A Critical Investigation into Microplastic Accumulation, Transportation and Physical Processes in the Marine Environment in and around Langstone and Chichester Harbours, Central Southern England.

Abstract

Plastics in the marine environment have become a huge topic over the last few years through the visible impact they have caused in the world's oceans. It is microplastics, however, that maybe the most dangerous, being largely unnoticed by the public and policy makers. Whilst many researchers focus on the scale and distribution of microplastics, this study focussed on the understudied transport mechanisms, and whether microplastics behave similarly to sand and gravel in sediment budgets. From the data collected, it is clear that microplastics are transported by aeolian and wave processes in the same manner as sediment, but questions remain if this result is consistent over a temporal scale.

Keywords: Microplastics; Coastal, Transportation; Sediment, Budget

Acknowledgements

The author would like to acknowledge Dr Jonathan Potts for his help in deciding upon and researching this project. The author would also like to thank David Jones for providing the data used in this project, as well as providing excellent support with regards to the data collection method and key concepts. This project was supported by funding provided by the charity Just One Ocean and the coastal partnership The Solent Forum through the Professor Mike Clark Award.

1. **Intro**

1.1 Rationale

Plastics in society have had widespread use, due to the versatility of the material in various types and forms, and the wide range of unique properties plastic possesses (Andrady and Neal, 2009). Such use has led to extremely high production of this material, with the amount of world plastic rising from 1.5 million tonnes in 1950 to 359 million tonnes in 2018 (Plastics Europe, 2019). This increase in production has resulted directly in a significantly large marine waste problem, with scientists estimating that 8 million metric tons of plastic enters the ocean every month (NOAA, 2019). Over the last 20 years, the issue of plastics in the world's oceans has become a hot topic amongst scientists and the public alike. The longevity of plastic waste and its durability is further correlated to its gradual accumulation in marine environments the world over. Seven of the ten top marine litter items recorded by the 2013 International Coastal Cleanup initiative were made of plastic, with this continuing to be the case years later (Table 1). 84% of beach litter found in 2016 on European beaches (Figure 1) being made up of plastic material (The European Commission Joint Research Centre, 2017).

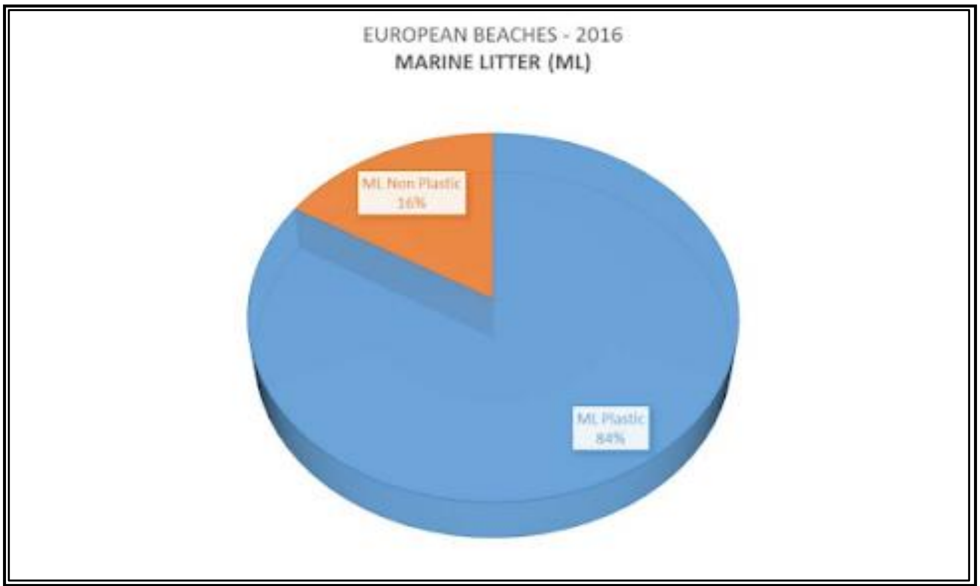

Figure 1: A chart showing the percentage of marine litter found on European beaches in 2016 between plastic and non-plastic (The European Commission, Joint Research Centre, 2017).

Rank	Material	General Name Litter Item	Code	Number of Items	% over total of ML	% over total of SUP
1	Plastic	Cigarette butts	G27	21 854	6.14 %	22.05 %
2	Plastic	Caps and lids - other	G20-G24	16 125	4.53 %	16.27 %
3	Sanitary waste	Food containers incl. fast food packaging	G10/G16/G30-G34/x_n	14 012	3.94 %	14.14 %
4	Sanitary waste	Cotton bud sticks	G95	13 579	3.82 %	13.70 %
5	Plastic	Wet wipes	G95-98/G144/x_a	8 101	2.28 %	8.18 %
6	Plastic	Drink bottles	G6-G8	6 095	1.71 %	6.15 %
7	Plastic	Other bags	G1-G5/G36-G37/G45/G101	4 429	1.25 %	4.47 %
8	Plastic	Cutlery	G34-G35	4 203	1.18 %	4.24 %
9	Plastic	Other bottles	G6-G9/G11-G13/G15-G16/G65	3 011	0.85 %	3.04 %
10	Plastic	Caps and lids - drinks	G21	2 605	0.73 %	2.63 %
11	Plastic	Shopping bags	G3	2 520	0.71 %	2.54 %
12	Plastic	Cups and cups lids	G33	1 995	0.56 %	2.01 %
13	Plastic	Straws and stirrers	G35	566	0.16 %	0.57 %

Table 1: The top 13 litter items collected from European beaches in 2016 ranked by abundance, with type of material and percentage of the total shown (The European Commission, Joint Research Centre, 2017).

Microplastics are defined as plastic pieces or fibers that are smaller than 5mm. They are derived from two main sources. Primary microplastics are plastic pieces that are smaller than 5mm when they enter the environment. Pre-production pellets (commonly termed nurdles) and microbeads fall under this category. Though designed to be resistant and long lasting, plastics in the environment can become brittle and break apart. Secondary microplastics are created from this degradation of larger plastics under environmental conditions and animal interaction, and are the dominant plastic type found in coastal environments (Barnes et al., 2009; Roos Lundström & Mårtensson, 2015).

Microplastics are especially damaging to the marine environment compared to larger marine litter due to their small size, where they are commonly mistaken for eggs by wildlife and ingested. Man-made chemicals and contaminants of global concern (WHO, n.d.) are given the name persistent organic pollutants (POPs), which are chemicals that reside in water bodies, are absorbed by and become concentrated on the surface of microplastics they contact. This provides the mechanism for POPs to enter the food chain (GESAMP, 2015), as when ingested these plastic pieces and absorbed toxins remain inside of animals, where they steadily accumulate through predation to dangerous levels at the top of the food chain. Cox et al. (2019) establishes that humans, as predators and as instigators of plastic production and pollution, have been shown to regularly eat and drink microplastics that could begin to affect us in adverse ways in the future.

Despite the increasing concern and studies over the impacts and worldwide spread of plastics and microplastics in particular, both in and out of the marine environment, not much is known of the transportation of such plastics and how they are affected regarding coastal physical processes. Some studies such as Zhang (2017), have investigated microplastic movement from estuaries to the continental shelf, however, this paper looks to investigate whether there is any credible link between sediment budgets and microplastic transportation in the coastal environment. Work by Zhang (2020) has begun to develop this concept, but more work is needed.

A sediment budget is described by Bowen and Inman (1966) as “an application of the principle of conservation of mass to littoral sediments”. Sediment budgets are a balance of sediment volumes within a coastal system, between sources, which are an input; and sinks, which are an output (Rosati, 2005). It is this balance, and the processes supporting it, that dictates the movement of sediment within these cells. This study hopes to establish that microplastics, being small and light comparable to sediment, interact with the coastline in a similar manner to this, so that sediment budgets can be used to help direct coastal clean-up efforts to achieve greater effectiveness.

Chichester and Langstone Harbours are both highly designated areas including Ramsar wetland. They have designations such as: Area of Outstanding Natural Beauty (AONB), Site of Specific Scientific Interest (SSSI), Special Protection Area (SPA), Special Area of Conservation (SAC) to name a few. In addition, they are popular areas for both tourists and residents alike, with many pleasure and work related activities taking place in and around them. This not only makes sampling here important in terms of protecting the natural beauty of the areas for the people who use it, but also as a microcosm of microplastic transportation in coastal environments as a whole, making this area of the coast a suitable location for this study.

1.2 Focus

With the scale of plastic pollution and the damaging influence it can have on the marine and coastal environment (GESAMP 2015) being discovered across the world, the natural next step is to tackle this new anthropogenic hazard.

1.3 Aims and Objectives

1.3.1 Aims

The overall aim of this dissertation is to investigate linking microplastic transportation and distribution to sediment budgets and transport mechanisms at the entrances to Langstone and Chichester Harbours.

1.3.2 Objectives

In order to achieve this aim, a series of objectives were established;

- To undertake a critical review of previous literature related to microplastic research and identification, sediment transport and sediment budgets. This literature is used throughout this study to justify the methods, objectives and conclusions reached.
- To identify current sediment transport methods occurring in and around the survey sites on the west and east of Hayling Island, East Head, West Wittering and Chichester Harbour.
- To evaluate using data, any potential links between sediment budgets and microplastic transportation, and to decide how likely microplastic movement can be related to sediment budgets.

2. Materials and Methods

2.1 Sample Collection

Due to the appearance and rapid proliferation of the coronavirus pandemic, the collection of primary data was ruled out in response to the UK government lockdown, which started on the 23rd of March. This not only made it unsafe to visit sample sites, but transport links that would have been needed for the collection of primary data were also unavailable. In response, secondary data was instead selected to allow for the continuation of the study. The data being used is given graciously by David Jones and his charity Just One Ocean. Whilst their 'Big Microplastic Survey' includes surveys from 55 different countries, the methodology used remains constant. Despite some variation in the literature with regard to depth (Löder & Gerdts, 2015, Masura et al., 2015, Hidalgo-Ruz et al., 2012), their methodology was decided after careful consideration of appropriate literature from Hidalgo-Ruz et al., (2012) and the MSFD Technical Subgroup on Marine Litter (2013) so that data collected could be significant enough for analysis, but also simple enough to allow for public participation and inexperienced volunteers. This method shall be reproduced here for ease of reference.

Due to the nature of his project, David and his organisation selected survey areas that were easy to access and had sandy sediment, a suitable type for the method being used. This was done with the intention of allowing volunteer participation in the study, so that greater amounts of data could be collected. Similarly, the size of the microplastics was restricted to that which can be seen with the naked eye. This was done not only to allow for easier data analysis, but to reduce the complexity of the process as a whole.

Amaral-Zettler et al. (2016) and Reisser et al. (2013) identified that floating polymers with little to no pollution were the most likely to be found on the beaches at the survey sites, as they make up 80% of total microplastics in a coastal environment (Claessens et al., 2013; Plastics Europe, 2018). This is due to the fact that plastic with high amounts of fouling by pollution and biota can sink due to their change in density, making them too heavy to become deposited in the coastal environment where sampling is taking place.

Figure 2 - Example of the equipment used on site, showing both a 1m² and 10cm² quadrats and a bucket for sediment separation. The sample being shown is taken from a strandline on West Hayling. Source: Author's own.

The data used was selected from sites sampled at both the east and west sides of Hayling Island, West Wittering beach, East Head Spit and within Chichester Harbour. Samples are taken from 5 x 1m² quadrats (Figure 2), each with a separation distance of 5m. Within the quadrats, 5 x 10cm² samples of 2cm depth were taken from each, giving 25 sediment extractions per sample. The plastic in each sample was separated onsite (Figure 3). Samples from 122 sites at the stated locations were used. This gave a total of 3,050 samples, covering a total area of 30,500cm², or 305m².

Figure 3 - Separation of sediment and plastic pieces using water filtration on site. Source: Author's own.

2.2 Sample processing

Samples collected were processed and analysed by David Jones and his volunteers. After being dried out from being left in a drying room for several days, the plastic in each separate sample was sorted using a magnifying glass and tweezers. Both micro and meso plastics were separated into individual groups. Five basic microplastic characteristics exist in the literature (Browne et al., 2015; Hidalgo-Ruz et al.,2012; Lee et al., 2015) which are as follows - source, type, colour, shape and level of erosion. Level of erosion was not collected by David and his organisation, as it was identified to be too subjective as a characteristic, particularly between volunteers. Whilst the other four characteristics were collected and identified, none are known to influence the distribution or transportation of microplastics in the coastal environment, only their potential ingestion by marine animals (Lavers et al., 2014; GESAMP, 2015; Holland et al., 2016), so were not considered further.

The groups fall into primary and secondary plastics, as well as micro and meso plastics, with this being the microplastics source. Primary plastics are complete pieces of a plastic product, whereas secondary consist of broken off pieces of larger items. To count as micro, it was decided that the largest length must be under 6mm. Microplastics were further divided by types. There are pre-production pellets (of which there are 4 shapes: discs, cubes, cylindrical and spherical), polystyrene balls and ‘other’. For meso plastics, there is only one type in which all plastics over 6mm are grouped. Micro and meso plastic groups are further subdivided by colour. The counts of these subdivisions are recorded to an online form on the Just One Ocean website, along with the date and coordinates of the sampling area.

2.3 Analysis

With the microplastic and mesoplastic data collected, manipulation of the data was required to investigate the distribution of the microplastics collected, and any links that could be made to coastal physical processes. For this purpose, maps were created in the ArcGIS Pro software using the data from the 122 sites. Separate maps of the total micro and meso plastic amounts at each site were made for each of the general areas being investigated. A key was created to easily identify differences in the plastic amounts collected, as well as transport mechanisms added using information from SCOPAC (2012a), a sediment transport study.

Statistical analysis was limited in use in this study, due in part to the nature of the study and the data provided. This made statistical comparison between the data sets difficult and judged not effective for achieving the aims and objectives already set out.

2.4 Limitations

Due to time and equipment restraints, all microplastics identified and sorted were greater than 1mm in size. With the naked eye, it is incredibly difficult to separate and sort microplastic pieces smaller than 1mm, which would require a microscope to sort correctly. In addition, as volunteers were used for the collection as well as the sorting process, this further made the sampling of microplastics smaller than 1mm infeasible.

West and East Hayling island, West Wittering and East Head were easily accessible as sites, with sand beaches that fit with the guidance by Hidalgo-Ruz et al (2012) and Löder & Gerdts, (2015). Within Chichester Harbour, many potential sites had to be discarded as there was no ease of access and the sediment was unsuitable to be sampled at.

Fourier-transform infrared spectroscopy (FTIR) could be used to further identify the types of microplastics found, however this was not necessary or feasible due to time and resource constraints for David's study, and deemed not necessary for this study as well.

3. Data:

The data used in this study was graciously provided by David Jones and his organisation Just One Ocean. It consists of 122 surveys taken from 5 survey sites - the west and east sides of Hayling Island Beach, West Wittering Beach, East Head Spit and Chichester Harbour. The results were collected between the years 2018-2020.

The complete data table for the total 122 sites can be viewed in Appendix (A), as well as the micro and mesoplastic count averages used to create Figure 5. It should be noted the particularly high number of sample sites at the West Wittering Beach and East Head Spit sites compared to the others. Not only are these sites easily accessible, but the majority of David's work with volunteers and studies into citizen science have taken place here, thereby leading to this network of sites.

Figure 4 - Map of all the sample sites investigated and their locations. West Hayling Island Beach (1), East Hayling Island Beach (2), West Wittering Beach and East Head Spit (3) and Chichester Harbour (4). Source: Author’s own.

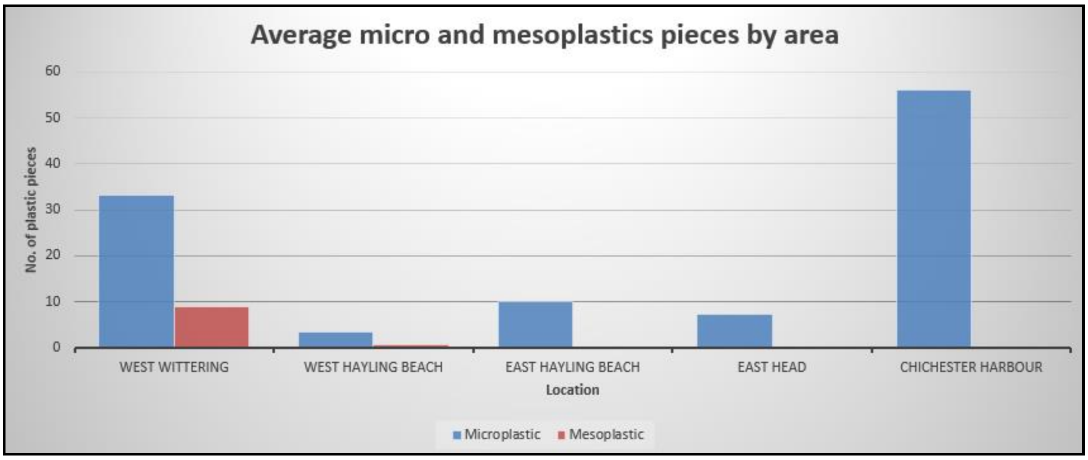

Figure 5 - A bar chart of the average no. of plastic pieces found at sample sites, both meso and micro for each area. Source: Author’s own.

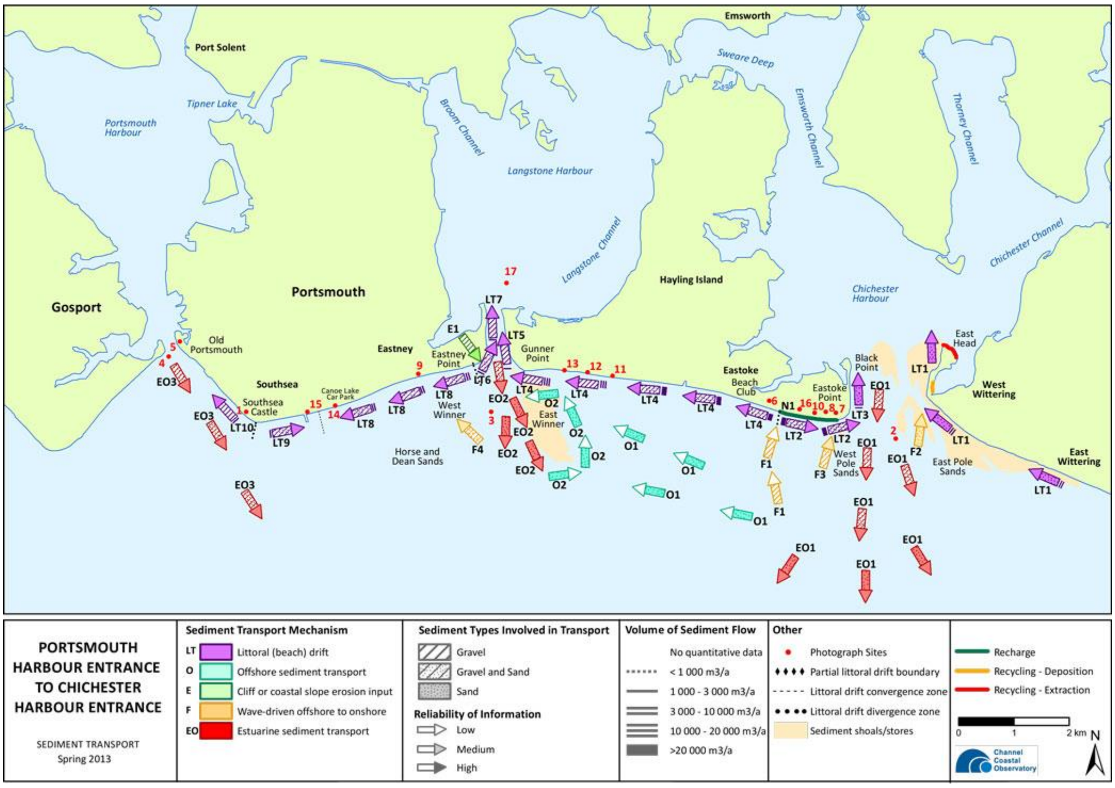

Figure 6 - Annotated map of Portsmouth, Langstone and Chichester Harbour entrances, showing sediment transport mechanisms, their direction and reliability. Source: SCOPAC (2012a).

Portsmouth, Langstone and Chichester Harbours: Sediment Transport

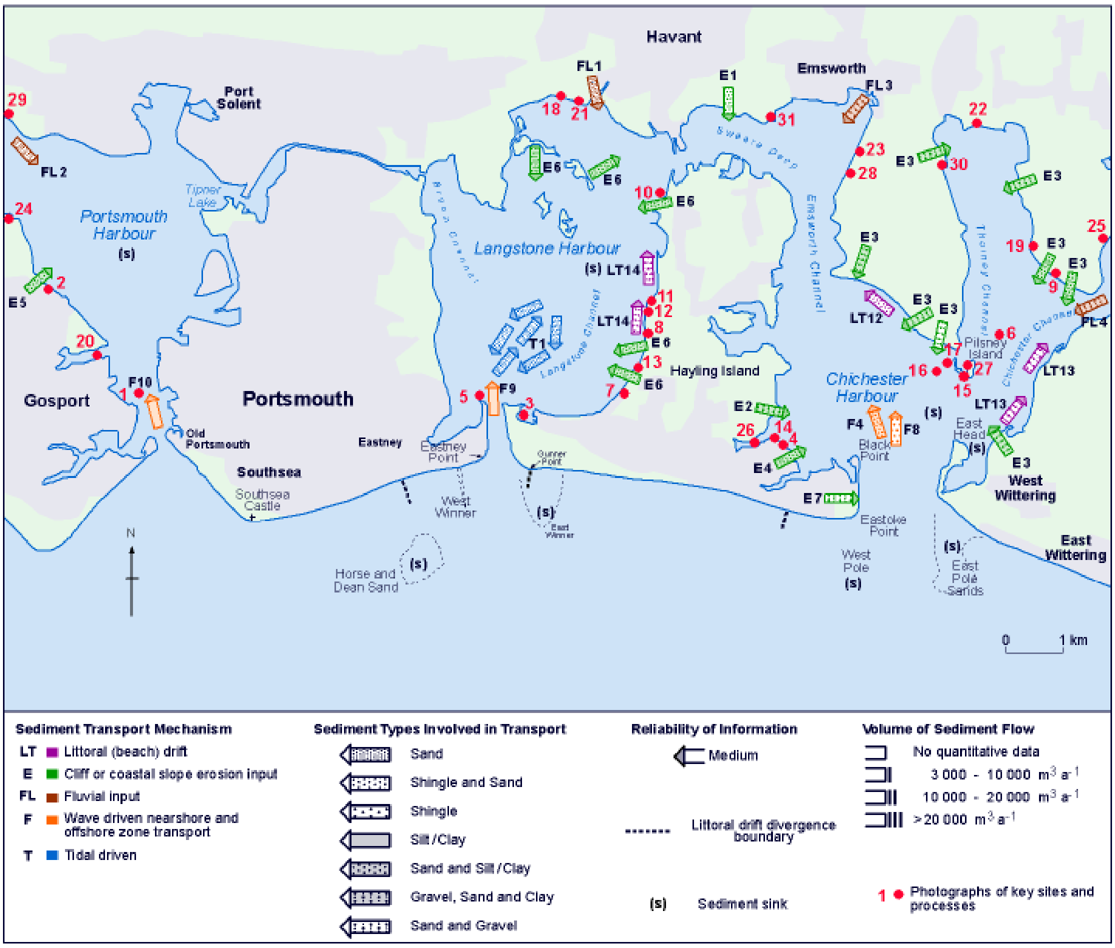

Figure 7 - Sediment transport mechanisms, their directions and reliability within Portsmouth, Langstone and Chichester Harbours. Source: SCOPAC (2012a).

Figure 8 - Maps of the sample sites taken from the west of Hayling Island beach, with meso and micro plastics values shown separately. Transport mechanisms have been overlaid on the study area for visual aid from SCOPAC (2012a). Source: Author's own.

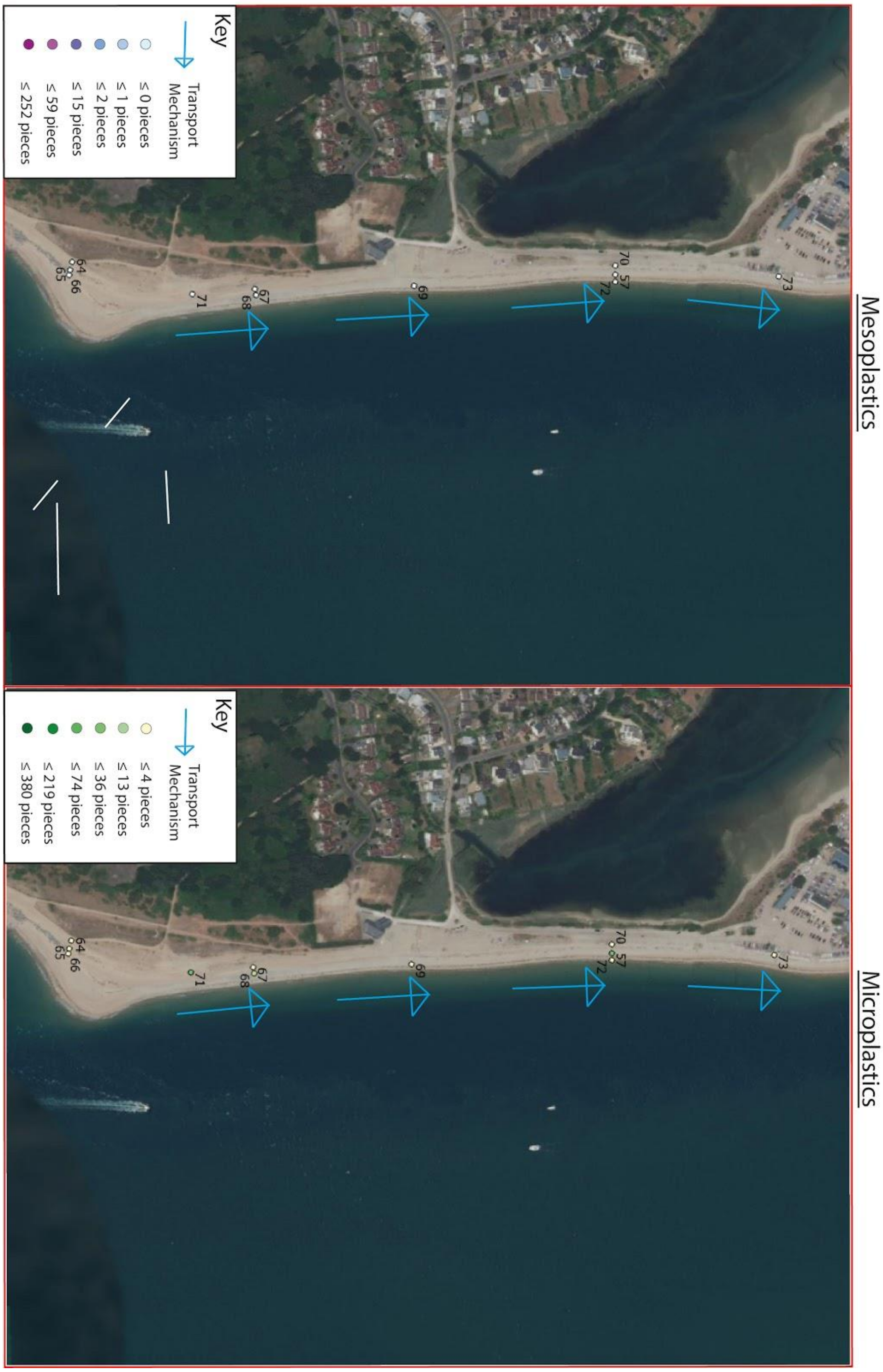

Figure 9 - Maps of the sample sites taken from the east of Hayling Island Beach, with meso and micro plastics values shown separately. Transport mechanisms have been overlaid on the study area for visual aid from SCOPAC (2012a). Source: Author's own.

Figure 10 - Maps of the sample sites taken from West Wittering Beach and East Head Spit, with meso and micro plastics values shown separately. Transport mechanisms have been overlaid on the study area for visual aid from SCOPAC (2012a). Source: Author’s own.

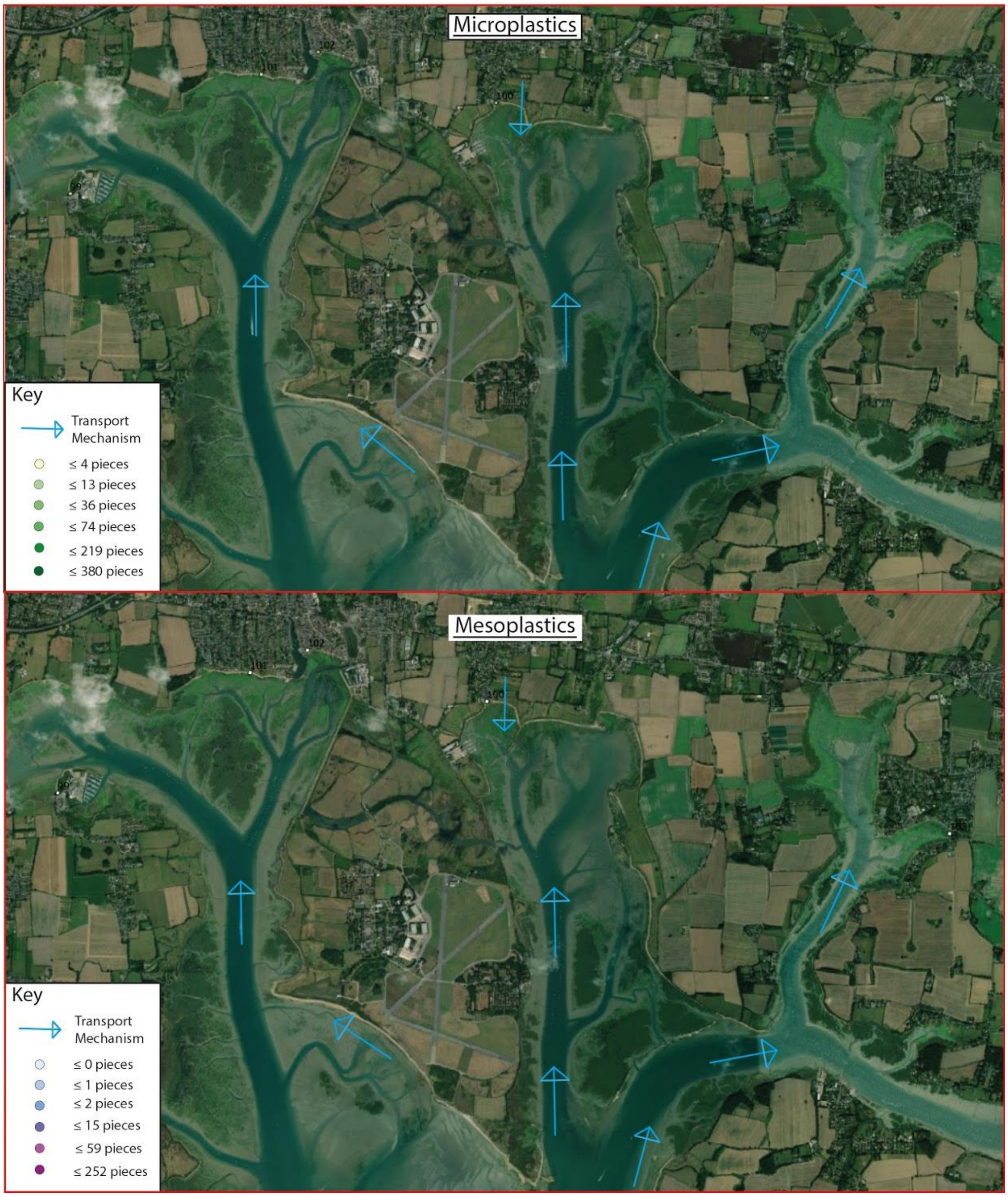

Figure 11 - Maps of the sample sites taken from within Chichester Harbour, with meso and micro plastics values shown separately. Transport mechanisms have been overlaid on the study area for visual aid from SCOPAC (2012a). Source: Author's own.

4. Discussion

From the introduction, we have identified the lack of knowledge around microplastic transport in coastal areas, and posited the concept of microplastic transport in relation to sediment transport mechanisms in sediment budgets. We have also identified that the microplastics found in the coastal environment are limited to floating microplastics with limited pollution, as they make up 80% of plastics found in the environment (Claessens et al.,
2013; Plastics Europe, 2018). Yanfang et al (2020) highlights that microplastics with a density greater than seawater will sink in the water column, depositing in benthic sediments. These microplastics were not suitable for sampling, and so were not investigated.

4.1 West Hayling Island Beach

Sampling at this site has shown the generally low numbers of micro and mesoplastics found on the beach, as supported by the average results of 3.6 for microplastic pieces and 0.6 for mesoplastic, found in Figure 5. Whilst the general pattern is quite low, there are some interesting individual results.

Site 60, as the northern most sample site in this area, has a much higher number of microplastics at 18 pieces collected. This result is expected given the dominant transport process in the area being littoral beach drift in a northerly direction. Floating microplastics, being moved via Stokes drift along the beach, could settle here, especially in the lee of a sand dune just south of this site (Figure 12). This would point to this area being a sink for microplastics, further backed up by the sand dune at this site, showing this area is already a sink for coastal sediments in the sediment budget. The SCOPAC (2012a) sediment transport study notes that erosion of sediment at Gunnar Point and subsequent transportation northwards has led to this build-up on the eastern side of Langstone Harbour entrance. Page 134 of beach profile analysis by HR Wallingford Ltd (1995) showed this northward drift using results that displayed erosion at the apex of Gunnar Point, and subsequent build-up of sediment further in toward the Langstone Harbour entrance. This fits with relation to the low microplastic amounts in the southerly direction of the beach, as pieces here are unlikely to be deposited for a long time and are instead moved by surface waves and longshore drift to the north.

Figure 12 – Overhead view of the area just south of the Hayling Island ferry and surrounding site 60, showing the sand dune that protects it from coastal processes. Source: Google Earth (2020).

Sites 62 and 63 also have higher microplastic amounts than average, at 7 and 13 respectively. These two are the most southern of all the samples taken at this site. The higher microplastic amount here could indicate a temporary sink, where microplastics would accumulate due to weak erosive energy being unable to remove it. The lack of mesoplastic at these sites further shows this sink is exclusive to microplastics due to their smaller size, but could also be due to beach clean-up groups focusing on mesoplastic pieces.

4.2 East Hayling Island Beach

Much the same as the west side of the island, the east end of Hayling Island beach shows a general trend of northward movement of sediment. Similarly, the averages for both micro and mesoplastic are low, 10 and 0 respectively. In fact, no mesoplastics were found at any sample sites in this area. The overall trends do not reveal much useful information, but individual results again prove interesting.

The expectation, as with west Hayling Island Beach, is that the northern most sample site will have the highest number of microplastics found. This is not the case. Site 57 shows the highest accumulation of microplastics at 56 pieces discovered. This site is located at an exposed area towards the upper end of the beach. The reasoning for the higher microplastic amount is believed to be due to wooden groynes along the beach in this area. The establishment of these coastal defences is intended to reduce sediment transportation and erosion of the shoreline, and to allow for build-up of sediments. In the same way, microplastics could build-up here along with sediment, trapped by the shelter from the groynes and forming a microplastic sink. Groynes represent a human influence on the sediment budget of the coast, disrupting sediment transport processes. This would prevent the further movement of microplastic along the beach, as represented by the low number found at site 73.

This one site is not complete evidence, as on the same part of the beach are two other sites, 70 and 72. The microplastic quantities found at these sites are sparse, with each only having 2 pieces present. This could be due to very local differences between the sites, as requires further investigation.

36 microplastics were found at Site 71, the second highest for this area. This site is around midway between the sea and the back of the beach. The reasoning for this higher amount of microplastics is unknown, but could be an indication of local factors impacting the movement of plastics. It is theorised that being located in the lee of Eastoke Point from the south could shelter the site

from transportation processes, such that microplastics become deposited here, whilst sites 67 and 68 are too far to benefit from this same protection.

Sites 64-66 at Eastoke Point have very low microplastic counts, which is likely due to the presence of rock groynes at the site and further east (Figure 13). Any sediment and microplastics from the beach moving by wave or aeolian processes would become trapped here, hence the low microplastic amounts at the 3 sites.

Figure 13 - Overhead view of Eastoke Point and the rock groynes found there. Source: Google maps 2020.

4.3 West Wittering Beach and East Head Spit

The West Wittering and East Head areas had the most varied micro and mesoplastic counts compared with the other areas. This is shown by Figure 5, with 33 microplastic pieces and 9 mesoplastic pieces on average across the sample sites. This is the highest average for mesoplastics.

Due to the depth of the channel and the strength of the tidal current, sediment transport has not proven to be possible between West Wittering and East

Hayling Island. This has resulted in the formation of East Head Spit, as sediment being transported westwards is forced to become deposited. At West Wittering beach, the vast majority of sites have greater than 13 microplastic pieces, with a handful of sites in the eastern group of sample sites having microplastic counts of over 200. Secondary microplastics made up 40% of the plastic found, and mesoplastic numbers were higher in the same location. This area is extremely popular with tourists in the summer months, with 15000 visitors expected on particularly busy days (West Wittering Estate, n.d.). As such the litter they bring can be left in these areas. Sand dunes in this area are likely to entrap these plastics and prevent their movement via wave or aeolian processes. Furthermore, the drift rate of sediment here is lower than areas eastwards down the coast, at 1-3000m^3 per year (SCOPAC, 2012b). This would make it easier for sediments, and by extension microplastics, to become entrained here and stuck in a sediment sink.

Sample sites from the East Head Spit beach have generally lower plastic amounts found than at West Wittering. Due to the groynes installed at the neck of the spit after the erosion of this area in 2004 (Chichester Harbour Conservancy, n.d.), transport of microplastics through surface sediment transport mechanisms to the spit from West Wittering is unlikely. Aeolian transport processes are shown to dominate here (SCOPAC, 2012b), moving sediment in a southerly and south-westerly direction landward and resulting in the accumulation of sand dunes on the spit. These have become established with specialized dune vegetation, and are protected to prevent trampling. It can be theorised that microplastics on the beach would be carried by this aeolian process in the same manner as sediment and become entrained in the sand dunes, forming a microplastic sink. Jones (2018) noted in his study that although sampling was not possible within the dunes, microplastics could be seen there in abundance.

4.4 Chichester Harbour

The sample sites within Chichester Harbour have the highest microplastic average at 56. The majority of the microplastics collected were identified as secondary, having been formed via secondary processes, which was identified from literature in the introduction as being dominant plastic type in coastal environments (Barnes et al., 2009; Roos Lundström & Mårtensson, 2015). The sheltered nature and shallow water of the harbour means that there is limited energy for sediment movement (SCOPAC 2012c). Microplastics deposited in this area are highly unlikely to become eroded out of microplastic sinks due to the lack of strong tides. The general transport mechanisms within the harbour are either suspended load transport through inlets or coastal slope erosion. Whilst certainly a source for sediment in the harbour, coastal slope erosion has the potential to be a source of microplastics, as mesoplastics released onto the shore, broken down under sunlight and environmental conditions to eventually form secondary microplastics. This is unsupported by current literature, and would need to be investigated further.

5. Conclusion:

There is building concern over the increase in microplastics in all levels of human and natural environments, including within the oceans (Barnes et al., 2009; R. Thompson et al., 2005). Here, microplastics pose a serious threat to coastal and marine life, as well as all other species that predate on them including humans. Yet despite the acknowledgement of the danger posed by microplastics and the studies looking at microplastic abundance, there has been very little research into the transport of microplastics in the coastal environment. Plastics do not originate from marine ecosystems yet can be found in some extremely remote locations. The aim of this research was to investigate linking microplastic transportation and distribution to sediment budgets and transport mechanisms at case study areas in and around Langstone and Chichester harbours. Having critically analysed existing research into plastics in the coastal environment and identified the need for this study, the next key objective was to identify current sediment transport methods occurring in and around the survey sites. This was provided by the SCOPAC (2012a) sediment transport study, which had investigated in detail the sediment transport mechanisms between and within Portsmouth, Langstone and Chichester Harbours. The observations listed were invaluable in discovering the sediment budgets of the case study areas and determining the possible mechanisms by which microplastics could be transported.

An inability to collect primary data due to the coronavirus pandemic and UK lockdown necessitated the collection of secondary data. The meso and microplastic data collected by David Jones and his volunteers provided the results needed to investigate plastic transport and its relation to sediment budgets. This link was further explored in the discussion section. After finishing this research, it is apparent that there is a clear link between microplastics and both sediment transport and budgets. This will be useful in informing future microplastic research and clean-up efforts, as knowledge of microplastic transportation and sinks will allow for better use of available resources, so that future work can be carried out with greater efficiency. For future studies, an investigation into microplastic transport and distribution over a temporal scale would be of interest. The data used in this study was all collected in summer months, so a similar study or data collection within winter months may provide unique results.

6. References:

Amaral-Zettler, L., Andrady, A., Dudas, S., Fabres, J., Galgani, F., Hardesty, D., ... Ziveri, P. (2016). *Sources, fate and effects of microplastics in the marine environment: Part 2 of a global assessment.* Reports and Studies GESAMP, 93, 217. https://doi.org/10.13140/RG.2.1.3803.7925.

Andrady, A. L., and Neal, M. A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society, 364*, 1977-1984. https://doi:10.1098/rstb.2008.0304.

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205.

Bowen, A. J., & Inman, D. L. (1966). *Budget of littoral sands in the vicinity of Point Arguello, California*, U.S Army Coastal Engineering Research Centre Tech Memo. No. 19, 56pp.

Chichester Harbour Conservancy. (n.d.). *East Head*.
Retrieved from https://www.conservancy.co.uk/page/east-head.

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human Consumption of Microplastics. *Environmental Science & Technology, 53*(12), 7068-7074. https://doi.org/10.1021/acs.est.9b01517.

European Commission, Joint Research Centre. (2017, March 17). From entanglement to invasions of alien species: the harm caused by marine litter. *ScienceDaily*. Retrieved from www.sciencedaily.com/releases/2017/03/170317082657.htm.

GESAMP. (2015). *Sources, fate and effect of microplastics in the marine environment: a global assessment* (Reports and Studies 90). Retrieved from https://www.researchgate.net/publication/275638703_SOURCES_FATE_AND_EFFECTS_OF_MICROPLASTICS_IN_THE_MARINE_ENVIRONMENT_A_GLOBAL_ASSESSMENT.

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: A review of the methods used for identification and quantification. *Environmental Science and Technology, 46*(6), 3060–3075. https://doi.org/10.1021/es2031505.

Holland, E. R., Mallory, M. L., & Shutler, D. (2016). Plastics and other anthropogenic debris in freshwater birds from Canada. *Science of the Total Environment, 571*, 251–258. https://doi.org/10.1016/j.scitotenv.2016.07.158.

HR Wallingford Ltd (1995). *Pagham Harbour to River Hamble (Coastal) Strategy Study, Volume 1: Pagham Harbour to Portsmouth Harbour,* Report EX 3121, Report to Pagham to Hamble Coast Strategy Group (Lead Authority: Chichester District Council), 134pp, 145 tables and figures.

Jones, D. (2018). *A Critical Evaluation of Microplastics in the Coastal Environment: A Case Study of Chichester Harbour* (Unpublished master’s dissertation). University of Portsmouth, Portsmouth.

Lavers, J. L., Bond, A. L., & Hutton, I. (2014). Plastic ingestion by flesh-footed shearwaters (Puffinus carneipes): Implications for fledgling body condition and the accumulation of plastic-derived chemicals. *Environmental Pollution, 187*, 124–129. https://doi.org/10.1016/j.envpol.2013.12.020.

Löder, M. G. J., & Gerdts, G. (2015). Methodology Used for the Detection and Identification of Microplastics—A Critical Appraisal*. Marine Anthropogenic Litter*, 201–227. https://doi.org/10.1007/978-3-319-16510-3_8.

Masura, J., Baker, J., Foster, G., & Arthur, C. (2015). Laboratory Methods for the Analysis of Microplastics in the Marine Environment, (July). Retrieved from https://marinedebris.noaa.gov/sites/default/files/publications-files/noaa_microplastics_methods_manual.pdf.

MSFD Technical Subgroup on Marine Litter. (2013). *Guidance on Monitoring of Marine Litter in European Seas*. https://doi.org/10.2788/99475.

NOAA (2019). *A Guide to Plastic in the Ocean*. Retrieved from https://oceanservice.noaa.gov/hazards/marinedebris/plastics-in-the-ocean.html.

Plastics Europe. (2019). Plastics-the facts 2019: an analysis of European plastics production, demand and waste data. Retrieved from https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B. D., Proietti, M., Thums, M., & Pattiaratchi, C. (2013). Marine plastic pollution in waters around Australia: Characteristics, concentrations, and pathways. *PLoS ONE, 8*(11). https://doi.org/10.1371/journal.pone.0080466.

Roos Lundström, F., & Mårtensson, A. (2015). *The Journey of Plastic trough Oceans : A study on quantifying micro plastic particles in ocean outside Costa Rican west coast*. BSc Thesis. Retrieved from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A826522&dswid=-9064.

Rosati, J. D. (2005). Concepts in sediment budgets. *Journal of coastal research, 21*(2), 307-322. Retrieved from https://apps.dtic.mil/dtic/tr/fulltext/u2/a482879.pdf.

SCOPAC. (2012). *Sediment transport study update 2012*. Retrieved from https://www.scopac.org.uk/sts/plc-landing.html.

West Wittering Estate. (n.d.). *History*. Retrieved from http://www.westwitteringestate.co.uk/estate/history.

WHO. (n.d.). *Persistent organic pollutants (POPs)*. Retrieved from https://www.who.int/foodsafety/areas_work/chemical-risks/pops/en/.

Yanfang, L., Zhang, H., & Tang, C. (2020). A review of possible pathways of marine microplastics transport in the ocean. *Anthropocene coasts, 3*, 6-13. https://doi.org/10.1139/anc-2018-0030.

Zhang, H. (2017). Transport of microplastics in coastal seas. *Estuarine Coastal and Shelf Science, 199*. https://doi.org/10.1016/j.ecss.2017.09.032.

7. Appendices:

Appendix A - Total Microplastic and Mesoplastic sample data

FID	ObjectID	x (long)	y (lat)	Survey Site Name/Locat	Date of Survey	Nurdle (r	Nurdle (	Nurdle (	Nurdle (	Bio Bea	Other F	Expande	Second	Total microplasti	Primary M	Seconc	Total Mesoplasti
0	327	-0.909	50.776	West Witterings beach	07/11/2019	0	0	0	0	0	0	0	6	6	0	0	0
1	328	-0.9089	50.775	West Witterings	07/11/2019	21	58	68	13	13	1	45	0	219	27	225	252
2	330	-0.9091	50.775	West Witterings	07/11/2019	0	0	0	0	0	0	0	0	0	0	0	0
3	332	-0.9086	50.776	West Witterings	07/11/2019	10	55	124	6	34	4	10	137	380	2	13	15
4	373	-0.909	50.776	West Wittering Beach	07/11/2019	0	0	0	0	0	0	0	8	8	0	0	0
5	384	-0.9086	50.776	West Wittering Beach	07/11/2019	19	55	70	11	23	2	21	144	345	3	56	59
6	374	-0.9089	50.775	West Wittering Beach	07/11/2019	21	69	73	17	12	1	27	147	367	3	47	50
7	413	-0.9114	50.777	West Wittering Beach	16/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
8	414	-0.9116	50.778	West Wittering Beach	16/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	0	0
9	416	-0.9114	50.777	West Wittering Beach	16/06/2020 23:00	1	1	1	1	1	0	0	1	6	1	1	2
10	417	-0.9112	50.777	West Wittering Beach	16/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
11	418	-0.9113	50.777	West Wittering Beach	16/06/2020 23:00	1	1	1	1	1	0	11	1	17	0	1	1
12	420	-0.9075	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
13	421	-0.9073	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
14	422	-0.9071	50.775	West Wittering Beach	17/06/2020 23:00	0	1	1	1	1	0	0	1	5	1	1	2
15	423	-0.9077	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	0	0	0	1	5	0	1	1
16	424	-0.9078	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
17	425	-0.911	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	0	1	0	0	1	5	0	1	1
18	426	-0.9111	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
19	427	-0.9114	50.777	West Wittering Beach	17/06/2020 23:00	0	1	1	1	1	0	0	1	5	1	1	2
20	428	-0.9114	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	1	1	2
21	429	-0.9115	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	1	1	2
22	430	-0.9071	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
23	432	-0.9078	50.775	West Wittering Beach	17/06/2020 23:00	0	1	1	1	0	0	0	1	4	0	1	1
24	433	-0.9079	50.775	West Wittering Beach	17/06/2020 23:00	0	1	1	0	1	0	0	1	4	0	1	1
25	434	-0.9081	50.776	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
26	435	-0.9109	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	0	0	0	0	1	4	0	1	1
27	436	-0.9111	50.777	West Wittering Beach	17/06/2020 23:00	0	1	1	1	1	0	0	1	5	0	1	1
28	437	-0.9114	50.777	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	4	1	10	1	1	2
29	438	-0.9117	50.778	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	4	1	10	0	1	1
30	439	-0.9117	50.778	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
31	441	-0.911	50.777	West Wittering Beach	21/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
32	442	-0.9113	50.777	West Wittering Beach	21/06/2020 23:00	1	1	1	1	0	0	0	1	5	0	1	1
33	443	-0.9114	50.777	West Wittering Beach	21/06/2020 23:00	0	1	1	1	1	0	0	1	5	0	1	1
34	444	-0.9112	50.777	West Wittering Beach	21/06/2020 23:00	1	0	1	0	1	0	0	1	4	0	1	1
35	445	-0.9113	50.777	West Wittering Beach	21/06/2020 23:00	1	1	1	0	1	0	0	1	5	0	1	1
36	446	-1.0234	50.788	Hayling Beach	24/06/2020 23:00	0	0	0	0	0	0	0	1	1	0	1	1
37	447	-1.0228	50.788	Hayling Beach	24/06/2020 23:00	0	0	0	0	0	0	0	0	0	0	1	1
38	448	-1.0221	50.787	Hayling Beach	24/06/2020 23:00	1	0	0	0	1	0	0	0	2	0	1	1
39	449	-1.0223	50.787	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	0	1	0	1	1
40	450	-1.023	50.787	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	1	2	0	1	1
41	454	-1.0226	50.787	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	1	2	1	1	2
42	455	-1.0233	50.788	Hayling Beach	24/06/2020 23:00	0	0	0	0	0	0	0	1	1	0	0	0
43	456	-1.0234	50.788	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	0	1	0	1	1
44	457	-1.0232	50.788	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	1	2	0	0	0
45	458	-1.0226	50.787	Hayling Beach	24/06/2020 23:00	0	0	1	0	0	0	0	1	2	0	1	1
46	459	-0.9074	50.775	West Wittering Beach	17/06/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
47	462	-0.912	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	1	1	0	1	1	7	1	1	2
48	463	-0.9122	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	0	1	0	1	1	6	0	1	1
49	464	-0.9123	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	0	1	0	1	1	6	0	1	1
50	465	-0.9125	50.778	West Wittering Beach	16/07/2020 23:00	1	0	1	1	1	0	1	1	6	1	1	2
51	466	-0.9119	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	1	1	0	1	1	7	0	1	1
52	472	-0.9122	50.778	West Wittering Beach	16/07/2020 23:00	0	1	1	1	1	0	1	1	6	0	0	0
53	473	-0.9124	50.778	West Wittering Beach	16/07/2020 23:00	0	1	0	0	0	0	0	1	2	0	1	1
54	474	-0.9119	50.778	West Wittering Beach	16/07/2020 23:00	0	1	1	0	1	0	1	1	5	0	1	1
55	475	-0.9119	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	1	1	1	0	1	7	0	1	1
56	476	-0.912	50.778	West Wittering Beach	16/07/2020 23:00	1	1	1	1	1	0	0	1	6	0	1	1
57	181	-0.9363	50.784	East Head	14/03/2018	10	10	3	0	32	1	0	0	56	0	0	0
58	127	-1.0252	50.794	Hayling Beach	23/06/2019 23:00	0	0	0	0	0	0	0	0	0	0	0	0
59	128	-1.025	50.794	Hayling Beach	23/07/2019 23:00	0	0	0	0	0	0	0	2	2	0	0	0
60	129	-1.0252	50.795	Hayling Beach	23/07/2019 23:00	1	4	4	2	0	0	0	7	18	0	0	0
61	130	-1.0222	50.786	Hayling Beach	23/07/2019 23:00	0	0	2	0	0	0	0	1	3	0	0	0

62	60	129	-1.0252	50.795	Hayling Beach	23/07/2019 23:00	1	4	4	2	0	0	0	7	18	0	0	0
63	61	130	-1.0222	50.786	Hayling Beach	23/07/2019 23:00	0	0	2	0	0	0	0	1	3	0	0	0
64	62	131	-1.0222	50.786	Hayling Beach	23/07/2019 23:00	0	1	1	0	0	0	0	5	7	0	0	0
65	63	132	-1.0222	50.786	Hayling Beach	23/07/2019 23:00	2	1	0	1	0	2	0	7	13	0	0	0
66	64	169	-0.9366	50.779	East Head	14/03/2018	0	1	1	0	0	0	0	0	2	0	0	0
67	65	170	-0.9365	50.779	East Head	14/03/2018	0	0	0	0	0	0	0	0	0	0	0	0
68	66	171	-0.9364	50.779	East Head	14/03/2018	0	0	0	0	0	0	0	0	0	0	0	0
69	67	173	-0.9362	50.78	East Head	14/03/2018	1	0	0	0	0	1	0	0	2	0	0	0
70	68	174	-0.9361	50.78	East Head	14/03/2018	2	3	1	0	2	0	0	0	8	0	0	0
71	69	176	-0.9362	50.782	East Head	14/03/2018	0	0	1	0	1	0	0	0	2	0	0	0
72	70	177	-0.9364	50.784	East Head	14/03/2018	2	0	0	0	0	0	0	0	2	0	0	0
73	71	180	-0.9361	50.78	East Head	14/03/2019	6	15	5	0	10	0	0	0	36	0	0	0
74	72	183	-0.9362	50.784	East Head	14/03/2018	0	0	2	0	0	0	0	0	2	0	0	0
75	73	184	-0.9362	50.785	East Head	14/03/2018	0	0	1	0	0	0	0	0	1	0	0	0
76	74	186	-0.9135	50.779	East Head	14/03/2018	4	4	10	0	2	0	0	7	27	0	0	0
77	75	187	-0.9135	50.779	East Head	14/03/2018	0	1	0	0	0	0	0	1	2	0	0	0
78	76	188	-0.9136	50.779	East Head	14/03/2018	2	1	1	0	0	0	0	0	4	0	0	0
79	77	190	-0.9146	50.779	East Head	14/03/2018	0	0	1	0	0	0	0	3	4	0	0	0
80	78	192	-0.9146	50.779	East Head	14/03/2018	0	0	1	0	0	0	0	2	3	0	0	0
81	79	194	-0.9149	50.779	East Head	14/03/2018	0	0	1	0	0	0	0	0	1	0	0	0
82	80	196	-0.9152	50.783	East Head	14/03/2018	0	0	2	0	0	0	0	7	9	0	0	0
83	81	198	-0.9153	50.786	East Head	14/03/2018	0	0	1	0	0	0	0	3	4	0	0	0
84	82	200	-0.9156	50.786	East Head	14/03/2018	0	0	0	0	0	0	0	1	1	0	0	0
85	83	201	-0.9159	50.786	East Head	14/03/2018	0	0	0	0	0	0	0	2	2	0	0	0
86	84	203	-0.9162	50.786	East Head	14/03/2018	0	0	0	0	0	0	0	4	4	0	0	0
87	85	204	-0.9142	50.789	East Head	14/03/2018	0	0	1	0	0	0	0	3	4	0	0	0
88	86	207	-0.9141	50.789	East Head	14/03/2018	18	11	15	0	1	0	0	2	47	0	0	0
89	87	208	-0.9162	50.786	East Head	14/03/2018	0	0	0	0	0	0	0	4	4	0	0	0
90	88	210	-0.9142	50.789	East Head	14/03/2018	0	0	1	0	0	0	0	3	4	0	0	0
91	89	212	-0.9143	50.789	East Head	14/03/2018	0	0	0	0	1	0	0	2	3	0	0	0
92	90	213	-0.9145	50.789		14/03/2018	0	0	0	0	0	0	0	4	4	0	0	0
93	91	214	-0.9126	50.789	East Head	14/03/2018	1	0	1	0	0	0	0	0	2	0	0	0
94	92	216	-0.9125	50.789	East Head	14/03/2018	0	0	0	0	0	0	0	1	1	0	0	0
95	93	218	-0.9124	50.789	East Head	14/03/2018	0	0	0	0	0	0	0	2	2	0	0	0
96	94	220	-0.9086	50.787	East Head	14/03/2018	0	0	1	0	0	0	0	0	1	0	0	0
97	95	222	-0.9085	50.787	East Head	14/03/2018	0	0	2	0	0	0	0	1	3	0	0	0
98	96	223	-0.9085	50.787	East Head	14/03/2018	0	0	0	0	0	0	0	22	22	0	0	0
99	97	225	-0.9093	50.787	East Head	14/03/2018	0	0	0	0	0	0	0	1	1	0	0	0
100	98	227	-0.9126	50.785	East Head	14/03/2018	0	0	1	0	0	0	0	2	3	0	0	0
101	99	172	-0.9713	50.833		11/07/2018 23:00	0	0	0	0	0	0	0	12	12	0	0	0
102	100	175	-0.9133	50.84		11/07/2018 23:00	0	0	3	0	0	4	0	46	53	0	0	0
103	101	178	-0.9451	50.843		11/07/2019 23:00	0	0	0	0	0	0	0	9	9	0	0	0
104	102	179	-0.9374	50.845		11/07/2018 23:00	0	0	0	0	0	0	0	31	31	0	0	0
105	103	182	-0.8512	50.828		11/07/2018 23:00	14	5	25	6	1	9	4	112	176	0	0	0
106	104	185	-0.9155	50.782		21/06/2018 23:00	8	3	24	0	1	1	0	37	74	0	0	0
107	105	189	-0.9151	50.786		21/06/2018 23:00	0	2	9	0	0	0	0	6	17	0	0	0
108	106	191	-0.9149	50.788		21/06/2018 23:00	2	0	0	0	0	0	0	8	10	0	0	0
109	107	193	-0.916	50.786		21/06/2018 23:00	0	0	0	0	0	0	0	1	1	0	0	0
110	108	195	-0.9147	50.789		21/06/2019 23:00	0	0	0	0	0	0	0	1	1	0	0	0
111	109	197	-0.9154	50.782		21/06/2018 23:00	0	0	1	0	0	0	0	3	4	0	0	0
112	110	199	-0.9157	50.782		21/06/2018 23:00	0	0	1	0	0	0	0	3	4	0	0	0
113	111	202	-0.9157	50.782		21/06/2018 23:00	1	1	1	0	0	0	0	3	6	0	0	0
114	112	205	-0.9141	50.779		11/04/2018 23:00	0	0	1	0	0	0	0	3	4	0	0	0
115	113	206	-0.9152	50.784		11/04/2018 23:00	0	0	0	0	0	0	0	3	3	0	0	0
116	114	209	-0.9153	50.783		11/04/2018 23:00	0	0	0	0	0	0	0	3	3	0	0	0
117	115	211	-0.9158	50.783		11/04/2018 23:00	0	0	1	0	0	0	0	1	2	0	0	0
118	116	215	-0.9163	50.782		14/03/2018	0	0	1	0	0	0	0	2	3	0	0	0
119	117	217	-0.9158	50.782		14/03/2018	0	2	1	0	0	0	0	3	6	0	0	0
120	118	219	-0.9154	50.782		14/03/2018	0	0	0	0	0	0	0	3	3	0	0	0
121	119	221	-0.9149	50.783		14/03/2018	0	0	0	0	0	0	0	3	3	0	0	0
122	120	224	-0.9126	50.785		14/03/2018	0	0	1	0	0	0	0	0	1	0	0	0
123	121	226	-0.9125	50.785		14/03/2018	0	0	2	0	0	0	0	0	2	0	0	0