between the period of July to October 2016 (July 15, 20, 25; August 1, 5, 11; and October 20). From a fixed point located above the high tide line (22º23’27”, 113º55’07”), three locations were sampled towards the sea: 1) the exposed beach below the high tide line, 2) the boundary (see section 2.1) and 3) the outer nearshore water (between 3 to 6 meters after the boundary; Figure 1b). At the boundary and outer nearshore, water samples were collected by sieving 75L of water using a >0.3 mm sieve. All debris remaining on the sieve were transferred into a glass bottle and then transported to the laboratory for further analyses. Beach samples were only collected on August 5th (n=1), August 11th (n=1) and on October 20th (n=3). The sand within a 0.0929 m^2 (1-ft^2) square to a depth of 2 cm was collected for further processing in the laboratory.

2.3. Sample preparation

Sample preparation for beach and water samples followed a method modified from NOAA’s guidelines for marine microplastics analysis (Masura et al., 2015). For beach samples, all sand was separated from floating solids by using a 3.5% table salt density separation, followed by wet sieving to separate all floating solids between > 5 mm, 1-5 mm and 0.3-1 mm size fractions. All solids on the 5-mm sieve were separated into categories based on physical properties, weighted and quantified. Microdebris was first treated with wet peroxide digestion, followed by air drying before classification, weighting and quantification. Water samples were stored in glass bottles and wet sieved at 5 mm, 1 mm and 0.3 mm. Macrodebris was air-dried on the 5-mm sieve and classified into physical categories before counting and weighing. Microdebris present on the 1-5 mm fraction was visually sorted to remove organic material, then both fractions (1-5 mm and 0.3-1 mm) were subjected to density separation using 3.5% salt solution, followed by a wet peroxide oxidation. Samples were oven dried, preceding analyses. The quantity of plastic debris in the water sample is expressed in g/m^3 and $pieces/m^3$, while the units for beach are reported as g and pieces per m^2.

2.4. Plastic classification and identification

Plastic debris was separated using a classification based solely on their physical properties of the plastics pieces (Table 1): size (>5 mm, 1-5 mm, and 0.3-1 mm), density (<0.7 g/mL for expanded polymers and >0.9 g/mL for non-expanded polymers), hardness, structure, dimensions and aspect ratio (the ratio between the longest length and the perpendicular width). This was done because physical characteristics control the buoyancy in water and therefore the fate of plastic debris (Filella, 2015; Ryan, 2015; Zhang, 2017). A mixture of methanol and water was prepared to obtain a solution with a density of 0.8 g/mL, which was used to distinguish debris with expanded polymers from non-expanded floating plastic. The total mass and total abundance of plastic pieces in each category for each sample was quantified. In addition, the size fraction ratio (>5mm: 1-5mm: 0.3-1mm) and the mean individual mass (total mass divided by the total abundance) of each category was estimated. The plastic composition is expressed in percentage, both by mass and abundance. Significant differences in debris composition between beach and outer nearshore environments, and between the boundary and outer nearshore environments, were identified separately using an independent-sample Wilcoxon Test. All statistics were performed using R 3.2.4.

3. Results

In total, we collected 1658 pieces of plastic debris from beach samples, with 4.8% corresponding to macroplastics and 95.2% to microplastics. From the 70 water samples, we identified 16042 plastic pieces with 3.33% corresponding to macroplastics and 96.7% to microplastics.

3.1. Debris in the outer nearshore

All samples from the outer nearshore contained plastic debris, and the frequency of occurrence of macroplastics and microplastics was 83.3% and 97.4% respectively. For microplastics, the frequency of occurrence in 1-5 mm and 0.3-1 mm fraction was 87.8% and 97.4% respectively. The average size fraction ratios (>5 mm: 1-5 mm: 0.3-1 mm) by mass and by abundance were 1: 0.013: 0.001 and 1: 2.10: 4.76.

The mass for macroplastics (> 5 mm) ranged between 0 and 0.59 g/m^3 with an average mass of 0.06 ± 0.11 g/m^3 and a abundance ranging between 0 and 0.87 pieces/m^3 with an average of 0.14 ± 0.20 pieces/m^3 (Figure 2a). In terms of mass, macroplastic debris was dominated by film (32.0%), followed by hard others (24.6%), soft others (17.6%), plates (10.9%), and soft straps (5.9%; Figure 3). In terms of abundance, film dominated the macroplastic fractions (33.2%), followed by expanded polymer (19.1%), soft straps (12.6%), plates (11.4%), and hard others (8.6%). The mean individual mass of macroplastic pieces was 0.40 g, which is similar to the mean individual mass for film, strings, and plates.

For microplastics, mass of the 1-5 mm fraction ranged between 0.000 and 0.591 g/m^3 with an average of 0.001 ± 0.122 g/m^3 and abundance ranged between 0 and 1.72 pieces/m^3 with an average of 0.29 ± 0.43 pieces/m^3 (Figure 2b). The dominant categories by mass were pseudopellets (34.5%), followed by films/plates (19.5%), others (10.4%), pellets (8.4%), and expanded polymers (7.9%). In terms of abundance, pseudopellets were dominant (29.6%), followed by films/plates (25.1%), expanded polymers (21.5%; Figure 3).

For the 0.3-1 mm size fraction, mass ranged between 0 and 0.0004 g/m^3 with an average of 0.0001 ± 0.0001 g/m^3 and abundance ranged between 0 and 2.43 pieces/m^3 with an average of 0.66 ± 0.67 pieces/m^3 (Figure 2c). In terms of mass, others dominated the fraction (66.6%), followed by long fragments (24.3%), fibres (10.6%) and expanded polymers (3.2%). In terms of abundance, others still dominated the fraction (80.0%), followed by expanded polymers (9.1%), long fragments (9.0%), and fibres (2.9%; Figure 3).

3.2. Debris at the boundary

The frequency of plastic occurrence at the boundary was around 95.7%. Plastic abundance was higher at the boundary than the outer nearshore for every sampling day, except for the August 1st and August 11th, in both >5 mm and 0.3-1 mm fractions. Interestingly, the two days with lower abundance at the boundary are characterized by different wind and precipitation conditions relative to the other sampling days. The average size fraction ratio (>5 mm: 1-5 mm: 0.3-1 mm) by mass and by abundance were 1: 0.072: 0.005 and 1: 8.5: 16.5 respectively.

The mass of macroplastics ranged between 0.0001 and 3.07 g/m^3 with an average of 0.25 ± 0.62 g/m^3 and the abundance ranged between 0 and 82 pieces/m^3 with an average of 5.3 ± 17.2

pieces/m^3 (Figure 2a). In terms of mass, macroplastics were dominated by hard others (34.9%) and plates (22.0%), followed by soft others (17.5%), films (9.9%), and expanded polymers (7.4%; Figure 3). In terms of abundance, expanded polymers dominated the macroplastic fraction (30.2%), followed by plates (19.9%), films (17.9%), hard others (14.7%), and soft straps (5.1%).

For microplastics, the mass of 1-5 mm fraction ranged between 0.0001 and 3.445 g/m^3 with an average of 0.018 ± 0.751 g/m^3 and the abundance ranged between 0 and 82.5 pieces/m^3 with an average of 5.26 ± 17.22 pieces/m^3 (Figure 2b). The category by mass was dominated by pellets (34.8%) and pseudopellets (31.1%), followed by expanded polymers (15.3%), others (5.0%), and films/plates (3.8%). In terms of abundance, expanded polymers dominated (44.1%), followed by pseudopellets (23.7%), films/plates (9.8%), others (8.7%), and pellets (6.4%; Figure 3).

The mass of the 0.3-1 mm fraction ranged between 0.0000 and 0.0072 g/m^3 with an average of 0.0013 ± 0.0024 g/m^3, while abundance ranged between 0.10 and 0.78 pieces/m^3 with an average of 10.24 ± 21.02 pieces/m^3 (Figure 2c). In terms of mass, others dominated the fraction (54.8%), followed by expanded polymers (18.8%), long fragments (15.6%), and fibres (4.4%). In terms of abundance, others still dominated the fraction (52.7%), followed by expanded polymers (38.6%), long fragments (6.0%), and fibres (2.3%; Figure 3).

3.3. Debris on the beach

The average size fraction ratio (>5 mm: 1-5 mm: 0.3-1 mm) by mass and by abundance were 1: 1.7: 0.019 and 1: 21: 0.00086 respectively. The mass of macroplastics ranged between 0 and 24.20 g/m^2 with an average of 7.87 ± 9.09 g/m^2, and the abundance ranged between 0 and 75 pieces/m^2 with an average of 21 ± 29 pieces/m^2. In terms of mass, expanded polymers dominated the fraction (44.9%), followed by films (28.9%), and plates (12.1%; Figure 3). Soft and hard straps were not found in beach samples. In terms of abundance, expanded polymer dominated the fraction (40.6%), followed by hard others (28.9%), and plates (18.1%). The mean individual mass for macroplastics debris did not change greatly from outer nearshore to the beach, ranging from 0.38 to 0.41 g.

For microplastics, the mass of 1-5 mm fraction ranged between 0.001 and 6.226 g/m^2 with an average of 2.744 ± 3.178 g/m^2, and the abundance ranged between 2 and 1442 pieces/m^2 with an average of 686 ± 723 pieces/m^2. Pellets comprised the majority of samples (34.5%), followed by pseudopellets (31.1%), expanded polymers (15.3%), and long pseudopellets (7.0%). In terms of abundance, expanded polymers dominated (44.1%), followed by pseudopellets (23.7%), films/plates (9.8%), others (8.7%), and pellets (6.4%; Figure 3).

The mass of 0.3-1 mm fraction ranged between 0 and 0.059 g/m^2 with an average of 0.030 ± 0.029 g/m^2 and the abundance ranged between 13 and 624 pieces/m^2 with an average of 377 ± 322 pieces/m^2. In terms of mass, others dominated the fraction (54.8%), followed by expanded polymers (18.8%), and long fragments (15.6%). In terms of abundance, others still dominated the fraction (52.7%), followed by expanded polymers (38.6%), and long fragments (6.0%; Figure 3).

4. Discussion

Results have been presented in weight and abundance for the three size fractions. However, for the clarity of the discussion, only weight is discussed for macroplastics and only abundance is evaluated for microplastics, as macroplastics drive the overall mass of plastic litter whereas microplastics drive the abundance of environmental plastic pieces (e. g. Lebreton et al., 2018).

4.1 Debris on the beach

The abundance of debris found on the LKT beach is within the range of debris found by previous studies in Hong Kong (Cheung et al., 2018; Fok and Cheung, 2015; Tsang et al., 2017). The mass of macroplastics observed in LKT (7.87 ± 9.09 g/m^2) is similar to the estimated mass of all plastic debris by Zhao et al., (2015) in the Pearl River Delta (7 ± 12 g/m^2). For microplastics, Cheung et al., (2016) found a seasonal trend in microplastic abundance, with more microplastic debris(0.315-5 mm) during the wet season (5.6 g/m^2 and 5595 pieces/m^2) compared to the dry season (0.76 g/m^2 and 889 pieces/m^2). From our October data, we observed an intermediate abundance of microplastics ranging from 0.001 to 6.285 g/m^2 with a mean of 2.77 ± 3.21 g/m^2 by mass and from 14 to 1938 pieces/m^2 with a mean of 1063 ± 973 pieces/m^2. Our study together with other Pearl River-based studies shows that the region is a hotspot of marine plastic pollution on beaches. For example, macroplastics in this study are 4.4 (by mass) and 1.5 times (by abundance) higher than the plastics (>2 mm) present in the tide line in the investigation of beaches in Fernando de Noronha, Brazil (Ivar do Sul et al., 2009) and also 3.7 (by mass) and 21 times (by abundance) higher than the supra littoral zone of beaches in Santa Catrina, Southern Brazil (Widmer and Hennemann, 2010).

4.2 Plastic debris quantity in nearshore waters: differences between the outer nearshore and the boundary

Both macroplastic and microplastic abundance at the outer nearshore is within the average of open ocean estimates (Eriksen et al., 2013b; Faure et al., 2015; Lebreton et al., 2018; Zhao et al., 2014). Further, our microplastics abundance data are similar to previous estimates of offshore microplastic estimates (Tsang et al., 2017; 47 pieces/m^3; and Cheung et al., 2018; 0.33 g/m^3 and 3.6 pieces/m^3). However, abundance at the boundary is higher than estimations from the offshore environment. While few estimates of plastic debris abundance in nearshore water are available, Nel & Froneman (2015) provide a rare example in nearshore South African waters. This study showed that microplastic abundance ranged between a minimum of 258 ± 53 pieces/m^3 with a maximum of 1215 ± 277 pieces/m^3 in the surf zone. These values are higher than the range observed in our study at any of the sampled nearshore waters. However, they did not discuss beach dynamics or wave action, which limits the reliability of our comparison.

When comparing outer nearshore and the boundary environments, we observed a higher abundance of plastic debris in the three size fractions at the boundary zone: macroplastics increase by a factor of 4.5 (by mass), microplastics from 1-5 mm increase by 18 times (by abundance) and 16 times for the 0.3-1 mm size (by abundance). It is noteworthy to mention that the significance of the increase in abundance of plastic in the boundary zone compared to the outer nearshore tends to increase with decreasing size fraction. This suggests that the plastic accumulation at the boundary could be even more critical for determining the fate of plastics pieces smaller than 0.3 mm. Our results suggest that the turbulent area located at the boundary accumulates more plastic debris by at least 4 times from all size fractions than the area in the outer nearshore, indicating that this area should be targeted for coastal clean-up efforts. A potential reason for the size-driven accumulation within the turbulent area could be linked to particle dynamics, as high energy environments would facilitate an increased suspension rate of smaller plastic debris in the water column and limit their sinking (Critchell and Lambrechts, 2016). Degradation of plastic debris within this turbulent environment can also be responsible for size-driven accumulation of plastic pieces within the turbulent zone. Waves dynamics can further enhance the breakdown of the bigger pieces leading to an increase number of small plastic pieces at that location. However, Isobe et al., (2014) suggested that most plastic degradation occurs onshore, followed by the transport offshore of the microplastic pieces produced. In order to test this hypothesis, future work should compare the abundance of plastic debris between beach and nearshore waters. However, the different units used to estimate plastic abundances in water and sand samples limits such a comparison. Indication of the preferential breakdown of plastic debris within the turbulent zone can also be estimated using plastic composition of the different size fraction (see section 4.3).

Finally, it is worth noting the temporal variability characteristic of the plastic abundances at the boundary but not at the outer nearshore. The abundance of plastic debris at the boundary is higher in July than in August or October. Unfortunately, the absence of sand samples in July limit our interpretation and highlights the need for additional studies. The temporal difference in the abundance counts within the boundary area leads in the absence of the preferential accumulation of plastic debris within the boundary zone for two sampling days (August 1st and August 11th), which are characterized by different wind and rain conditions. On both days, rain was observed at the sampling site, but wind conditions were different. On August 11th, the wind was weaker than any other sampling days, suggesting that weather conditions might also influence the preferential boundary accumulation. However, we observed no difference in the abundance of plastic debris itself. Considering that the preferential accumulation at the boundary may be due to active suspension of plastic debris in the water column and/or enhance breakdown, it seems reasonable rain and wind could affect these processes. To better resolve this issue, further detailed analyses are required to better understand more precisely the integrated effects of the hydrodynamics forces (i.e. wind, wave, tide) as suggested by Zhang (2017).

4.3. Comparison of plastic debris composition

Statistically significant changes are observed in the composition of plastic debris between beach and the outer nearshore environments. In the macroplastic fractions, the proportional mass of expanded polymers is higher at beach location, and progressively decreases from the beach to the outer nearshore. This suggests that lighter material is accumulating on the beach, and that breaking wave and/or backflush dynamics do not allow for the transportation of expanded polymers into offshore waters, which is consistent with previous observations suggesting that less dense macroplastics can accumulate more easily on the beach (Browne et al., 2010; Isobe et al., 2014; Thiel et al., 2013; Thornton and Jackson, 1998). While previous studies reported very high abundance of expanded polymer microplastics (up to 90%) on Hong Kong beaches (Fok et al., 2017; Fok and Cheung, 2015), we report much lower abundances of freshly deposited samples below the high tide line. This suggests that expanded polymers observed at the high tide line may represent a long-term accumulation that allows for the physical breakdown of macro-expanded polymer debris into microplastics (Browne et al., 2010; Thornton and Jackson, 1998). Macroplastic plates and films were observed to increase from the beach to the outer nearshore, suggesting that wave dynamics enhanced their transport and potentially strengthened their accumulation in nearshore waters instead of the beach. Plates and films are characterized as thin plastic debris (Table 1) with small volumes, whereas others types of plastic debris (Table 1) with high volume seems to accumulate at the boundary and outer nearshore indicating the importance of the volume in the buoyancy of the macroplastic debris as suggested by Ryan (2015). In the microplastic fractions the abundance of expanded polymer pieces from 1-5 mm decreases from the beach to the outer nearshore similar to the macroplastic trend. However, a much higher proportion is found at the boundary in comparison to macroplastic expanded polymer debris. This suggests that smaller expanded polymer pieces will be more affected by turbulent waters, and they will concentrate in high-energy environments due to their low-density and their high capacity to be maintained in suspension in the water column (Critchell and Lambrechts, 2016). The high abundance of expanded polymer debris at the boundary in the smaller size fractions (0.3-1mm) confirms the importance of wave dynamics in the distribution of expanded polymer microplastics. As mentioned earlier, breakdown of bigger expanded polymer pieces can also explain the preferential accumulation at the boundary. Here, we observed that expanded polymer between 1 to 5 mm fractions are higher in all the locations (beach, boundary and outer nearshore), but the proportion of expanded polymer only increases between the 1-5 mm to 0.3 to 1 mm size fraction at the boundary supporting an enhance degradation process at the boundary. Fibres from the 1-5 mm size fraction also increase in abundance from the beach into the outer nearshore, suggesting that wave energy drives their transport to offshore waters, as their low surface area limits water column suspension at the boundary.

5. Conclusions

In this study, we investigated the dynamics of plastic litter on the beach and in nearshore waters, in order to fill the gap between the monitoring efforts. By looking at both macroplastic and microplastic abundances at the boundary (the area of turbulent waters created by the combination of breaking waves and backflush) and outer nearshore waters, we observed that the boundary area concentrates both macro- and microplastic litter, suggesting that this region deserves special attention for plastic removal. In addition, our results indicate that the smaller size fractions are more affected by this increase, suggesting that plastic pieces smaller than 0.3 mm can be more affected by the accumulation. The composition of plastic litter on the beach and in the nearshore waters appears to be also influenced by the wave dynamics and debris buoyancy. We suggest that the preferential accumulation observed at the boundary is related to physical characteristics of the plastic pieces (high buoyancy, high surface area), which leads to increase water column suspension and also probably to their degradation at this location (at least for expanded polymer pieces). Understanding the nearshore dynamics of plastic litter is crucial to better quantify global fluxes of plastic litter into the ocean. This study highlights the importance of physical characteristics and therefore the need to identify specific plastic types when evaluating the dynamics of nearshore plastic debris. Our results also emphasize the need to consider both long-term and short-term temporal variability in addition to hydrodynamic forces to fully assess the dynamics of plastic litter in the nearshore environments.

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Table caption

Table 1. Classification of plastic debris based on their physical properties.

Figures captions

Figure 1. a) Map showing Hong Kong and Lung Kwu Tan location. b) Schematic of the Lung Kwu Tan beach at high tide. Sample location are marked with a red cross. Water samples were collected at the boundary and at the outer nearshore and beach samples were collected below the high tide line.

Figure 2. Comparison of average macroplastic weight (a) and microplastic abundance (b; 1-5 mm and c; 0.3-1 mm) between the boundary and outer nearshore environments for each sampling day and the average of all samples. Error bars represent the standard error of the mean.

Figure 3. Plastic debris composition for beach, boundary, and outer nearshore samples by size fraction. The sample size is indicated by n for each location and size fraction. Composition is reported in weight for macroplastics and abundance for microplastics.