CHARACTERISTICS AND DISTRIBUTION OF LITTER AND MICROPLASTICS IN TABLE BAY, CAPE TOWN, SOUTH AFRICA

by

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DECLARATION

I, Wakuenda Alex Bukasa, declare that the contents of this dissertation represent my own unaided work, and that the thesis/dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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ABSTRACT

The increasing amount of waste such as litter and microplastics has drawn society's attention because of their ubiquitous and complex nature and associated damage to the economy, human, and ecological well-being. This study investigated the characteristics and distribution of litter (> 25 mm) and microplastics (<5mm) in Table Bay, Cape Town. The study went further to also investigate meso-sized items (5–25 mm). The two sites, Woodbridge Island and Derdesteen beaches were selected based on their similar exposure to wind and current as well as their difference in the frequency of visitors, major land use, and proximity to residential areas (suburban or rural) and rivers. Each sampling site was 100 meters long, where litter, mesolitter, water and sediment samples for the extraction of microplastics were collected in 2021. The collection of litter was done for 10 consecutive days on both sites in summer and autumn, where all visible discarded objects were collected. Mesolitter was collected in summer alone for 10 consecutive days using a 0.5 m x 0.5 m sieve with a 2 mm metallic mesh. Water and sediment samples were collected on both sites in summer and autumn for microplastics extraction. Polymer identification was done through spectroscopy, using a Perkin Elmer-Two Fourier transform infrared attenuated total reflectance (FTIR-ATR) Spectrometer. Non-parametric analyses were conducted on the data using a Mann–Whitney (MW) test for two groups, as the test for normality were not met. Data variances for statistical analysis were presented using the standard error of the mean (SE) and parameter significance was set at $p < 0.05$. All analyses were done using the SPSS v28.

A total of 11 179 litter items weighing 20 028.07 g (20 kg) were collected during this study. The occurrence of litter varied seasonally with autumn accounting for more items than summer by count (52.63% and 47.37% respectively) and less by weight (24.45% and 75.55% respectively). In addition, the litter count showed no significant between the two seasons ($U = 741$, $p = 0.570$) while the litter weight showed a significant one ($U = 595$, $p = 0.049$). Litter also varied by site, with 89.49% of the total count found in Woodbridge Island compared to 10.51% at Derdesteen. The same trend was observed for the total weight of litter where 61.62% was found at Woodbridge Island compared to 38.38% at Derdesteen. The statistical tests showed significant differences in litter count ($U = 67$, $p < 0.001$) and weight ($U = 500$, $p = 0.004$) between the two sites. The daily accumulation rate of litter varied over the 10 consecutive days of sampling in summer and autumn. The brand audit showed that most of the identified brands in Table Bay were of local origin, mostly made of snack (78.95%) and beverages packaging (21.05%). Plastic was the most abundant litter type recorded, accounting for 90.27% by count and 43.45% by weight. Hygiene objects, metal, wood, rubber, marine, clothing, paper, glass, unclassified items were encountered alongside plastic. Foam, fragments, cigarette butts, wrapping, bottles, lollipop sticks, straws, utensils, and shopping bags were the types of plastic litter found during the survey. Of these plastic litter types, foam (Styrofoam) was the most abundant both by count and weight, with 41.74% and 48.32% of all the plastic litter collected. Furthermore, Polyethylene (PE) was the dominant polymer type found (69.23%) and was followed by polypropylene (PP), cellulose acetate (CL), and polystyrene (PS). The Clean Coast Index was calculated and both beaches could be classified as very clean.

For meso-sized litter items, only collected in summer, 1428 items were counted and weighed 12.20 g. Of all mesolitter collected, 98.46% were recorded at Woodbridge Island and 1.54% at Derdesteen while all litter weight (100%) was found at Woodbridge Island. In addition, there were significant differences in mesolitter count ($U = 5172$, $p = 0$) and weight ($U = 11\,460$, $p = 0.02$) between the two sites. Inter and intra-beach variabilities were observed in this study. The daily accumulation rate of mesolitter varied over the 10 consecutive days of sampling. In terms of mesolitter characteristics, plastic items (mesoplastics) were the most abundant type found in this study, making up 99.05% by count and 78.69% by weight, with metals accounting for 21.31% of the remaining weight. Of the mesoplastics, pellets represented 69.75 % of all meso-plastics by count, followed by foam (18.49 %) and fragment (10.78 %). Polyethylene (PET) was the most dominant polymer type found in mesolitter with 59.52 % of all polymers found.

Of the 688 microplastics (MPs) extracted from water and sediment samples, 57.81 % were recorded in summer and 40.19% in the autumn however, no significant difference was found between the two seasons ($U = 525$, $p = 0.861$). 75.66 % of all microplastics were recorded on Woodbridge Island, compared to 24.34 % in Derdesteen. Statistical tests showed a significant difference in microplastics between the Woodbridge Island and Derdesteen ($U = 258.5$, $p = 0.002$). Fibre was the most abundant MPs type found, while blue was the most abundant colour, and the size category of 0.1 to 0.5 mm was dominant. This study provided evidence of the occurrence of litter, mesolitter, and microplastics and highlighted their seasonal and site variabilities, and their characteristics in the coastal environment of Table Bay in Cape Town. In addition, factors such as wind, land use, proximity to metropolitan areas, and public access contributed to litter, mesolitter, and microplastics occurrence in Table Bay. The findings of this study laid the groundwork for a better understanding of the spatial and temporal variations and characteristics of litter, mesolitter and microplastics. They contributed towards historical data of litter, mesolitter, and microplastics in Table Bay and serve as baseline for future research.

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See,

"It takes a whole village to raise a child"

(African Proverb)

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ABBREVIATIONS AND ACRONYMS

CCI	Clean Coast Index
CCT	City of Cape Town
CL	Cellulose acetate
DEA	Department of Environmental Affairs
DEDAT	Department of Economic Development and Tourism
DEFF	Department of Environment, Forestry, and Fisheries
DFFE	Department of Forestry, Fisheries, and the Environment
FTIR	Fourier transform infrared spectroscopy
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
MPs	Microplastics
MPs/L	Microplastics per litre
MPs/Kg	Microplastics per kilogramme
NEM: WA	National Environmental Management Acts-Waste Acts
NWMS	National Waste Management Strategy
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
SPSS	Statistical Package for the Social Sciences
WCG	Western Cape Government
WHO	World Health Organisation

GLOSSARY

Clean Coast Index	Clean Coast Index is a tool for evaluation of the actual coast cleanliness (Alkalay et al., 2007).
Litter	Litter comprises discarded manufactured items such as plastic, rubber, metal, paper, processed wood, textiles, and glass that are likely to end up in marine and coastal environments (Barnardo and Ribbink, 2020)
Microplastic	Microplastics are plastic particles less than 5 mm in size from primary and secondary sources (Castillo et al., 2016)

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 Statement of the Research problem

With changes in consumer behaviour and technological advancement, the amount of waste generated has increased in quantity and composition. Poor waste management and weak policies have caused litter, including microplastics, to end up in the environment, with pollution reaching alarming levels. The presence of litter of varying sizes (macro-and meso-) in the marine environment, for instance, threatens marine and coastal wildlife, the economy, and human health as well as damages the aesthetic of the coastline (Lamprecht, 2013; Thompson et al., 2009). Microplastics threaten the food chain because of their potential to adsorb and transfer toxic chemicals (Reisser et al., 2014). In addition, the small size of microplastics makes them easily ingestible by marine organisms (Auta et al., 2017). South Africa and Cape Town in particular experience the effect of population growth, economic development, and urbanization, potentially resulting in increased quantity and composition of waste (Nyika et al., 2019). Cape Town, the legislative capital and the second most populous urban area of the country, generated over 5,5 million tons of waste in 2015 alone (DEDAT, 2016; CCT, 2018). Considering that the state of waste management in South Africa is poor and is characterised by inadequate waste collection and disposal, waste potentially leaks into the environment (Arabi and Nahman, 2020). There is a need to better understand the occurrence of waste in the marine environment. Hence, this study investigated the characteristics and distribution of litter, mesolitter, and microplastics in the environment. To achieve this aim, two beaches in the coastal area of Table Bay in Cape Town were selected as the study area.

1.2 Research question

The central question of this research was: what are the characteristics and distribution of litter and microplastics in Table Bay? This is an important and timely topic of investigation due to the increasing concern about the impact of waste on the environment. The research objectives will provide a comprehensive understanding of the issue by examining the characteristics and distribution of litter (including mesolitter) and microplastics on Woodbridge Island and Derdesteen beaches in Table Bay during summer and autumn.

1.3 Aims

The research aimed to investigate the characteristics and distribution of litter and microplastics in Table Bay.

1.4 Objectives

The research objectives were:

1. To determine the characteristics and distribution of litter in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay.

2. To determine the characteristics and distribution of meso-litter on Woodbridge Island and Derdesteen beaches in Table Bay.

3. To determine the characteristics and distribution of microplastics form water and sediment in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay.

1.5 Significance of the study

The findings of this study laid the groundwork for a better understanding of the spatial and temporal variations and characteristics of litter, mesolitter and microplastics. They contributed towards historical data of litter, mesolitter, and microplastics in Table Bay and serve as baseline for future research. The findings of this research provide a comprehensive understanding of the characteristics and distribution of litter and microplastics which will inform regional and international strategies for mitigating the impact of waste on the environment. The context of the study also highlights the importance of addressing root causes of the issue, such as poor waste management and weak policies, in addition to mitigating the immediate impacts of litter and microplastics in the environment.

1.6 Delineation of the study

The scope of the research is solely focused on litter, mesolitter, and microplastics in the coastal environment of Table Bay in Cape Town, South Africa. Furthermore, it only deals with microplastics from water and sediment samples. Woodbridge Island and Derdesteen, positioned at 14.6 km apart, are the two sandy beaches considered in this study.

1.7 Layout of the thesis

This thesis consists of the following 6 chapters:

CHAPTER 1	States the research problem, research questions, the aim and objectives, significance of the study, delineation of the study, and the layout of the thesis.
CHAPTER 2	Presents the background of the problem, a review of relevant research associated with the problem addressed in this research.
CHAPTER 3	Presents the materials and methods used for field sampling and laboratory analysis of litter, mesolitter, and microplastics.
CHAPTER 4	Reports the results of litter, mesolitter, and microplastics in Table Bay.
CHAPTER 5	Discusses the results obtained regarding the litter, mesolitter and microplastics from Table Bay.
CHAPTER 6	Provides a general conclusions and recommendations for future research.

CHAPTER TWO

LITTERATURE REVIEW

CHAPTER 2

LITTERATURE REVIEW

Because of population growth and urbanization, marine litter and microplastics have become a global problem, threatening marine and coastal wildlife, the economy, and human health as well as damaging the aesthetics of the coastline (Lamprecht, 2013). The problem is accentuated by the changes in consumer behaviour and technological advancement, which have led to an increase in the quantity and composition of discarded materials. Marine litter comprises discarded manufactured items such as plastic, rubber, metal, paper, processed wood, textiles, and glass that end up in marine and coastal environments (Barnardo and Ribbink, 2020). Litter leaks into the marine environment from sea and land-based sources (Opie, 2021; Galgani et al., 2015). Sea-based sources are either a result of accidental loss, or mismanagement of waste at sea linked to anthropogenic activities off-shore (Opie, 2021; Cheshire et al., 2009). These activities include fishing, recreational boats, and offshore oil rigs. Land-based sources, include point and non-point sources such rivers, stormwater systems, windblown litter and materials left by beach goers, harbours and unprotected landfills and dumps located near the coast (Galgani et al., 2015; Ryan et al., 2009). The small-sized litter of 5–25 mm, referred to as mesolitter (Haseler et al., 2018) are more likely to end in the marine environment alongside bigger items. Amongst the different types of marine litter, plastic is the most harmful, abundant, and persistent, making up 60–80% of all marine litter (Abalansa et al., 2020). The use of plastic-based products in the packaging, food, travel, and clothing industries has significantly replaced metal, glass, and paper (Abayomi et al., 2017). This shift in consumer behaviour is attributed to the relative cheapness, durability, lightweight, and malleability of plastic materials (Boucher and Friot, 2017). However, due to improper disposal, plastic has become a major part of marine litter, as mentioned previously. The negative effects of marine litter include wildlife choking and starvation, the spread of non-native and potentially harmful organisms, toxic chemical adsorption, and the degradation of plastic litter into microplastics (Naidoo et al., 2020; Barnes et al., 2009; Gall and Thompson, 2015). Microplastics are plastic particles less than 5 mm in size from primary and secondary sources (Castillo et al., 2016). The primary microplastics are produced directly for specific purposes, such as pallets, industrial abrasives, exfoliants, and other cosmetics or toiletry products (WHO, 2019). Secondary microplastics result from the breakdown of large plastics in the environment due to factors such as sunlight, temperature, wave action, oxygen availability, and turbulence (Auta et al., 2017; WHO, 2019). Microplastics have the potential to adsorb and transfer toxic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) through the food chain (Reisser et al., 2014; Rochman et al., 2013; Endo et al., 2005), and are susceptible to ingestion by marine organisms due to their size (Auta et al., 2017).

Thus, the accumulation of litter and microplastics in the environment potentially causes a range of adverse effects.

2.1 Global Litter

Global plastic production, estimated at 335 million tonnes in 2016, is expected to double in 2035 and quadruple in 2050, while the quantity of plastic debris, a constituent of litter, is likely to rise because of this (Jambeck et al., 2015; Mrowiec, 2018). Globally, litter is mostly characterized by items such as plastic, paper, metal, textile, glass, and rubber, with accumulation rates varying considerably across the globe (Galgani et al., 2015). The accumulation rates are attributed to factors such as the proximity to large cities, shore use, seasonal changes, hydrodynamics, and maritime activities (Agamuthu et al., 2019; Galgani et al., 2015). As for the litter type, plastics are considered the most important element of marine litter, accounting for 50 to 90% of all marine litter found worldwide, with 4.8 to 12.7 million tons of plastic entering the marine environment in 2010 alone (Agamuthu et al., 2019). The amount of plastic entering waterways and eventually the oceans is predicted to reach 22 million to 58 million tons per year by 2030 (Borrelle et al., 2020). Furthermore, the global density of plastic litter on beaches is 1 item/m^2 (Galgani et al., 2015). The most common global plastic litter types are packaging, fishing nets and lines, polystyrene, and plastic fragments (Galgani et al., 2015). Globally, plastic packaging accounts for 50% of the total plastic litter (Ncube et al., 2021). This is attributed to population growth resulting in high demand for food, coupled with the global trend characterized by fast foods, ready-made meals, on-the-go beverages, and snacks, which drive the need for single-use food packaging (Ncube et al., 2021). Consequently, single-use plastics (plastic straws, plastic bags, plastic bottles, etc..) are mass-produced, about 330 billion pieces a year, and is often used for a few hours before it is disposed of (Barra and Leonard, 2018; Ncube et al., 2021). In terms of spatial distribution, the middle-and low-income countries' poor waste management results in up to 90% of their plastic being improperly disposed of (Ncube et al.,2021). The high-income countries, due to their improved waste management, have demonstrated a decline in plastic litter despite a high per capita consumption of plastic packaged products (Ncube et al.,2021). The global pattern of plastic litter is high in Africa and Asia and is predicted to increase (Lebreton and Andrady, 2019).

The top ten plastic waste producers are China, the Philippines, Indonesia, Vietnam, Malaysia, Egypt, Sri Lanka, Thailand, Nigeria, and Bangladesh (Issifu and Sumaila,2020). Larger litter items break down into meso-and micro-litter in the marine environment because of photodegradation, oxidation, and mechanical abrasion (Kershaw et al., 2019, Opie, 2021). Mesolitter consists mostly of primary meso-items such as industrial pellets and Styrofoam balls and secondary meso-items (Kershaw et al., 2019). With much discussion about the terminology for various debris sizes, 1–25 mm for mesolitter and 0.001–1 mm for microplastics were proposed by GESAMP (Kershaw, 2015), although most recent literature has adopted 5 mm as the upper limit for micro-debris. There is a limited understanding of the dynamics of mesolitter in the marine environment as most research focuses on macro and micro items, and limited work has been carried out on mesolitter (Lee et al., 2017). However, to understand the likely long-term impact of marine pollution, it must be determined whether meso-and macro-sized items coexist on the same beaches. Hence, this study also investigated the litter of meso-size in Table Bay. Mesolitter is a category of litter comprised of items between 5–25 mm (Kershaw, 2015; Haseler et al., 2018), although the current study will use 2 mm as the lower limit, as done by Ryan et al. (2018). Because of its small size, mesolitter has the potential to threaten marine organisms through ingestion, adsorption, and transfer of toxic chemicals (Galgani et al., 2015). Additionally, wind and currents can easily displace mesolitter from one area to another, potentially introducing non-native species. Furthermore, ingestion of meso-litter can cause intestinal blockage, malnutrition, poisoning, and blockage in filter-feeding organisms (Arias and Marcovecchio, 2017). Organisms such as *Balaenopteridae, Delphinidae, Kogiidae, and Ziphiidae* are affected by mesolitter (Eisfeld-Pierantonio et al., 2022). It is difficult to compare mesolitter between studies because of the size limit that different surveys chose, as well as the units. Recent studies express the density of mesolitter per unit area of the beach (Lee et al., 2017; Haseler et al., 2019; Okuku et al., 2020a) which have the risk of yielding biased estimates (Ryan et al., 2018). Thus, the current study adopted the size limits (2–25 mm) and units (item/m) used by Ryan et al. (2018).The occurrence of mesolitter was investigated on 20 beaches in South Korea. The research reported a mean mesolitter abundance of 13.2 item/m^2 weighing 1.5 g/m^2 dominated by hard plastics and Styrofoam (Lee et al., 2017). In the Baltic Sea's beaches in Germany, a total of 3177 pieces of litter were collected during 10 surveys over an area of 100 m^2 (31.8 pieces/m^2) (Haseler et al., 2019). Of the 3 177 pieces collected, micro-litter represented 219 pieces (2.2 pieces/m^2–6.9%), followed by meso-litter with 607 pieces (6.1 pieces/ m^2–19.1%), and macro-litter with 2351 pieces (23.5 pieces/m^2–74.0%).

Okuku et al. (2020a) surveyed mesolitter on Kenyan coastal beaches, discovering that mesoplastic was the most abundant type. Counts were high in beaches close to populated areas, with a mean of 2572.7 ± 1320.0 items/m^2 compared to those in areas close to semi-populated areas (328.6 ± 94.1 items/m^2) and remote areas (122.7 ± 20.7 items/m^2). This was explained by the fact that populated areas receive higher numbers of visitors and have the most tourist infrastructure (hotels, restaurants, etc.), which consequently increases the amount of litter generated on these beaches, unlike remote beaches, which are not influenced by tourism (Okuku et al., 2020a). Mesoplastic, a constituent of mesolitter, is composed of harmful substances such as antimicrobials, hydrocarbons, and flame retardants, which can cause significant changes in marine and biodiversity health (Moore, 2008). Additionally, submerged meso-plastics can destroy important nursery habitats by interfering with or smothering their inhabitants (Gordon et al., 2011).

2.2 Global Microplastics

Microplastics are increasingly being recognized as highly persistent and threatening to the marine biota and their associated marine habitats worldwide (Castillo et al., 2016; Barboza et al., 2018). Boucher and Friot (2017) reported the microplastic contribution by certain geographical areas as follows: Southeast Asia (15.9%), North America (17.2%), and Africa and the Middle East (8.7%). The global estimate of accumulated microplastic particles in 2014 ranged from 15 to 51 trillion particles, weighing between 93 and 236 thousand metric tons (Van Sebille et al., 2015). However, these estimates are higher than previous global estimates, but they vary widely due to a lack of data in the majority of the world's oceans, differences in model formulations, and fundamental knowledge gaps in the sources, transformations, and fates of microplastics in the ocean (Van Sebille et al., 2015). According to Boucher and Friot (2017), the global release of primary microplastics into the ocean is estimated to be 1.5 million tons per year, with estimates ranging between 0.8 and 2.5 million tons per year depending on the optimistic or pessimistic scenario. These figures are not based on field measurements but rather on modelling sources and leakages from economic and household activities from exclusively publicly available data for multiple sites (Boucher and Friot, 2017). Galgani et al. (2015) reported that the global concentration of microplastics ranges from thousands to hundreds of thousands of particles per km^2. The majority of primary microplastics losses (98%) are caused by land-based activities, with only 2% caused by sea-based activities (Boucher and Friot, 2017). Furthermore, the largest proportion of land-based microplastics comes from the laundering of synthetic textiles as well as from the abrasion of tyres while driving.

2.3 Litter in South Africa

South Africa, like the rest of the globe, is dealing with the issue of marine litter along its coastline. From 1984 to 1989, Ryan and Moloney (1990) investigated 50 beaches along the coast of South Africa. The results showed that 88% of the litter collected was plastic, composed mostly of packaging and other disposable items. In addition, non-plastic items were made of wood, glass, metal, paper, cloth, and wax products (Ryan and Moloney, 1990). In 1995, the survey of Milnerton and Koeberg beaches in Table Bay indicated that plastic litter was the most abundant litter type, representing 81.7% of all litter collected (Swanepoel, 1995). Plus, half of the plastic litter was Styrofoam. Two years later, in 1997, three beaches were surveyed along an undeveloped coastline in two South African localities. Plastic litter was found to be the most abundant litter type, representing 83% of total litter count and 47% of total litter weight (Madzena and Lasiak, 1997). In addition, Madzena and Lasiak (1997) found that popular tourist beaches showed the widest range of litter types. Later in 2012, Lamprecht (2013) investigated the change in marine litter on the same beaches as Swanepoel (1995) (Milnerton and Koeberg) in Table Bay. The results showed that plastic debris represented 93.3% of all materials collected by count and 58.9% by weight (Lamprecht, 2013). In addition, plastic items were characterized by fragments, polystyrene (Styrofoam), sweet wrappers, lids, bottles, and cotton buds, while non-plastic items were characterized by wood, glass, and cloth. Ryan et al. (2014) surveyed to determine the density of marine debris in the African sector of the Southern Ocean where no difference in litter density was found between sub-Antarctic and Antarctic waters on either side of the Antarctic Polar Front. In addition, the result showed that only 52 litter items larger than 1 cm in diameter were found over the 10,467 km of at-sea transects, of which 96% were plastic (Ryan et al., 2014). Furthermore, the most common plastic litter found was packaging (58%), followed by pieces (19%) and fishing materials (17%). Chitaka and von Blottnitz (2019) indicated an increase in plastic debris compared to previous surveys reported by Swanepoel (1995) and Lamprecht (2013). Chitaka and von Blottnitz (2019) survey of five beaches (Hout Bay, Milnerton, Muizenberg, Paarden Eiland, Wolfgat Nature Reserve) in Cape Town showed that plastic items made up 94.5–98.9% of the total litter count. The mass of items collected ranged from 0.01–367 g, with items weighing less than 1 g contributing 61–85% of the count (Chitaka and von Blottnitz, 2019). In addition, bottles, lids, food packaging, lollipop sticks, polystyrene, utensils, and fragments were the most prevalent plastic litter found. In addition, the average litter accumulation rate was 36 to 2961 items per day per 100 linear meters across the beaches surveyed in Cape Town. Ryan (2020) indicated that the higher plastic densities observed close to major urban areas in South Africa "not only indicates that most marine plastic comes from local sources, but it also suggests that a large proportion of land-based plastic does not disperse far from source areas". In addition, Ryan et al. (2020) observed that the differences in the types of litter found on the beaches and those found on the streets are influenced by transport as well as environmental factors. Paper and cardboard were found to constitute 25% of street litter but only less than 1% of beach litter, while glass and metal were hardly found on the beaches (Ryan et al., 2020). In addition, cotton bud sticks, lids, plastic fragments, and polystyrene trays are more common on beaches. Ryan and Perold (2021) highlighted the complex dynamic of litter between rivers and the sea, implying that a significant amount of floating litter transported through small rivers washes on the beach soon after entering the sea. Litter occurrence in marine settings is influenced by a variety of factors, including catchment area characteristics, beach characteristics, weather conditions, ocean water movements, proximity to metropolitan areas, and public access (Madzena and Lasiak, 1997; Lamprecht, 2013; Willis et al., 2017; Chitaka and von Blottnitz, 2019, Ryan et al., 2018; Ryan et al., 2020).

2.4 Microplastics in South Africa

The occurrence of microplastics has affected countries around the world, including South Africa. Nel and Froneman (2015) investigated microplastics on the south-eastern coast of South Africa. The survey aimed to determine whether bays are characterized by higher microplastics than open stretches of coastline in both beach sediment and surf-zone water. The results showed little difference in microplastic density between bays and the open coast. In addition, more than 90% of microplastics were blue/black fibres, and no primary microplastics were found (Nel and Froneman, 2015). Furthermore, the results indicated that the presence of microplastics was not influenced by the proximity to land-based sources or population density but rather by the water circulation (Nel and Froneman, 2015). Nel et al. (2017) carried out a subsequent study to understand the link between population demographics and microplastics along the Southern African coast. The study showed no spatial differences in microplastics between high and low population density areas, except for Richard's Bay and Durban harbours (Nel et al., 2017). The two harbours were a source of microplastics while the lack of spatial variation between the high and low population areas was caused by the large-scale ocean currents (Nel et al., 2017). Hence, on two occasions (Nel and Froneman, 2015; Nel et al., 2017), ocean currents were identified as the main influence on microplastic distribution. Naidoo et al. (2015) conducted a characterization study of microplastics in five urban estuaries of Durban, where a higher concentration of cosmetic microbeads and fibres from sediment samples was found. The cosmetic microbeads and fibres found in the five estuaries of Durban originated from both industrial activities in the harbour and proximity to the ship repair station (Naidoo et al., 2015). In 2016 and 2017, de Villiers (2019) investigated microfibre in sediment at 175 sites along over 2700 km of South Africa's coastline. The highest levels of microfibre were found at sites in the proximity of large coastal wastewater treatment work discharge points, with the highest found on beaches along the East Coast of South Africa (de Villiers, 2019). De Villiers (2019) attributed the observed temporal variations in microfiber levels to seasonal changes in river runoff. Furthermore, in the Cape Peninsula, the highest level of microfibre in beach sediment was found close to wastewater discharge points at Seekoeivlei in False Bay and Milnerton in Table Bay. In South Africa, the potential of microplastics to accumulate in biota was investigated. Naidoo et al. (2016) investigated microplastics in the estuarine mullet (Mugil *cephalus*), revealing that 73% of estuarine mullet had microplastics in their digestive tracts with a mean of 3.8 particles per fish. In addition, more than half of the microplastics were fibre and nearly a third were fragments. In terms of colour, white and clear microplastics were the most common microplastics found (Naidoo et al., 2016). Gerber (2017) found that microplastics in mussels were more abundant in sites closer to river mouths than those further away, with an average of 2.22 ± 0.79 / g tissue w/w in KwaZulu Natal. The findings suggest that microplastics are flushed from freshwater to coastal or marine environments. In Cape Town, Sparks (2020) investigated microplastics in mussels in the coastal area of Cape Town. The study revealed that most microplastics in the mussels were filaments, that were dark in colour, and of between 50 and 1000 µm in size (Sparks, 2020). The abundance of microplastics ranged between 0–22 particles/gram (wet weight) and 0.3–43 particles/individual for all sites surveyed. Furthermore, Sparks (2020) noted a significant difference in microplastic abundance in mussels between the West Coast and False Bay. The abundance of microplastics on the Northwest Coast of Cape Town was higher than that of the Southwest Coast and there was no significant difference between the North and South of False Bay (Sparks, 2020). However, the current study investigated microplastics in water and sediment only. In a subsequent study, Sparks et al. (2022) reported the highest concentrations of microplastics yet recorded in Southern Africa. Sparks et al. (2022) surveyed the coastal sediment of a marina in Simon's Town, South Africa and found a median count of 5769 MPs/Kg dry weight for all sites.

2.5 Review of Waste Management in South Africa & Cape Town

South Africa, like many other countries, deals with the challenging process of managing waste, which is aggravated by economic development, population growth and urbanisation. The term waste in South Africa as defined in the National Environmental Management Acts-Waste Acts (NEM: WA) is any substance, whether that substance can be reduced, reused, recycled, or recovered; 1) that is surplus, unwanted, rejected, discarded, abandoned, or disposed of; 2) which the generator has no further use for production; and 3) that must be treated or disposed of (DEFF, 2020). The management of waste in South Africa is within the mandate of the Department of Forestry, Fisheries, and the Environment (DFFE) and is derived from section 24 of the Constitution of the Republic of South Africa (Act 108 of 1996) (DEFF, 2020). The section states that "*everyone has the right to an environment that is not harmful to their health or wellbeing, and to have the environment protected, for the benefits of the present and future generations, through reasonable legislative and other measures that prevent pollution and other degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development*." To carry out this mandate, the DFFE has created and implemented policies, legislation, strategies, and programs of which the National Environmental Management: Waste Act 59, 2008 (referred to as the Waste Act) and the National Waste Management Strategy (NWMS) are the most important (DEA, 2019; DEFF, 2020). In addition, the NWMS is a Waste Act statutory requirement. The country, through its NWMS 2020, outlined a strategic approach to reduce littering and illegal dumping and the production of single-use plastics such as food wrappers, disposable cups, and straws that are currently destroying marine habitats (DEFF, 2020). Population growth, economic development and urbanization are factors influencing waste generation in South Africa through resource consumption, manufacturing, and industrial development (Nyika et al., 2019). South Africa's waste classification as outlined in the classification and management regulations R634, is based on risk, and thus divided into hazardous and general waste (Nyika et al., 2019). Furthermore, the country's waste management is centred around the waste management hierarchy (reduce, reuse, recycle, and disposal). The management of general waste is geared away from landfill towards the reuse and recycling of this waste (Nyika et al., 2019). Over the past three decades South Africa has successfully developed a recycling economy partly driven by an active informal waste sector (Godfrey and Oelofse, 2017). There is still much to be done to improve the state of waste management given that significant quantities of waste are still disposed of to landfill (Godfrey and Oelofse 2017). In 2017, the country generated 55 million tonnes of general waste and 66.9 million tonnes of hazardous waste, according to the 2018 State of Waste Report, with only 11% and 6%, respectively, being diverted from landfill (DEFF, 2020). The largest contribution to the total quantity of general waste was organic (56.3%), made mostly of biomass, followed by municipal waste (8.9%), metals (7.4%), and commercial and industrial waste (6.6%) (DEA, 2018). In the Western Cape Province, 7.7 million tons of waste were generated in 2015, mostly comprised of municipal solid waste and agricultural waste (DEDAT, 2016). Furthermore, the City of Cape Town generated over 70% of the waste in the province in 2015, where the general waste category was dominant, followed by construction, agriculture, commercial and other types of waste (DEDAT, 2016; CCT, 2018). The state of waste management in South Africa is poor and is characterised by inadequate waste collection and disposal, potentially leaking into the environment (Arabi and Nahman, 2020). Efforts to improve the management of waste in the country resulted in a high increase in the plastic recycling rate in 2018 (46.3%) (Arabi and Nahman, 2020).

2.6 Table Bay

Table Bay, located on the west part of Cape Town in the Western Cape province, is a small, shallow embayment with a maximum depth of about 35 meters and a surface area of about 100 km^2 (Vos *et al.*, 2021). Furthermore, the bay stretches between the two headlands of Melkbosstrand and Green Point, with the bay's mouth primarily northwest and west-facing. Robben Island is also located to the northwest of the bay. The western shoreline of the Cape Peninsula is formed by a rocky coastline that extends southwards from the port of Cape Town until Cape Point (Vos *et al*., 2021). The bay is distinguished by 3 km of rocky shores at Blouberg and Mouille Point, as well as a 13 km long sandy beach between Blouberg and Table Bay harbour (Van Ballegooyen, 2007). The Western Cape's weather is characterized by a Mediterranean climate influenced by the Indian and Atlantic oceans (WCG, 2014). This results in dry and hot summers and wet and cold winters. Weather patterns such as rainfall and wind, for instance, have the potential to influence the accumulation of materials on the beach (Chitaka and von Blottnitz, 2019). The City of Cape Town is relatively dry, with an average annual rainfall of 515 mm and dry seasons spanning November to March, with yearly temperatures ranging from 7 °C to 27 °C and rarely falling below 4 °C or rising above 31 °C (WCG, 2014). In January, the average minimum and maximum temperatures are 16°C and 26°C, respectively, and in July, they are 7°C and 18°C (WCG, 2014). The Black and Diep Rivers mouths join in the Diep Estuary which connects the rivers to the Atlantic Ocean in Table Bay (Opie, 2021) with Woodbridge Island beach situated within 1 km of the large temporarily closed Diep Estuary. Lamprecht (2013) highlighted that rivers have the potential to pollute Table Bay (Lamprecht, 2013).

Large cold fronts approaching Cape Town are typically accompanied by strong northerly and north-westerly winds reaching gale force, causing the region's winter rainfall (Van Ballegooyen, 2007). The number of items entering the oceans is affected by the location of the source and the density of the items as well as the prevailing wind conditions (Chitaka and von Blottnitz, 2019). The movement of ocean water is a driving force behind particle accumulation along the coast (Chitaka and von Blottnitz, 2019). According to Vos *et al.* (2021), currents in Table Bay are weak and primarily wind driven. Wind driven surface current velocities in the bay typically range from 20 to 30 cm/s, with bottom current velocities of less than 5 cm/s (Van Ballegooyen, 2007). The invasion of upwelling cold water (9–13°C) in Table Bay from the Oudekraal upwelling centre causes the generally shoreward bottom flows observed in the southern part of the bay (Van Ballegooyen, 2007). Water flows into the bay from the north and northwest during the relaxation phases of the upwelling cycle (Van Ballegooyen, 2007). In the winter, wind from the north or north-westerly direction pushes water southward, causing a slight clockwise motion.

CHAPTER 3

METHODOLOGY

CHAPTER 3

METHODOLOGY

3.1 Study area

Cape Town is the legislative capital and the second most populous urban area in South Africa. The city of Cape Town has a population of 3,740,026 spanning over 2,461 km^2 (StatsSA, 2011). Table Bay, located in Cape Town comprised of a mix of rocky and sandy beaches (Van Ballegooyen, 2007). The two sampling sites Woodbridge Island and Derdesteen are sandy beaches positioned about 14.6 km from each other in Table Bay (Fig.3.1). The first site, Woodbridge Island beach (33°53'0.63" S, 18°29'9.62" E) in the suburb of Milnerton, is the closest to the Cape Town Harbour, and is used for recreational purposes such as bathing, surfing, walking, and angling (Swanepoel, 1995). Daily beach clean-up activities are organised by the municipality in Woodbridge Island. In addition, Woodbridge Island beach is within 1 km of the Diep River outlet. The second site, Derdesteen Beach (33°46'1.03" S, 18°26'39.22" E), is in the Blaauwberg Nature Reserve and is situated over 15 km from the Cape Town Harbour as well as residential areas (Fig.3.1 and A.2). Furthermore, major land-use in Derdesteen includes fishing and surfing. In Derdesteen, beach clean-up activities take place once every month. The two sites were chosen based on their similar exposure to weather conditions as well as their difference in the frequency of visitors, major land-use, and proximity to residential areas (suburban or rural) and the river.

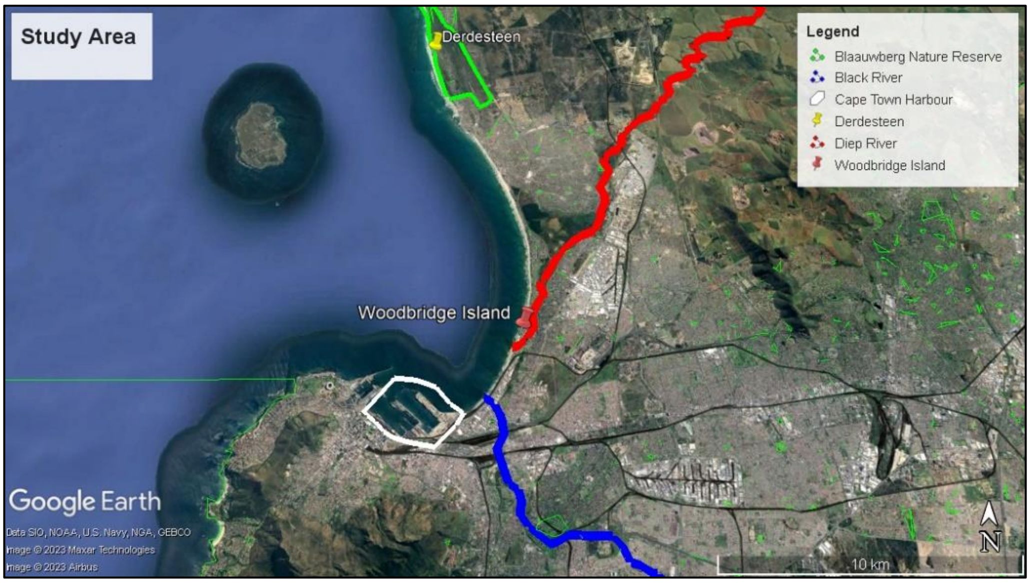

Figure 3. 1: Location of the study sites in Table Bay

(Google Earth Pro, 2023)

3.2 Sample collection

Woodbridge Island and Derdesteen beaches were the two collection sites selected in Table Bay (Fig 3.1). The samples were collected after the spring high tide along a predetermined length of the beach, from the edge of the water to the back of the beach, with each sampling site extending up to 100 meters in length. The collection area was divided into two sections: an intertidal zone with wet sand and a supratidal zone with dry sand (Fig 3.2). The dry zone accounts for the debris left behind by beach goers or windblown while the wet zone accounts for those deposited on shore by currents. Furthermore, the strandline, which was marked by the most recent high tide mark, separated the two tidal zones. Litter, meso-litter, and water and sediment (for MPs extraction) samples were collected. The litter as well as water and sediment samples were collected on both sites during the summer and autumn seasons of 2021, whereas meso-litter was only collected on both sites during the summer of 2021. Five replicates of litter, mesolitter, sediment, and water samples were each collected at Woodbridge Island and three at Derdesteen. The difference in number of replicates is due to Woodbridge Island being the impact site and Derdesteen the control site. The impact site was the focus of the study, and effort more concerted at the impact site. Also, safety concerns and practicality of sampling were a constraint, especially that the two sites were 14.6 km apart and sampling was done on the same day.

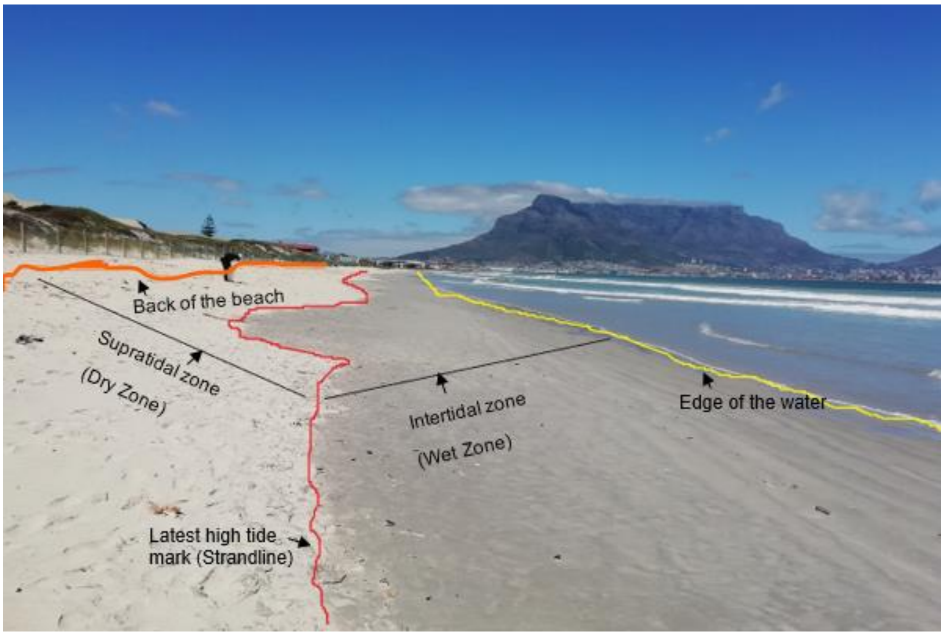

Figure 3. 2: Delineation of areas for sample collection in Table Bay

3.2.1 Litter

The collection of the litter samples followed Barnardo and Ribbink's (2020) protocol for macro-litter monitoring along shorelines. The litter was collected for 10 consecutive days per season (summer: 03rd February 2021-12th February 2021, and autumn: 26th April 2021-5th May 2021) on the beach's dry and wet sand within 100 meters and separated accordingly (dry and wet), as shown in Figure (3.2). The 100-metre stretch was divided into four 25-metre quadrats where the litter was collected systematically by walking in a predetermined pattern (Fig. 3.3). The collected litter was taken to the Microplastics lab at the Cape Peninsula University of Technology for further classification and weighing.

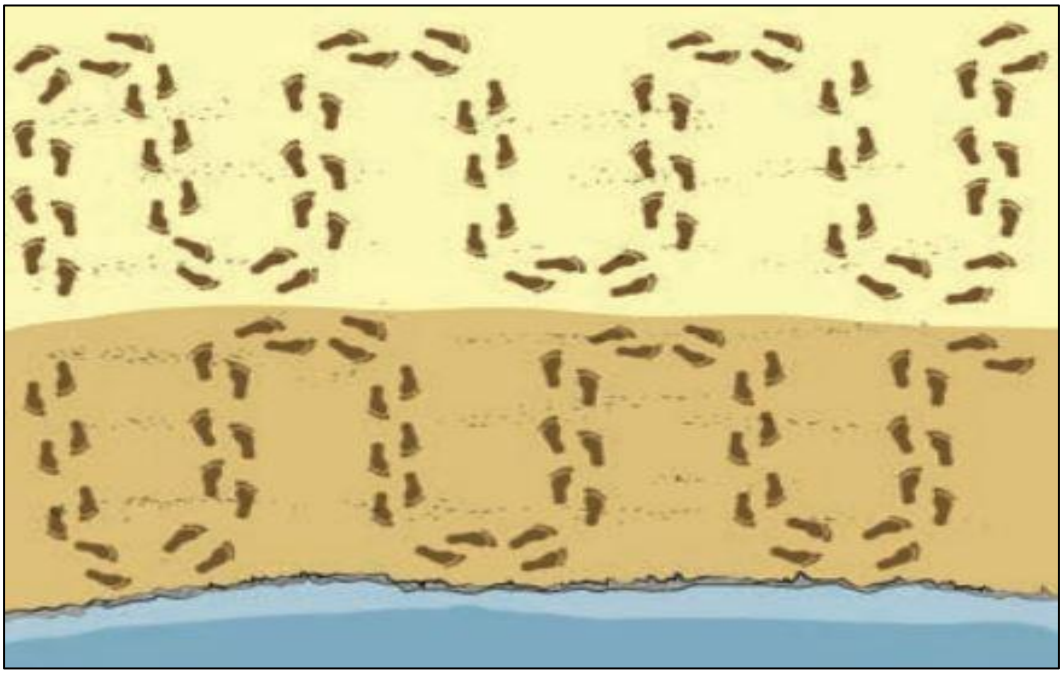

Figure 3.3: Planned walking pattern within the study area (Barnardo and Ribbink, 2020)

3.2.2 Mesolitter

Like Ryan et al. (2018), this study considered 2 mm as the lower size limit for meso-litter and the upper size limit of 25 mm. During the summer, meso-litter was collected for ten consecutive days (03rd February 2021-12th February 2021) at both sites using the same delineation shown in Figure (3.2) where the site was divided into intertidal zones. On-site mesolitter was collected using a 0.5 m x 0.5 m sieve with a 2 mm metallic mesh. Five 25-meter-apart transects were laid out in the study area, extending from the backshore to the water's edge in Woodbridge Island (the impact site) and three 50-meter-apart transects in Derdesteen (the control site). On each transect, four meso-litter samples were collected: two on the dry area (with on the backshore and the other in the halfway to the strandline), and two in the wet area (one on the strandline, and one on the lowest water mark). The top 5 cm of beach sand was collected with a shovel and sieved through the 0.5 m x 0.5 m sieve with a 2 mm metallic mesh . The collected items were placed in Ziploc bags and transported to the Microplastics lab at the Cape Peninsula University of Technology for further classification and analysis.

3.2.3 Microplastics-Water samples

The collection of water samples for microplastics extraction was done on the 03rd of February and 26th of April (autumn) 2021. Two procedures were utilised for water samples using a metallic bucket to minimize contamination that would have resulted from using a plastic bucket. The first procedure was to collect five replicates of 20 L filtered on-site with a 250 µm sieve for Woodbridge Island and three replicates for Derdesteen for the summer and autumn seasons. The particles on the mesh were placed in falcon tubes and transported to the laboratory for further examination. The second procedure was collected at Woodbridge Island, with five replicates of 1 L and three replicates at Derdesteen using glass jars.

All samples were transported to the Cape Peninsula University of Technology for further analysis.

3.2.4 Microplastics-Sediment samples

The collection of sediment samples for microplastics extraction was done on the 03rd of February and 26th of April 2021. On a 100-meter stretch of beach, two replicates were collected on the dry area of the beach on five transects (25 meters apart) in Woodbridge Island and three transects (50 meters apart) on Derdesteen beach. Woodbridge Island was the impact site and Derdesteen was the control site, hence the difference in the number of replicates on both sites. At the respective sites, the upper 5 cm of sediment within a 0.25m x 0.25m quadrat was sampled and stored in pre-cleaned jars using MilliQ water. These jars were taken to the Cape Peninsula University of Technology Microplastics laboratory for further analysis.

3.3 Analysis

3.3.1 Quality control

A white cotton coat was worn in the laboratory to reduce exposure to ambient microplastics during the analysis phase. No plastic items were used in the laboratory, all glassware and items used were rinsed three times with MilliQ ultra-pure water. MilliQ water was used to make up all solutions used in the laboratory (e.g., hypersaline solutions and KOH). The solutions were filtered using a 20 µm mesh to minimise microplastic contamination. All beakers and containers were covered with foil and petri dishes kept closed. During the analyses, all windows and doors in the laboratory were closed. Lab controls were used during microplastic analysis to capture ambient microplastics. These controls were put under the microscope to check for any ambient microplastics.

3.3.2 Litter analysis

The litter was classified, counted, and weighed using an adapted method of the Barnardo and Ribbink (2020) protocol. The eleven main types considered were: paper and cardboard, wooden objects, rubber objects, glass objects, textile objects, hygiene objects, plastic objects, foam objects, marine and fishing gear, metallic objects, construction materials, and other/unclassified (Fig. 3.4a). For plastic litter, shopping bags, straws, cigarette lighters, cigarette butts, bottles, lollipop sticks, personal care, stationary, utensils, wrapping, fragment, and foam were the types surveyed (Fig. 3.4b). In addition, a brand audit was performed to find the source of the identified brands comprised in the litter collected on site. This was done by identifying brand name, manufacturer, country of origin, type of packaging and type of product. Different types of products which included household products (detergent, cleaning tools etc.), food packaging (food wrappers, beverage bottles etc.) and personal care products (soap, shampoo bottles, toothpaste etc). Items were classified as either local or foreign. The daily count and weight of items were recorded to find the daily accumulation rate. To assess the beach cleanliness, the clean coast index (CCI) is a widely used tool (Alkalay et al., 2007). The index easily measures debris as a beach cleanliness indicator. Hence to assess the cleanliness of the study sites, the CCI was used. The calculation of the CCI is presented in the following equation:

$$\frac{\text{Total litter on sampling unit}}{\text{Total area of sampling unit}} X\ K, \qquad (1)$$

The index reflects the total number of items m², which is the product between the transect beach length (100 m in this case) and beach width (from the strandline to the back of the beach). Consistent with the CCI index calculation of Alkalay et al. (2007) and Asensio-Montesinos et al. (2021), a coefficient K = 20 was inserted into equation (1). CCI varies from "Very Clean" (0–2), "Clean" (2–5), "Moderate Dirty" (5–10), and "Dirty" (10–20) to "Extremely Dirty" (>20).

a)

No	Litter type
1	Paper
2	Wood
3	Rubber
4	Glass
5	Clothing
6	Hygiene
7	Plastic
8	Marine
9	Metal
10	Construction
11	Unclassified

b)

No	Plastic litter type
1	Shopping bags
2	Straws
3	Cigarette Lighters
4	Cigarette Butts
5	Bottles
6	Lollipop Sticks
7	Personal Care
8	Stationary
9	Utensils
10	Wrapping
11	Fragment
12	Foam

Figure 3.4: Material types surveyed in Table Bay: a) Different litter types and b) different plastic litter types

3.3.3 Mesolitter analysis

Mesolitter was classified, counted, and weighed using an adapted method of the Barnardo and Ribbink' (2020) protocol. The following eight mesolitter types were surveyed: pellets, cigarette butts, foam, fragment, glass, metal, rubber, and unclassified. All mesolitter items ranged between the lower size limit of 2 mm and the upper size limit of 25 mm. The daily count and weight of items were recorded to find the daily accumulation rate.

Table 3.1. Types of mesolitter surveyed in Table Bay

No	Mesolitter types
1	Pellets
2	Cigarette Butts
3	Foam
4	Fragment
5	Glass
6	Metal
7	Rubber
8	Unclassified

3.3.4 Microplastics analysis

Prior to MPs analysis, MPs were extracted from collected water and sediment samples as previously described by Sparks (2020). All meshes were cleaned with MilliQ water and kept in petri dishes to minimize contamination. In the laboratory, water samples were vacuum filtered using a vacuum pump through a 20 µm mesh to extract microplastics. The 20 µm meshes filtered in the laboratory, as well as the 250 µm extracted on site, were kept in petri dishes until they were analysed.

In the laboratory, 150 g of sediments from each replicate were transferred to aluminium containers and dried for 24 hours, or until the weight was constant. Following drying, 100 g were transferred to glass jars for digestion with 10% KOH (prepared using MilliQ water and filtered using 20 µm mesh) to break down organic matter, followed by another 24 hours in the oven. Following that, the KOH solution was filtered out of, and the hypersaline solution was poured into digested samples and vigorously stirred for 2 minutes with a metallic spoon for microplastic extraction. The sample was allowed to settle for 10 to 15 minutes after the two-minute stir. With the addition of hypersaline solution of 359 g NaCl/L was used, as previously reported by Sparks (2020), for dense particles to sink to the bottom and microplastics float to the surface. The supernatant was transferred to petri dishes after being vacuum filtered twice through a 20 µm mesh.

MPs in water and sediment were counted visually with a Zeiss Stem I DV4 stereo microscope at 40 magnification and identified using Sparks' methods (2020).

The total number of microplastics for water was recorded as MPs per litre (MPs/L) and expressed as percentage while sediment was recorded as MPs per kilogram (MPs/Kg) and expressed as a percentage.

MPs were classified according to type (Fibre, fragment, sphere, and foam), colour (white, transparent, yellow, red/pink, blue/green and black/grey) as well as size (< 0.1, 0.1–0.5, 0.5–1, 1–2, 2–5 and > 5mm in length). Microplastics sizes were determined through microscopic observation of samples laid on 1 mm graph paper.

3.3.5 Fourier transform infrared spectroscopy (FTIR) analysis

Sparks and Awe (2022) used a Perkin Elmer Two Fourier transform infrared-attenuated reflectance (FTIR-ATR) Spectroscopy to identify polymers. Spectra were recorded with a wave number ranging from 4000 to 450 cm^{-1} and a data interval of 1 cm^{-1} and scans set to 10 Prior to use, the ATR crystal was cleaned with 70% propenol, and background scans were performed before each sample analysis. Using fine tweezers, plastic particles of up to 25 mm were placed on the FTIR and compressed against the diamond head at a force of at least 80 N. Polymer identification was done by comparing spectral scans with the ST Japan Library and a Perkin spectral library provided by the supplier (Perkin Elmer). The scanned microplastics were identified. Polymers categories assessed were polyethylene (PE), polypropylene (PP), cellulose acetate (CL), and polystyrene (PS) with a percentage similarity cut-off of 70%. For litter, 10% of the litter sample was processed for FTIR analysis and 100% of mesolitter.

4.4 Data processing

3.4.1 Litter

The litter data was converted to items per metre (item/100m). For the characteristics and distribution of litter, data from all sites and seasons were analysed together. Furthermore, the analysis compared the results for both seasons at both sites (Woodbridge Island and Derdesteen). The study also compared litter between wet and dry areas of the beach, as well as the daily accumulation of litter over the ten days sampled in each season. The tests for normality were not met and non-parametric analyses was conducted on the data using a Mann–Whitney (MW) test for two groups. Variances of data for statistical analysis was presented using standard error of the mean (SE) and significance of parameters set at $p < 0.05$. To measure the strength the linear relationship between variables where the change in one affects the other, spearman correlation analysis was used. A correlation between litter count and weight, as well as litter and weather data were performed. All analyses were done using the Statistical Package for the Social Sciences (SPSS) v28 software.

3.4.2 Mesolitter

The data on meso-litter was converted to items per metre (item/m). Data from all sites during the summer season were analysed to determine the characteristics and distribution of meso-litter. The analysis also compared the results from both sites (Woodbridge Island and Derdesteen) during the summer season. The study also compared meso-litter between wet and dry areas of the beach, as well as the daily accumulation of meso-litter over the course of ten days in summer.

The tests for normality were not met and non-parametric analyses was conducted on the data using a Mann–Whitney (MW) test for two groups and the Kruskal–Wallis's test for analysis between more than two groups. Variances of data for statistical analysis was presented using standard error of the mean (SE) and significance of parameters set at $p < 0.05$. All analyses were done using the Statistical Package for the Social Sciences (SPSS) v28 software.

3.4.3 Microplastics

Data on microplastics from both water and sediment samples were expressed as particles per unit (MPs/unit) with MPs/L for water and MPs/Kg for sediment samples. Aside from individual counts, data on microplastic size, shape, and colour were also collected. The data was processed to show the characteristics of microplastics (shape, colour, and size) for Woodbridge Island and Derdesteen in both summer and autumn. Furthermore, the data was analysed to show the differences in microplastics characteristics between summer and autumn. Furthermore, the properties of microplastics derived from sediment, water-250, and water-20 were investigated. The tests for normality were not met and non-parametric analyses was conducted on the data using a Mann–Whitney (MW) test for two groups and the Kruskal–Wallis's test for analysis between more than two groups. Post hoc analyses for significant differences between sites were done using pairwise comparisons of the Kruskal–Wallis's analysis, using the Derdesteen site as a control site. Variances of data for statistical analysis was presented using standard error of the mean (SE) and significance of parameters set at $p < 0.05$. All analyses were done using the Statistical Package for the Social Sciences (SPSS) v28 software.

3.4.4 Weather data

Daily rainfall, wind, and tides data (speed and direction) for the Table Bay were obtained from the 2021 Tides and solunar charts for fishing (www.tides4fishing.com, 2021). Milnerton was used as a proxy for Woodbridge Island and Derdesteen. Hourly wind speed and direction were averaged daily in summer and autumn. The same was done for Woodbridge Island and Derdesteen beaches. No rainfall events were reported during the sampling period. Spearman's rank correlation was computed using SPSS to assess the relationship between wind speed versus litter count, and wind speed versus litter weight.

CHAPTER 4

RESULTS

CHAPTER 4

RESULTS

4.1 Litter

The results of this study showed seasonal and site variations of litter in Table Bay. During the summer and autumn sampling events, a total of 11 179 litter items (M = 139.74 items/100m, SE= 20.69 items/100m) weighing 20 028.07 g (20 kg) (M = 249.96 g/100m, SE = 66.14 g/100m) were collected in Table Bay. Seasonal variations showed more litter by count for autumn compared to summer, and more litter by weight for summer compared to autumn. Site specific variations of litter showed that Woodbridge Island accounting for more litter (by count and weight) than Derdesteen. Both beaches were classified as very clean during the clean coast index assessment (Woodbridge Island:1.67; Derdesteen: 0.19). Furthermore, intra-beach variations were also observed where the dry zone comprised more litter than the wet zone. The daily variation of litter was also observed in this study. Plastic was the most abundant litter type found during this study with over 90% and 47% of all litter by count and weight respectively. Of the plastic litter, foam was the most abundant type by count and weight (41% and 48% respectively) and polyethylene was the most dominant polymer type. Brand auditing showed that over 90% of litter found in Table Bay were of local origin.

4.1.1 Litter per season and site

In terms of litter count per season, 5 296 items/100 m were found in summer, while 5 883 items/100m were found in autumn, respectively, accounting for 47.37% and 52.63% of the total litter count (Fig.4.1a). There was no significant difference in litter count between the two seasons ($U = 741$, $p = 0.570$). In terms of litter weight per season, 15 132.14 g/100m was found in summer compared to 4 895.92 g/100m in autumn, respectively, accounting for 75.55% and 24.45% of the total weight (Fig.4.1b). There was a significant difference in litter weight between both seasons ($U = 595$, $p = 0.049$).

For litter count per site, 10 004 items/100 m were found in Woodbridge Island compared to 1 175 items/100m in Derdesteen, representing 89.49% against 10.51% (Fig.4.2a). There was a significant difference in litter count between the two sites ($U = 1522$, $p = 0.01$). The results for litter weight per site showed 12 341.24 g/100m were found in Woodbridge Island compared to 7 686.83 g/100m in Derdesteen, representing 61.62% and 38.38% respectively (Fig.4.2b). There was a significant difference in litter weight between the two sites ($U = 500$, $p = 0.004$).

Furthermore, the CCI showed that both Woodbridge Island (0.329) and Derdesteen (0.004) fell within the "very clean" category (Table 4.1).

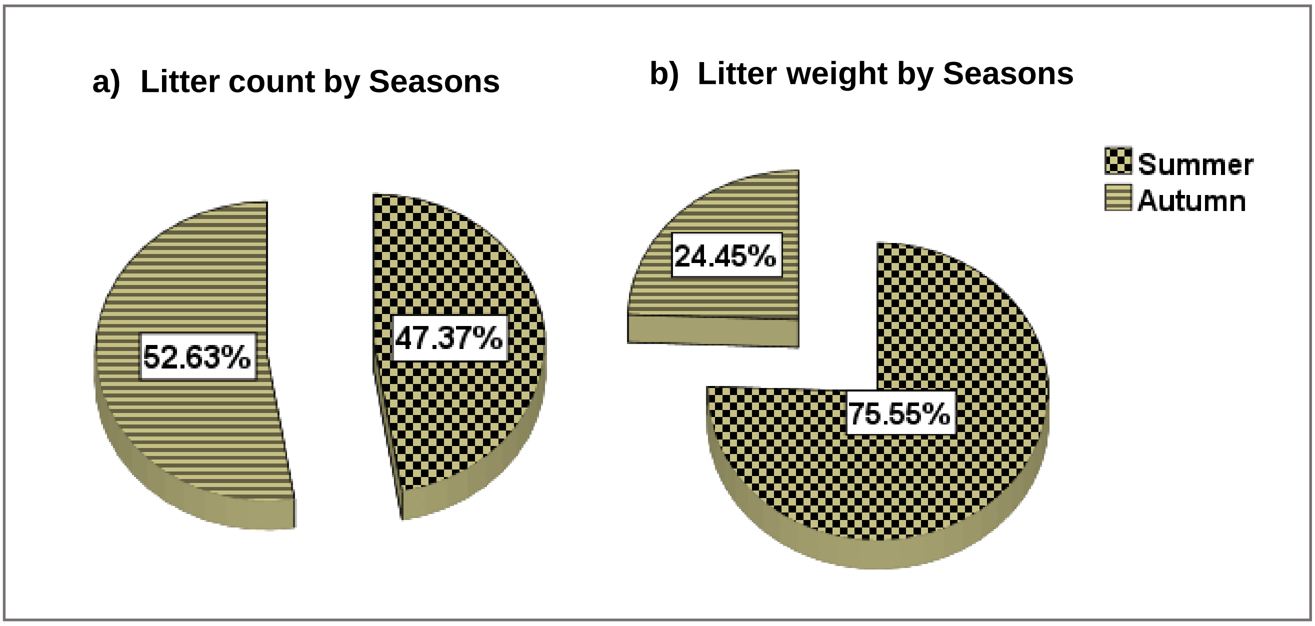

Figure 4.1: Litter distribution of by count (a) and weight (b) between two seasons in Table Bay

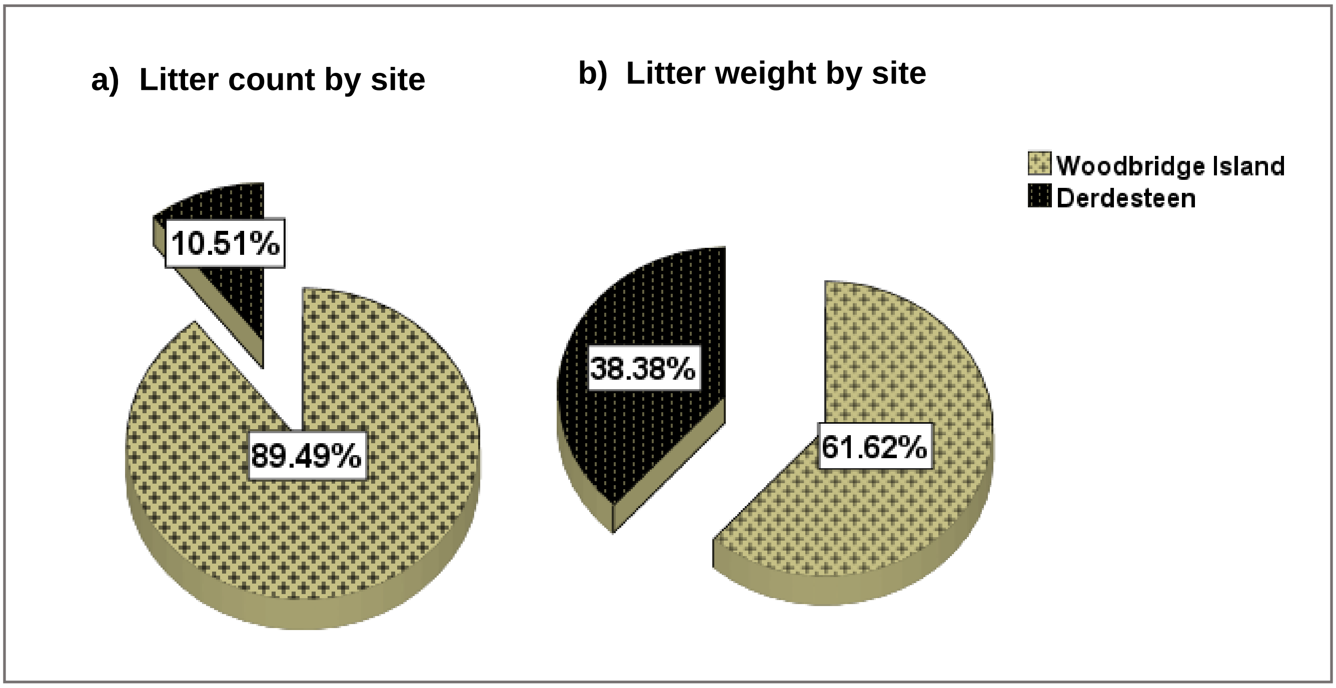

Figure 4.2: Litter distribution of by count (a) and weight (b) between two sites in Table Bay

Table 4. 1: CCI for Woodbridge Island and Derdesteen in Table Bay. The CCI varies from "Very Clean" (0–2), "Clean" (2–5), "Moderate Dirty" (5–10), and "Dirty" (10–20) to "Extremely Dirty" (>20)

	Woodbridge Island	Derdesteen
CCI (Clean Coast Index)	1.67	0.19

4.1.1.1. Litter in the Wet and Dry zones

The results for litter count per beach zone showed that 4 967 items/100m (124.18±34.94) were collected in the wet zone, while 6 212 items/100m (155.30±22.40) were collected in the dry zone, respectively, accounting for 44.43% and 55.57% of the total litter count (Fig.4.3a). There was a significant difference in litter count between the two zones ($U = 1059$, $p = 0.013$). The results for litter weight per beach zone showed that 4 287.30 g/100m (106.80±28.10) were collected in the wet zone, while 15 740.76 g/100m (393.15±126.03) were collected in the dry zone, respectively, accounting for 21.41% and 78.59% of the total litter count (Fig.4.3b). There was a significant difference in litter weight between the two zones ($U = 1151$, $p < 0.001$).

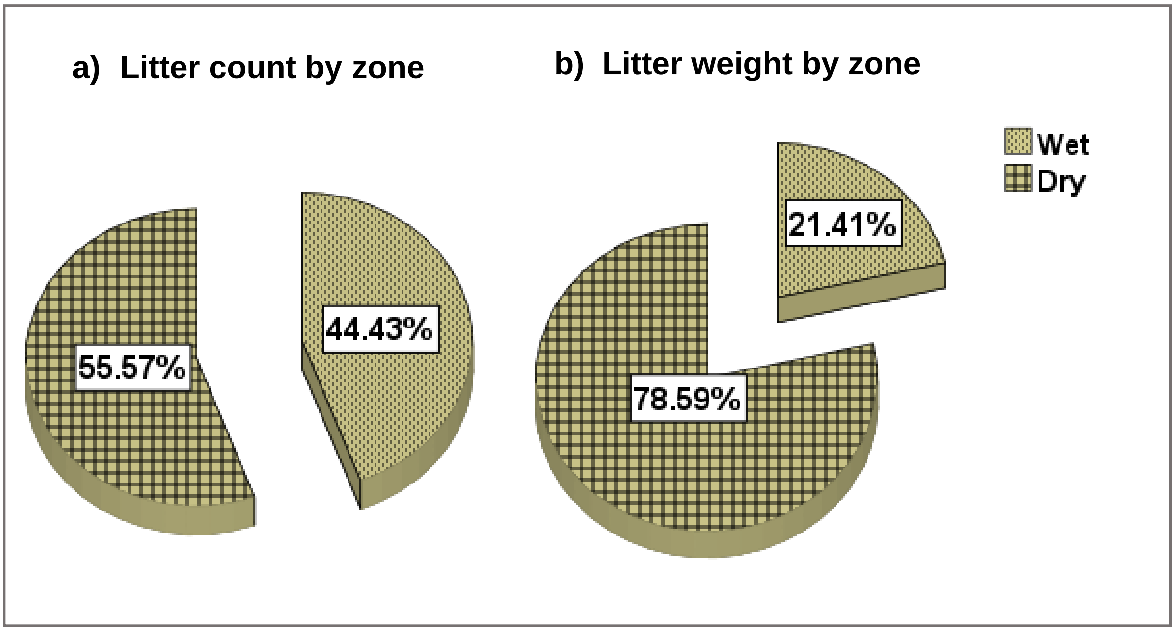

Figure 4.3: Distribution of litter by count (a) and weight (b) between the dry and wet zones of the beach on all sites and seasons combined

4.1.1.2. Daily accumulation rate

The mean daily accumulation of litter by count for the summer period was lower than autumn and higher at Woodbridge Island compared to Derdesteen overall with the highest number recorded on day 2 at Woodbridge Island in autumn (Fig.4.4a).The lowest number was recorded on day 7 at Derdesteen in autumn. For the litter weight, the mean daily accumulation was higher in summer compared to autumn and higher at Woodbridge Island compared to Derdesteen overall (Fig.4.4b). The highest weight was recorded on day 5 at Woodbridge Island in summer with the second highest at Derdesteen in the same season. The lowest weight was recorded on day 5 at Derdesteen in autumn. Spearman's rank correlation was computed to test the strength of the relationship between daily litter weight and count in Table Bay. There was a moderate positive correlation between the variables ($r = .666$, $p<0.001$) (Fig.4.5).

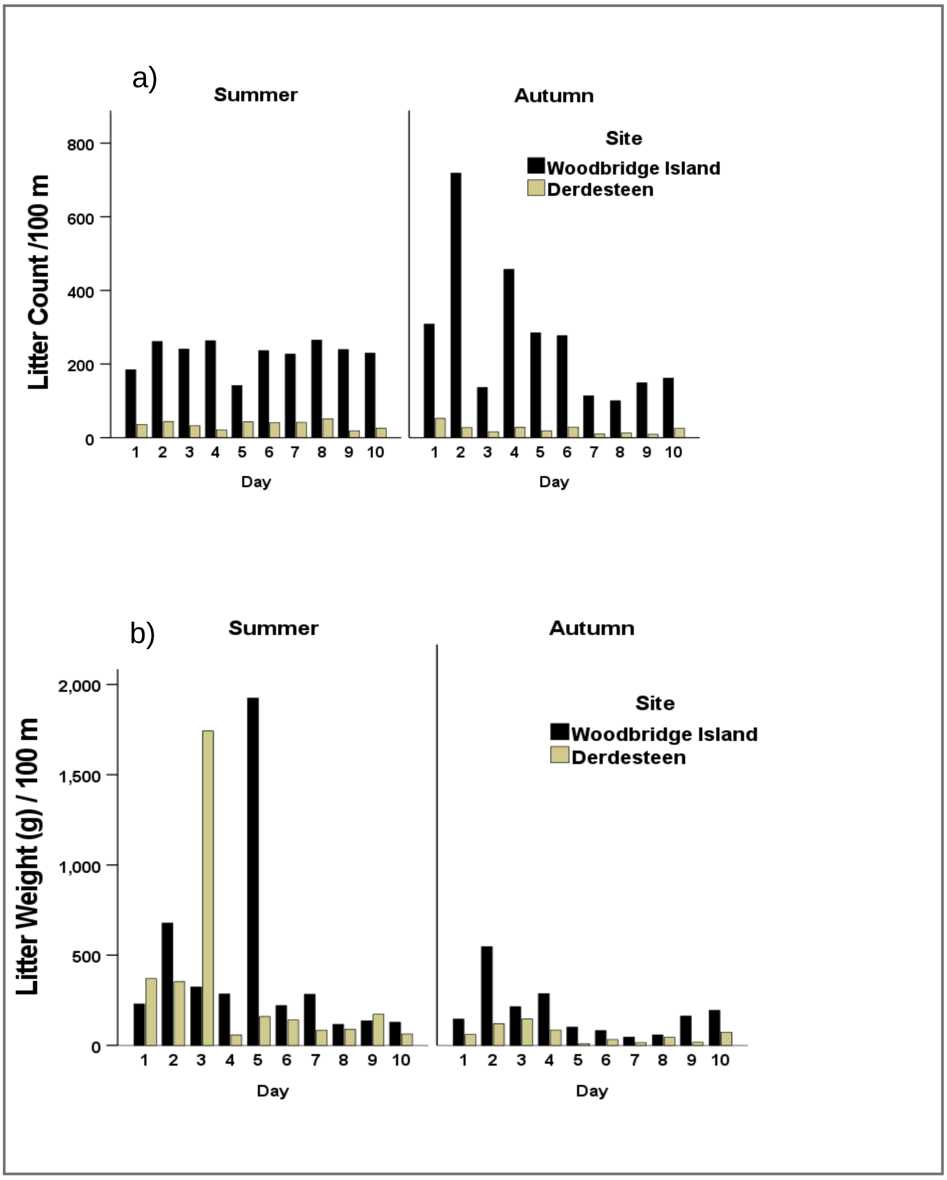

Figure 4. 4: Daily mean accumulation of litter by count/100m (a) and weight/100m (b) in Table Bay

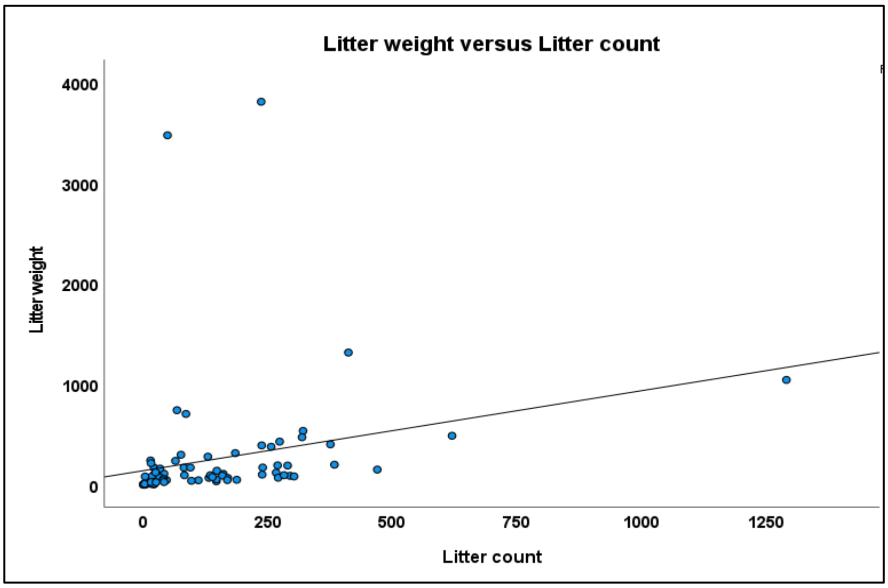

Figure 4.5: Correlation between litter weight (g/100m) and count (items/100m) of collected items in Table Bay

4.1.2 Characteristics of litter

Plastic was the most abundant litter type by count, accounting for 90.27% of the eleven litter types recorded for both sites; Woodbridge Island and Derdesteen; and both seasons (Summer and Autumn), followed by hygiene objects (3.93%), wood (2.72%), metal (1.08%), and the remaining (rubber, marine, clothing, paper, glass, unclassified) with less than 1% each, while construction materials were non-existent (Fig. 4.6a). Plastic litter was also the most abundant litter type by weight, accounting for 43.45% of all litter, followed by glass (29.50%), wood (20.11%), others/collapsed sum (2.75%), clothing (1.76%), metal (1.44 %), hygiene (1%) (Fig. 4.6b). The brand audit showed that 94.29% of identified brands were from local source compared to 5.71% from foreign source (Fig. 4.7a) while the items were mainly made of snack packaging (78.95%) and the rest of beverages (21.05%) in Table Bay (Fig.4.7b).

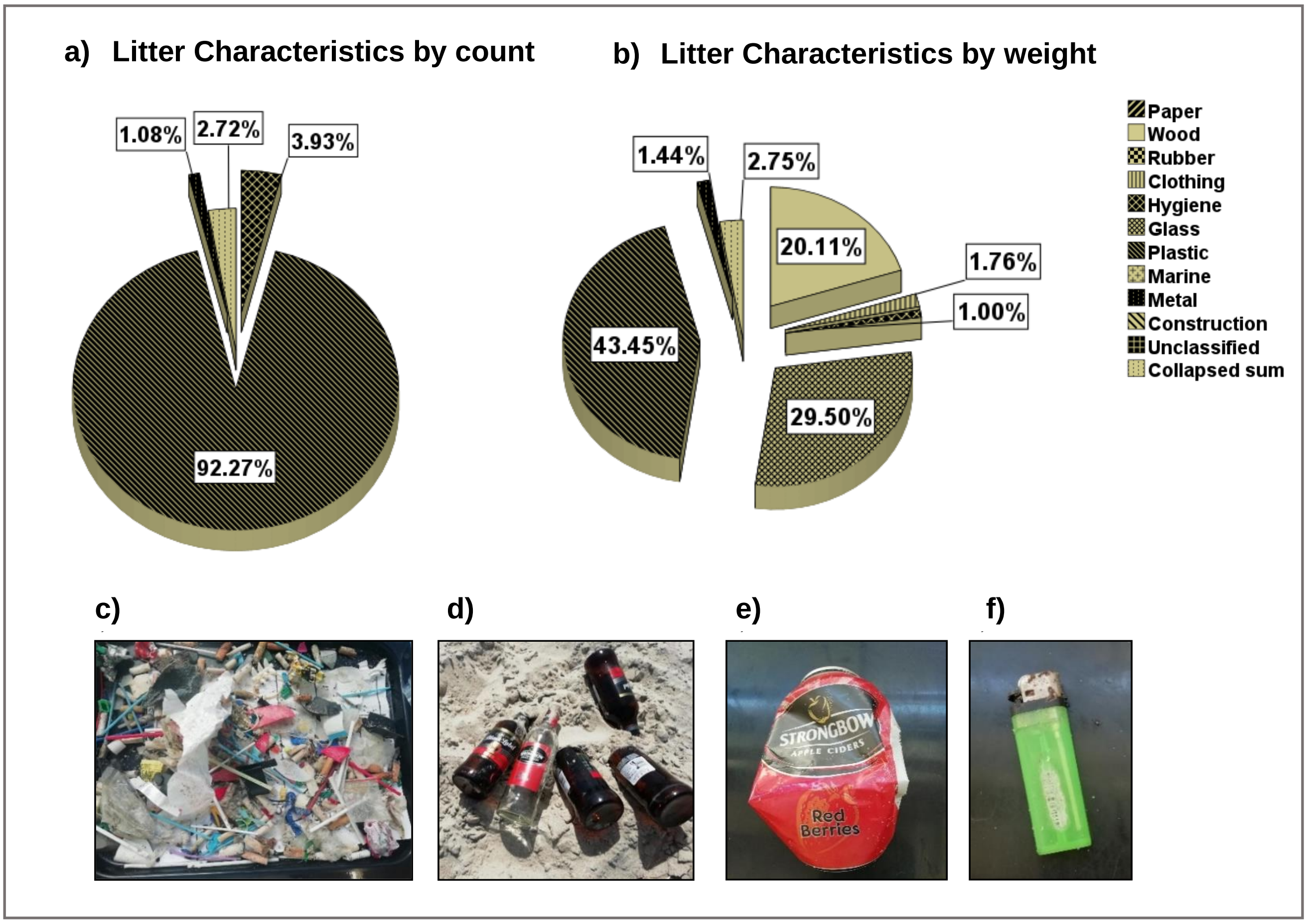

Figure 4. 6: Litter characteristics by count (a) and weight (b) in Table Bay. Images of different litter types: lollipop sticks, cigarette butts, wrapping, earbuds, foams (c), glass bottles (d), metal/aluminium can (e), and cigarette lighter (f) collected in Table Bay

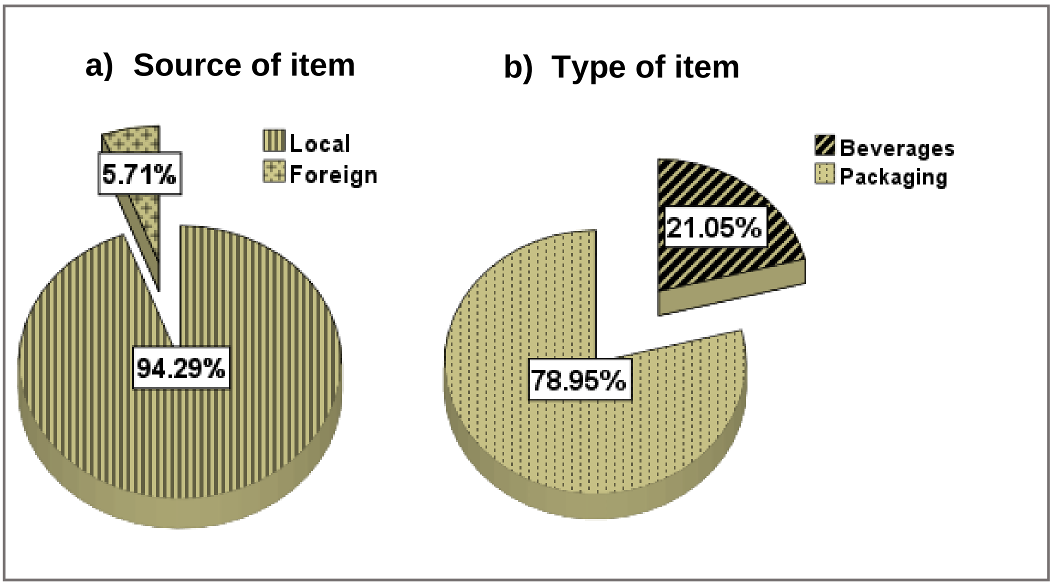

Figure 4. 7: Brand audit for litter collected in Table Bay with Source of identified item (a) and item type (b)

4.1.3 Plastic Litter

4.1.3.1 Plastic Litter per season and site

In terms of plastic litter per season, 4 574 items/100m were found in summer (M = 114.35 items/100m, SE = 16.79 items/100m), while 5 512 items/100m were found in autumn (M = 137.80 items/100m, SE = 34.42 items/100m), respectively, accounting for 45.35% and 54.65% of the total plastic litter count in Table Bay (Fig.4.8a). The total weight of plastic litter was higher in summer with 6 996.35 g/100m (M = 144.90 g/100m, SE = 79.75 g/100m) compared to 2 598.20 g/100m (M = 64.95 g/100m, SE = 16.45 g/100m) in autumn, respectively accounting for 72.92% and 27.08% (Fig.4.8b). Of all the plastic litter collected, 89.10% were found in Woodbridge Island compared to 10.90% in Derdesteen per count(Fig.4.9a). The total weight of plastic litter was higher in Derdesteen with 51.09% compared to 48.91% in Woodbridge Island (Fig.4.9b).

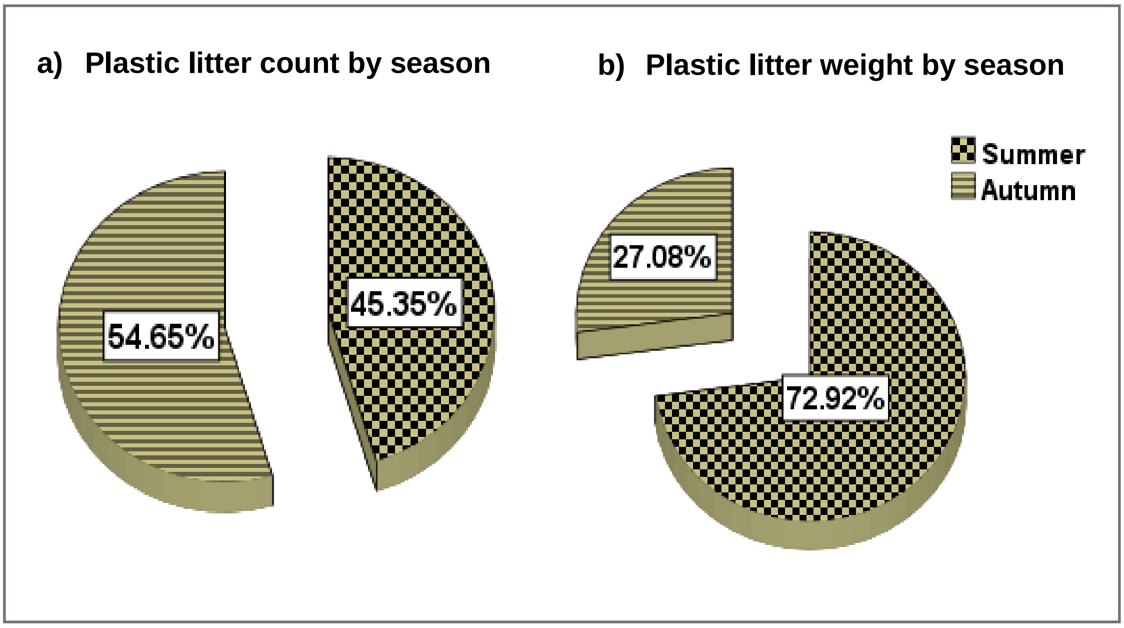

Figure 4.8: Plastic litter count (a) and weight (b) by season for both sites

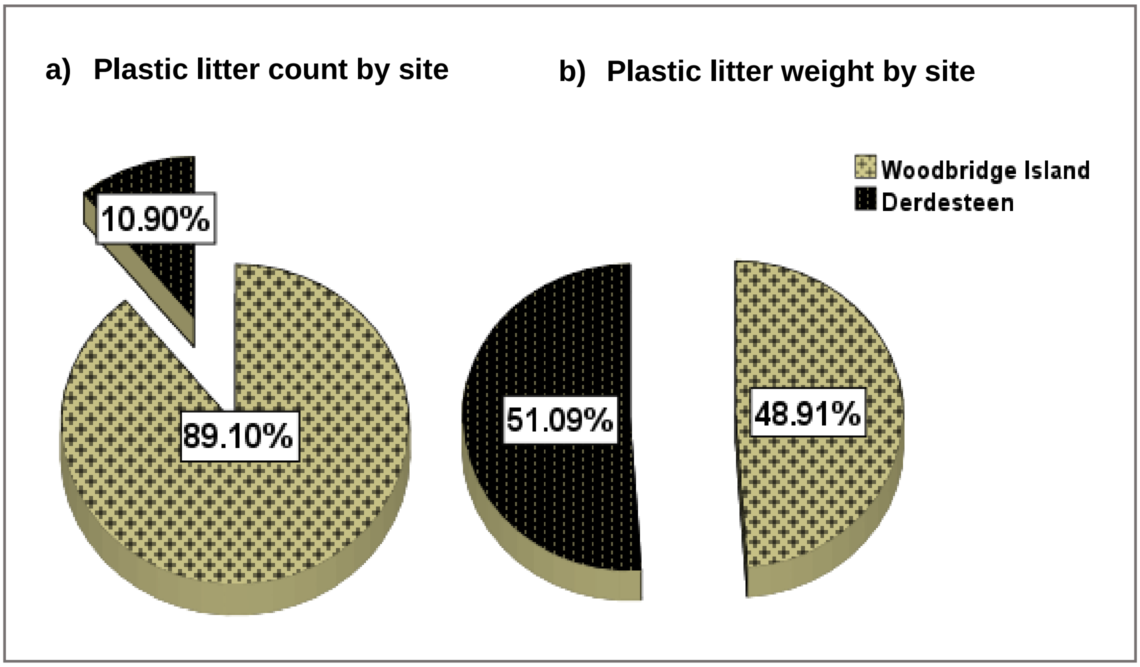

Figure 4.9. Plastic litter count (a) and weight (b) by site for both seasons

The distribution of plastic litter between the wet and dry zones of the beach showed that 4 574 items/100m (M = 118.20 items/100m, SE = 32.64 items/100m) were found in the wet zone and 5 512 items/100m (M = 133.95 items/100m, SE = 20.13 items/100m) were found in Derdesteen, respectively, accounting for 46.88% and 53.12% of the total plastic litter count (Fig.4.10a). The total weight of plastic litter was higher in the dry zone with 6 996.35 g/100m (M = 172.42 g/100m, SE = 79.51 g/100m) compared to 2 598.20 g/100m (M = 67.44 g/100m, SE = 17.98 g/100m) in the wet zone, respectively accounting for 71.88% and 28.12% (Fig.4.10b).

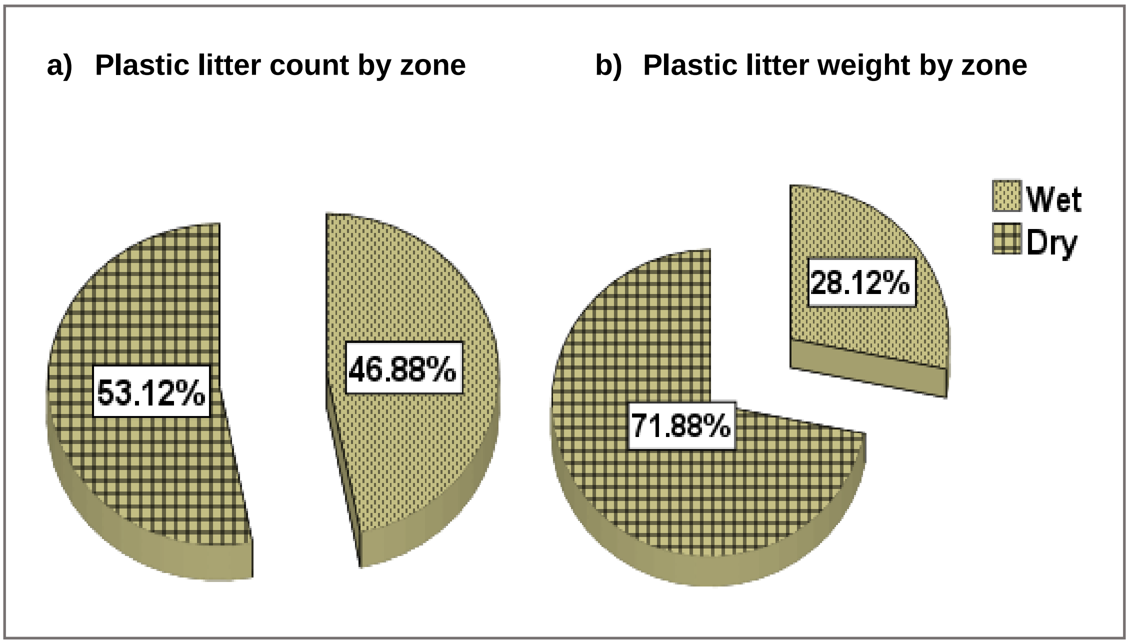

Figure 4.10: Plastic litter between the wet and dry zones of the beach in Table Bay

4.1.3.2 Characteristics of Plastic litter

Plastic was classified into twelve types, of which foam was the most abundant both by count and weight, with 41.74% and 48.32% of all the plastic litter collected. In terms of count, foam was followed by fragments (28.17%), cigarette butts (9.15%), wrapping (8.06%), bottles (6.41%), lollipop sticks (3.77%), straws (2.12%), and the remaining items accounted for less than 1% each (Fig. 4.11a). In terms of weight, foam was followed by utensils (19.10%), bottles (13.38%), wrapping (9.62%), cigarette buts (2.50%), lollipop sticks (2.31%), shopping bags (1.13%), straws (1.10 %), and the remaining items each had less than 1 % of the total (Fig. 4.11b). Polyethylene (PET) accounted for 69.23% of polymer types, followed by polypropylene (PP) cellulose acetate (CA), both with14.10%, and polystyrene (PS) at 2.56% (Fig.4.12).

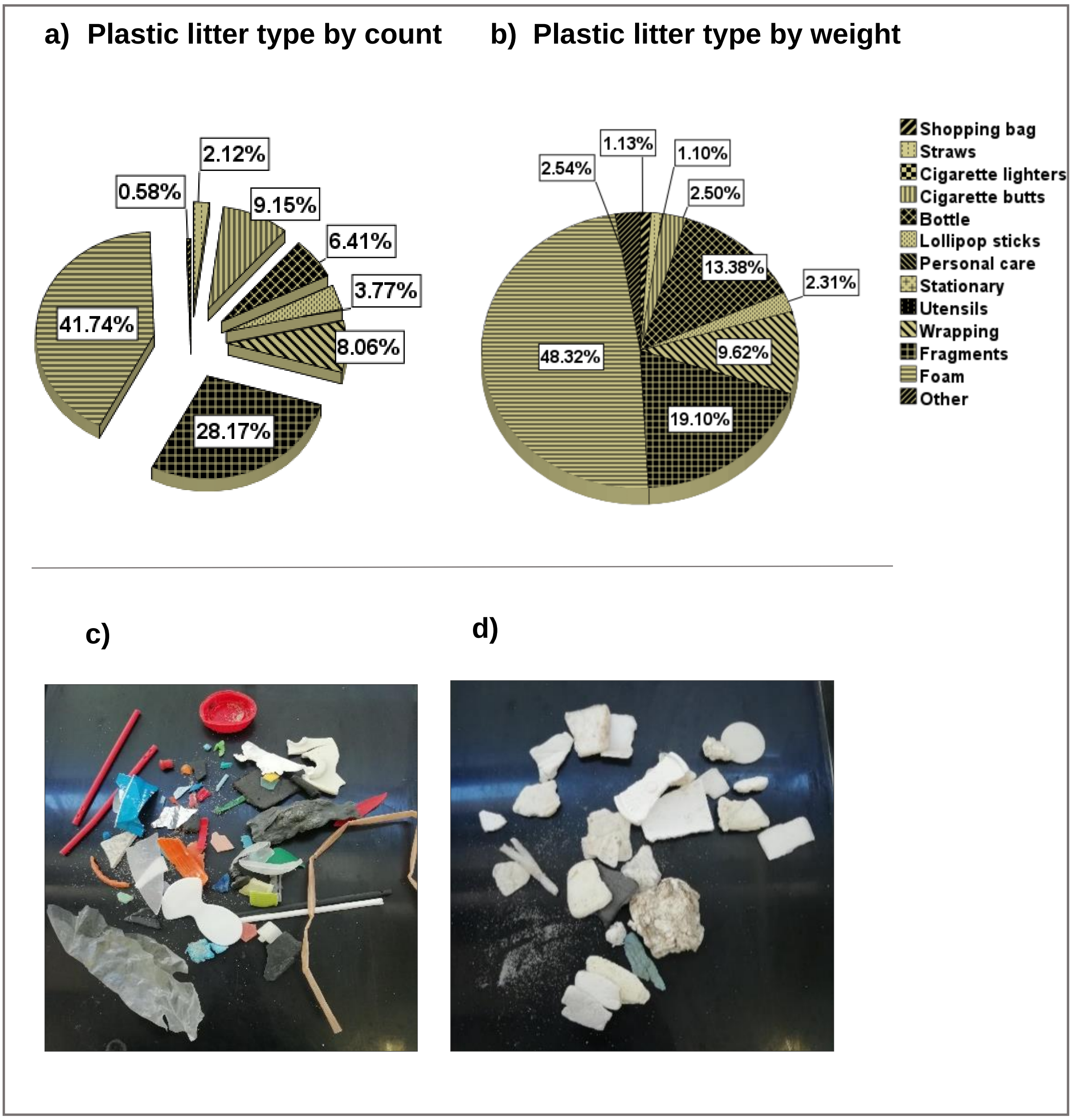

Figure 4. 11: Types of plastic litter by count (a) and weight (b) for both Woodbridge Island and Derdesteen in both Summer and Autumn. Different types of plastic litter: straws, lollipop sticks, and fragments (c) as well as foams (d) were collected in Table Bay

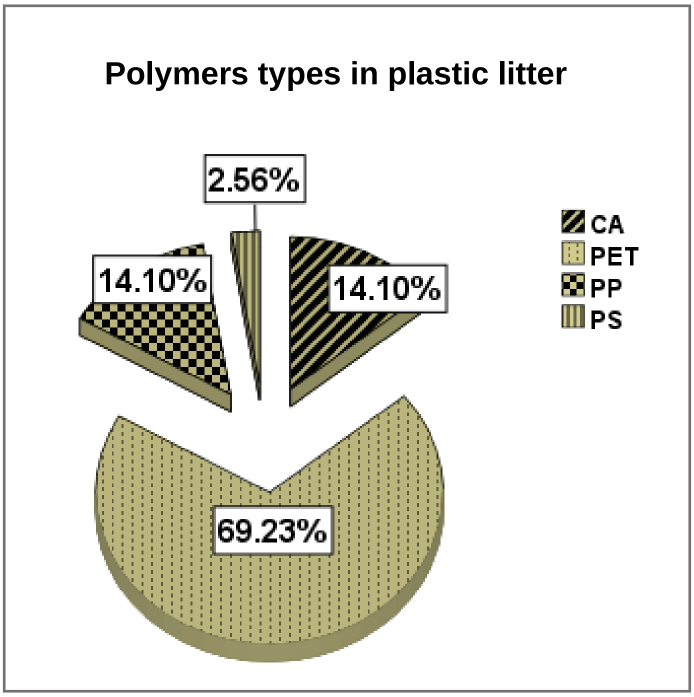

Figure 4.12. Polymer types in plastic litter characterised by Cellulose acetate (CA), Polyethylene (PET), Polypropylene (PP), and Polystyrene (PS) collected in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay

4.2 Mesolitter

In the summer of 2021, a total of 1 428 items (M = 4.46 items/m, SE = 0.60 items/m) of meso-size (2–25 mm) weighing 12.20 g (M = 0.04 g/m, SE = 0.01 g/m) were collected for 10 days on Woodbridge Island and Derdesteen in Table Bay. Site specific variations showed that Woodbridge Island accounted for more mesolitter by count and weight than Derdesteen. The intra-site variations showed that more mesolitter items (both by count and weight) were found in the dry zone compared to the wet zone. A daily variation of mesolitter across the ten-sampling day was also noted. Mesolitter items were classified into eight categories of which pellets were the most dominant by count and weight. The composition of mesolitter showed that plastic items (pellets, foam, and fragment) were the most abundant type found in this study, making up 99.05% by count and 78.69% by weight, with metals accounting for 21.31% of the remaining weight. Polyethylene was the most dominant polymer type found in this study.

4.2.1 Mesolitter per site

On Woodbridge Island, 1 406 items/m (M = 7.03 items/m, SE = 0.92 items/m) representing 98.46 % of the mesolitter count were found compared to 22 items/m (M = 0.18 items/m, SE = 0.09 items/m) on Derdesteen, representing 1.54 % (Fig.4.13a). There was a significant difference in mesolitter count between the two sites (U = 5172, p = 0). In terms of weight, the totality of weight was found on Woodbridge Island with 12.20 g/m (M = 0.06 g/m, SE = 0.02 g/m) representing 100 % of the total weight (Fig.4.13b). There was a significant difference in mesolitter weight between the two sites (U = 11 460, p = 0.02).

The mean accumulation rate of mesolitter in this study showed more items by count were recorded in the wet zone (4.68 ± 0.94 items/m/day) compared to the dry zone (4.25 ± 0.76 items/m/day) (Fig. 14a). However, no clear variability was observed for the mean weight of mesolitter items, with approximately 0.04 ± 0.02 g/m/day in both the wet and dry zones (Fig. 14b). In addition, there was no significant differences in mesolitter count (U= 14 021 p = 0.093) and weight (U = 12 727, p = 0.756) between the two zones.

The daily accumulation of mesolitter by count showed a decreasing trend from day 1 (1.94±1.11 items/m) to day 2 (0.81±0.36 items/100m), followed by an increase on day 3 (2.50±0.86 items/m). A steady rise was observed on days 4, 5, 6, and 7 (3.25±1.72 items/m, 5.50±3.03 items/m, 3.56±0.87 items/m, and 5.18±1.30 items/m, respectively). This rising trend in the daily count of mesolitter was marked by a decrease on day 8 (4.31 ±1.31 items/m) followed by an increase on day 9 (11.50 ±3.65 items/m). A decrease was observed on day 10 (6.06±1.78). The highest daily mean count of mesolitter was observed on day 9 (11.50 ±3.65 items/m), while the lowest was on day 2 (0.81±0.36 items/m) (Fig 4.15a). The daily accumulation of mesolitter by weight showed a decreasing trend from day 1 (0.04±0.04 g/m) to days 2, 3 and 4 (0 g/m each) followed by an increase on day 5 (0.07±0.07 g/m). A decrease was observed on day 6 (0 g/m), followed by an increase on day 7 (0.04±0.04 g/m) and a decrease on day 8 (0.03±0.03 g/m). An increase in mesolitter weight was observed on day 9 (0.17±0.09 g/m), followed by a decrease on day 10 (0.03±0.03 g/m). The highest daily mean weight of mesolitter was observed on day 9 (0.17±0.09 g/m) while the lowest was on days 2, 3, 4, and 6 (0 g/m) (Fig 4.15b).

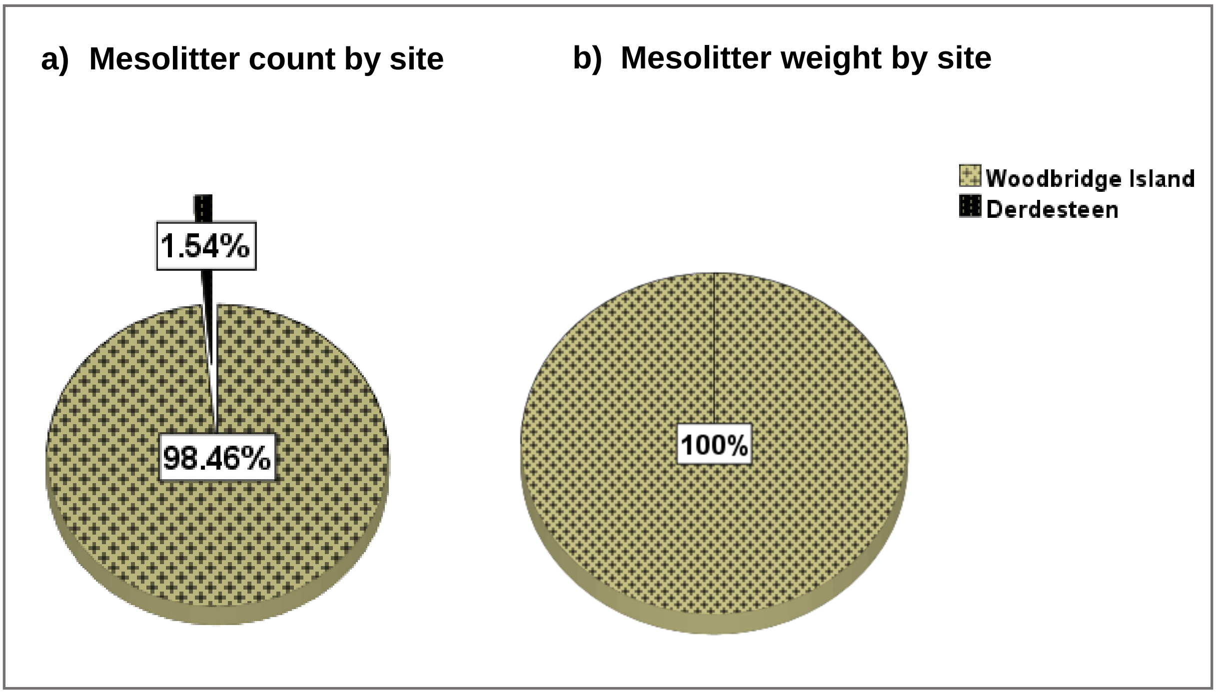

Figure 4.13: Mesolitter count (a) and weight (b) between Woodbridge Island and Derdesteen beaches in Table Bay

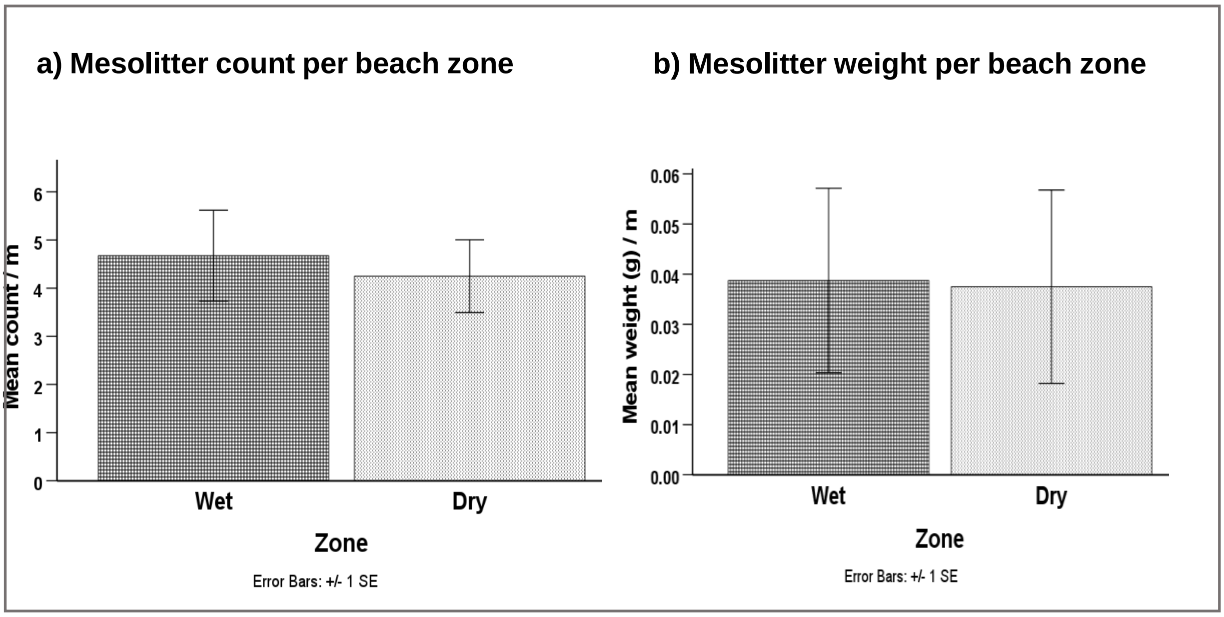

Figure 4. 14: Distribution of mesolitter between the wet and dry zones for both the Woodbridge Island and Derdesteen by count (a) and weight (b)

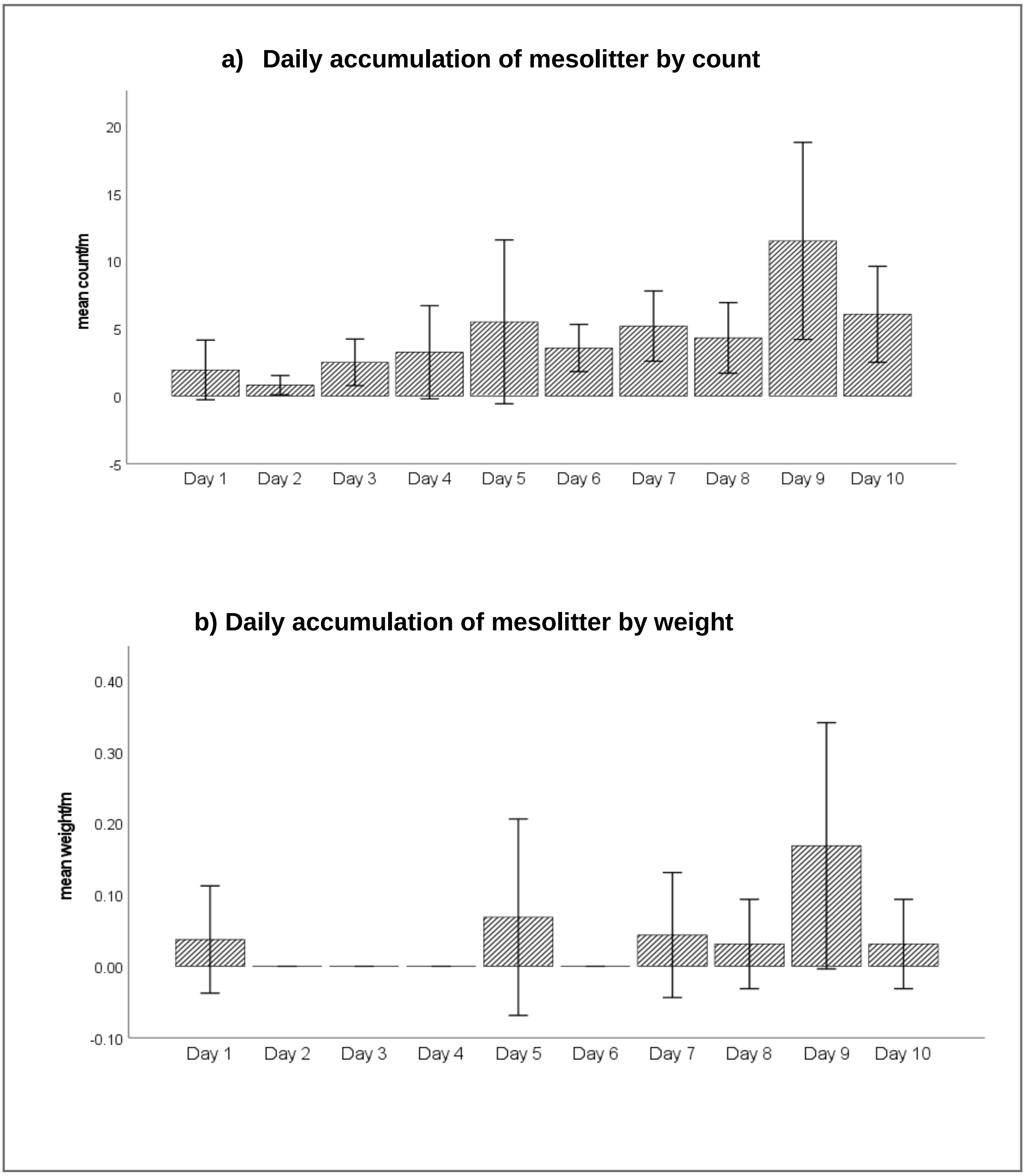

Figure 4. 16: Daily accumulation of mesolitter by count (a) and weight (b)

4.2.2 Characteristics of meso-litter

Mesolitter items were collected in the summer of 2021 on Woodbridge Island and Derdesteen and classified into 8 categories. After weighing and counting, pellets accounted for 69.75 % of the total count, followed by foam (18.49 %) and fragment (10.78 %), with the remaining categories accounting for less than 1%. (Fig. 4.17a & 4.19). Pellets continued to lead the classification in terms of weight with 78.69 %, followed by metals with 21.31%, and the remaining categories were not represented (Fig. 4.17b). The composition of mesolitter showed that plastic items (pellets, foam, and fragment) were the most abundant type found in this study, making up 99.05% by count and 78.69% by weight, with metals accounting for 21.31% of the remaining weight. Polymer identification using FTIR showed that polyethylene (PET) was the most abundant polymer type, accounting for 59.52%, followed by polypropylene (PP) at 27.38%, polystyrene (PS) at 12.50%, and cellulose acetate (CA) with 0.60% (Fig.4.18).

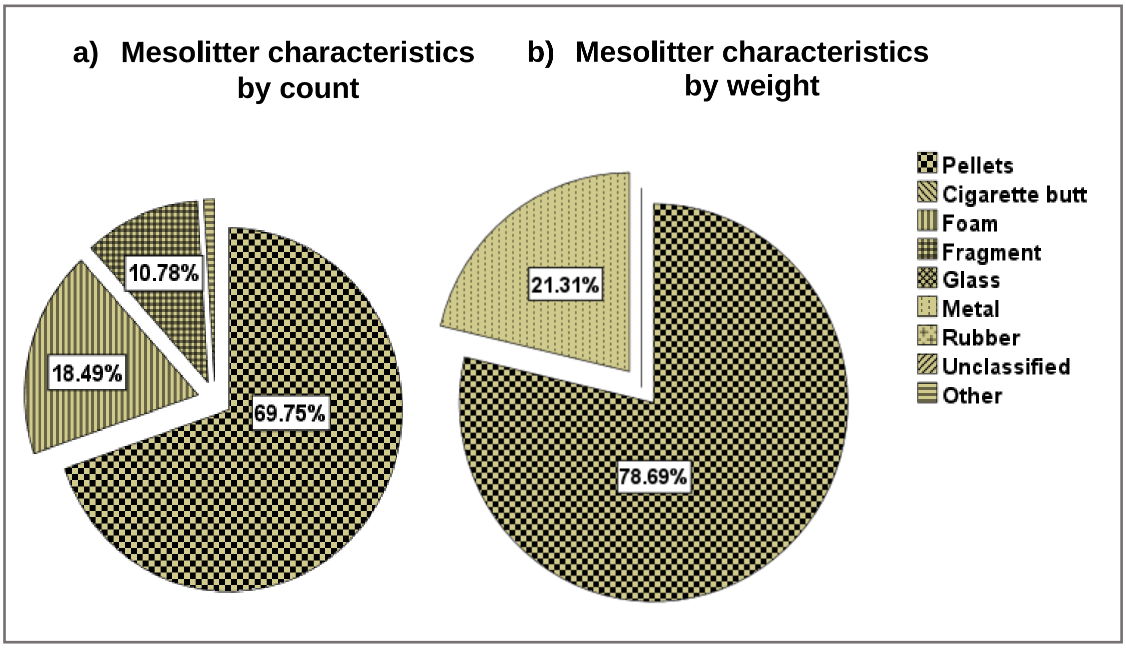

Figure 4.17: Types of mesolitter by count (a) and weight (b) for both Woodbridge Island and Derdesteen in Summer 2021

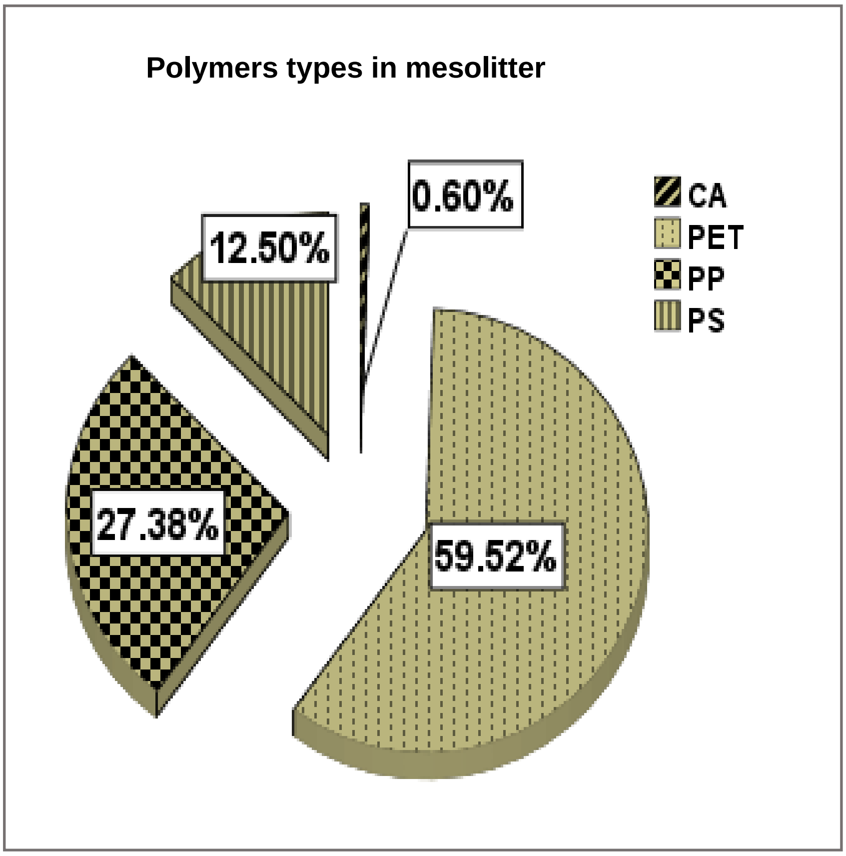

Figure 4.18: Polymer types in mesolitter characterised by Cellulose acetate (CA), Polyethylene (PET), Polypropylene (PP), and Polystyrene (PS)

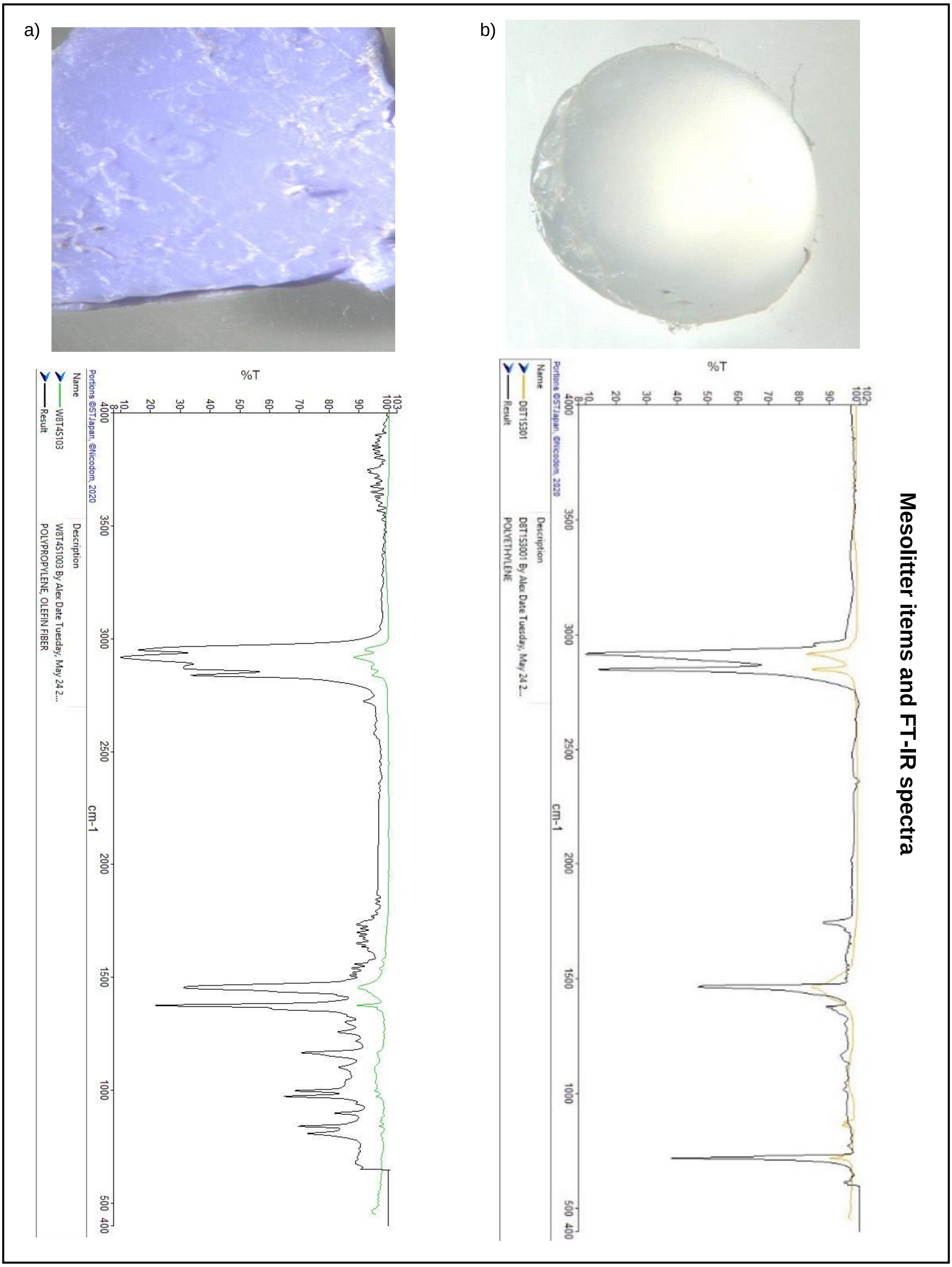

Figure 4.19: Mesolitter items and their corresponding spectra. Purple plastic fragment collected in Table Bay and its corresponding spectrum (a). Transparent pellet collected in Table Bay with its corresponding spectrum (b)

4.3 Microplastics

A total of 688 microplastics (MPs) were recorded in water and sediment samples processed from two sampling sites in summer and autumn in Table Bay. A seasonal variation was observed, with summer accounting for 57% of all MPs compared to 42% for autumn. A site-specific variation of MPs showed that Woodbridge Island accounted for more MPs than Derdesteen. Fibre was the most abundant MPs type found, accounting for over 97 % of all MPs collected in Table Bay. In terms of colour, blue was the most dominant MPs accounting for 46.46 % of all microplastics collected. In terms of size, results showed that microplastics between (0.1-0.5) were the most abundant, accounting for 50.32%. The mean MPs during this study was 91.25 (±10.50 SE) MPs/Kg of sediment, followed by 7.68 (±2.44 SE) MPs/L of water-20 µm and, 0.85 (±0.17 SE) MPs/L of water-250 µm, each respectively accounting for 95.53%, 4.02%, and 0.45% of the total extracted microplastics.

4.3.1 Microplastics per season and site

Of all the microplastics found, 57.81 % were found in summer and 42.19 % in autumn (Fig.4.20a) however, there was no significant difference in microplastics between the two seasons (U = 525, p = 0.861) On the other hand, 75.66 % of all microplastics were found in Woodbridge Island compared to 24.34 % in Derdesteen (Fig.4.20b) and statistical tests showed a significant difference in microplastics between the two sites (U = 258.5, p = 0.002).

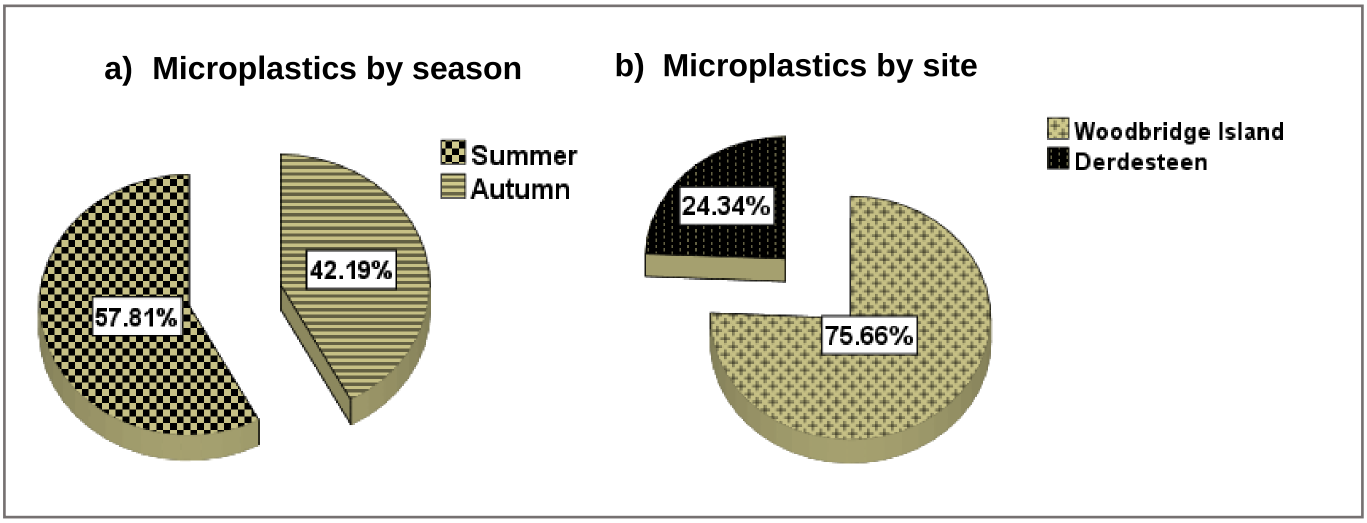

Figure 4.20: Distribution of microplastics by season (a) and site (b) in Table Bay

The figure (4.21) below shows the characteristics of microplastics based on type, colour, and size for both summer and autumn, as well as Woodbridge Island and Derdesteen. In terms of type, fibre was the most abundant type of microplastic collected (97.37 %), followed by spheres (1.52 %), and fragments and foam each accounted for less than 1% of all microplastics collected (Fig.4.21a and 4.23). In terms of colour, blue was the most common, accounting for 46.46 % of all microplastics collected, followed by black (19.62 %), transparent (17.04 %), red (12.94 %), yellow (2.47 %), and white (1.48 %) (Fig. 4.21b). In terms of size, results showed that microplastics between (0.1-0.5) were the most abundant, accounting for 50.32%, followed by those below 0.1 (46.52%), 0.5-1.0 (2.56%), 1.0-2.0 (less than 1%), and 2.0-5.0 and > 5.0 were non-existent (Fig. 4.21c).

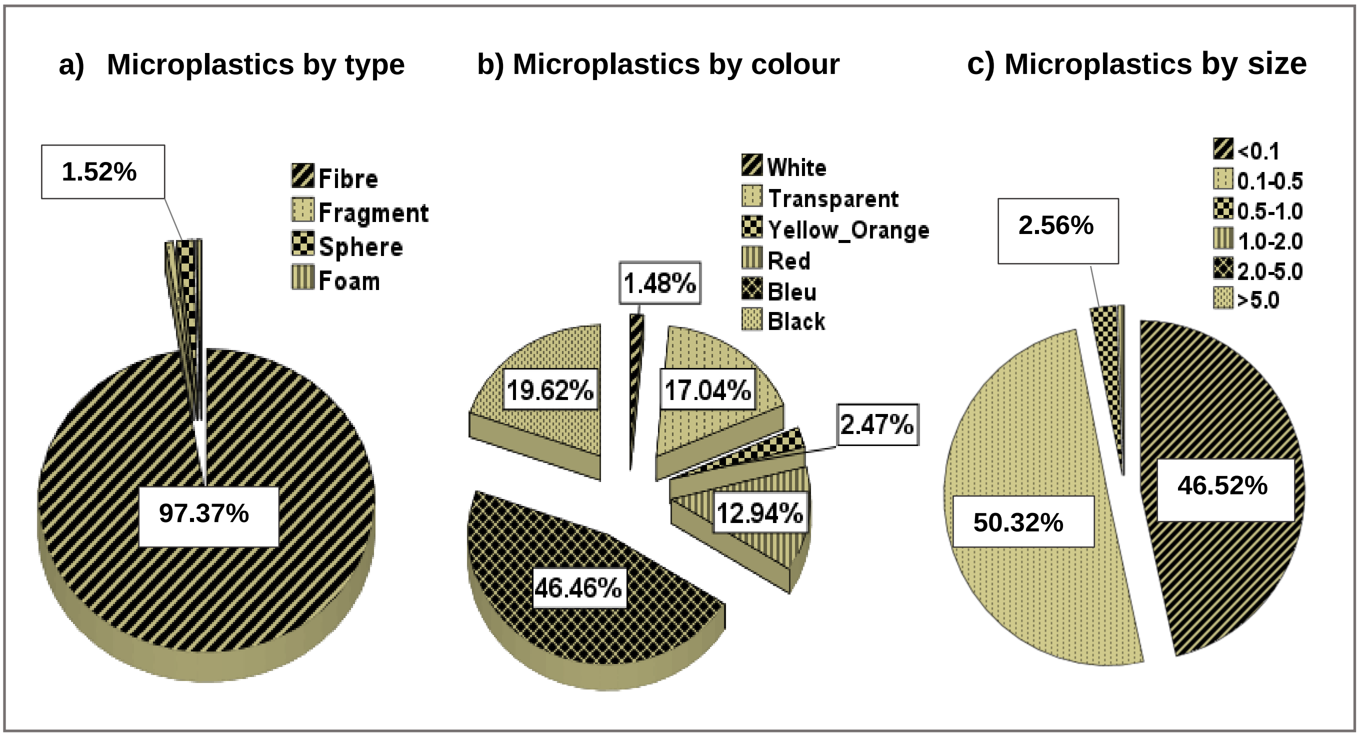

Figure 4.21: Characteristics of microplastics by Type (a), Colour (b) and, Size (c) in Table Bay during summer and autumn

The collected microplastics were characterized according to the sample type, which included water at 20 µm, water at 250 µm, and sediments. The mean MPs for all sites and seasons combined was 91.25 (±10.50 SE) MPs/Kg of sediment, followed by 7.68 (±2.44 SE) MPs/L of water-20 µm and, 0.85 (±0.17 SE) MPs/L of water-250 µm, each respectively accounting for 95.53%, 4.02%, and 0.45% of the total extracted microplastics (Fig.4.22a). In summer, the mean amount of microplastics retrieved from sediment samples on both sites was 105 (±17.56

SE) MPs/Kg, followed by 10.25 (±4.79 SE) MPs/L for water-20 μm samples and, 0.61 (±0.18 SE) MPs/L for water-250 μm samples (Fig.4.22b). In autumn, the mean amount of microplastics retrieved from sediment samples on both sites was 77.50 (±11.05 SE) MPs/Kg, followed by 5.13 (±0.79 SE) MPs/L for water-20 μm samples and, 1.09 (±0.27 SE) MPs/L for water-250 μm samples (Fig.4.22b). On Woodbridge Island, sediment samples contained a mean of 110 (±14.81 SE) MPs/g microplastics, while water-20 μm and water-250 μm samples contained respectively 10.40 (±3.68 SE) MPs/L and 0.86 (±0.16 SE) MPs/L respectively (Fig.4.22c). On Derdesteen, the mean microplastics for sediment was 60 (±7.39 SE) MPs/g, followed by 3.17 (±0.70 SE) MPs/L for water-20 μm and, 0.85 (±0.39 SE) MPs/L for water-250 μm respectively (Fig.4.22c).

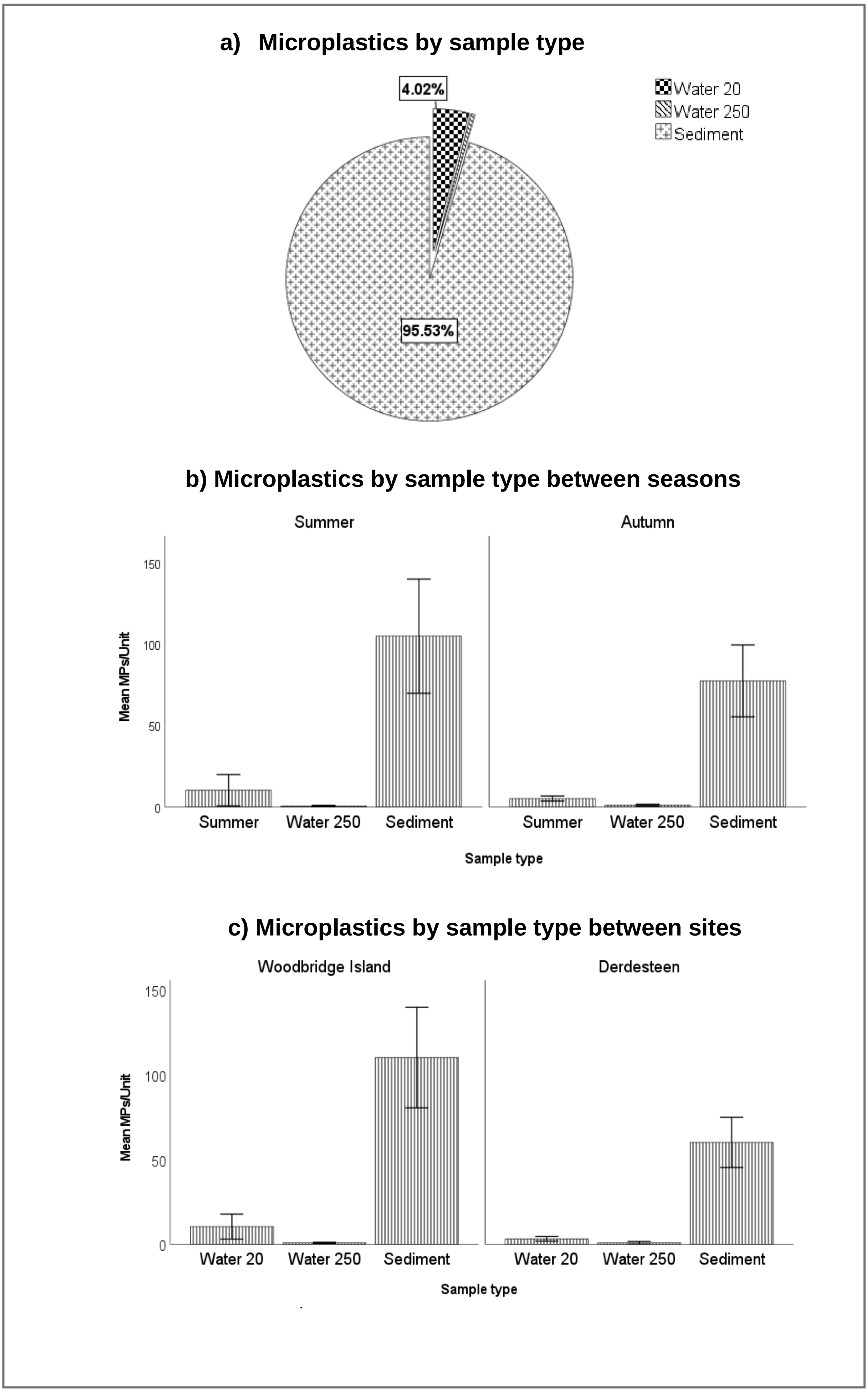

Figure 4.22: Microplastics by sample type for all sites and seasons (a), between seasons (b) and sites (c) in Table Bay

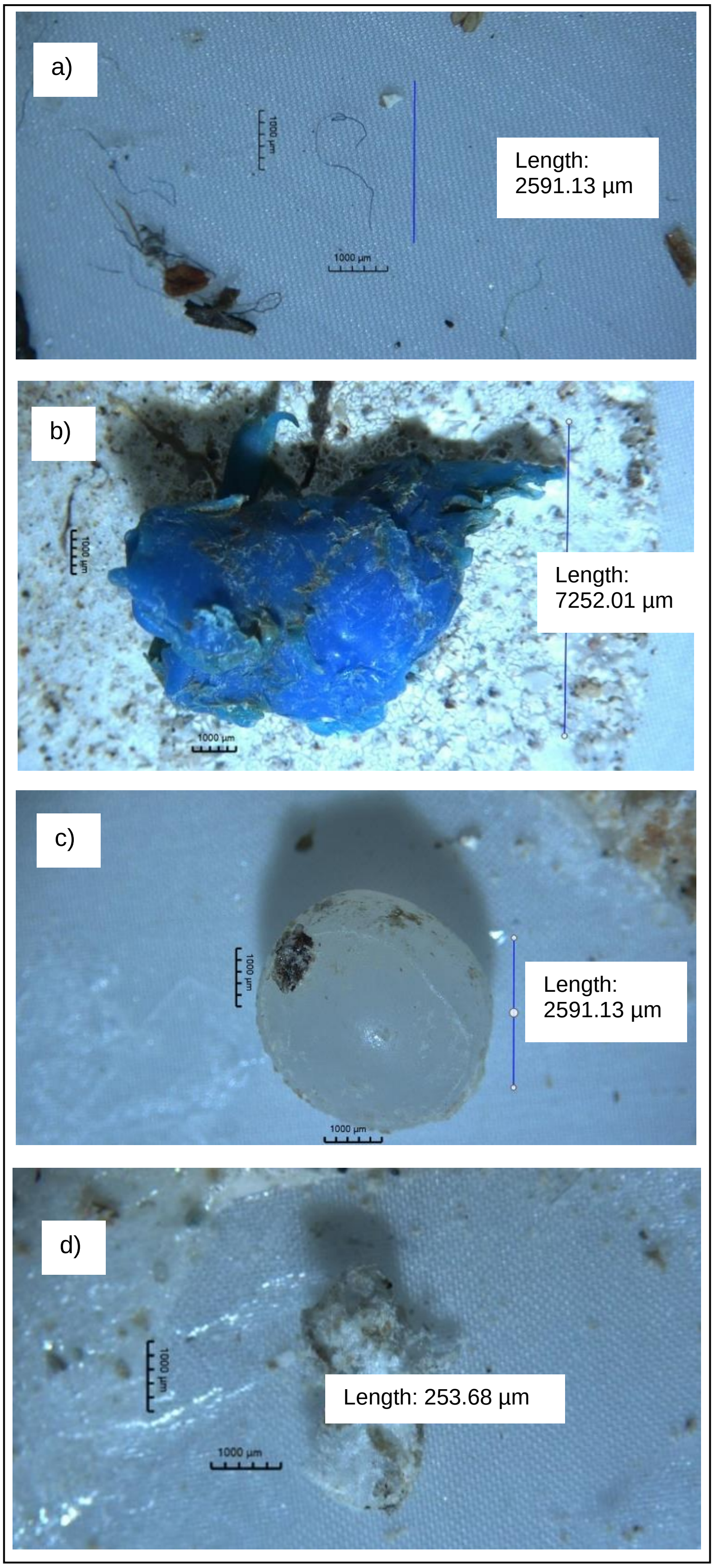

Figure 4.23: Images of microplastic items found in Table Bay. Fibre (a), Fragment (b), Sphere (c), and Foam (d). All images were captured using a camera mounted on the

4.4 Weather data in Table Bay

During the sampling periods in summer and autumn on both sites, the wind was predominantly from the south with a speed of 20-29 km/h blowing 30 % of the time during the sample collection (Fig.4.24a). This was followed by 10-19 km/h wind speed range and >30 km/h blowing from the south 10% of the time each. During the sampling period in summer, the wind was predominantly blowing from the south-east with a speed range of >30 km/h blowing 40 % of the time during the sample collection, followed by 20-29 km/h blowing 30 % of the time (Fig.4.24b). In autumn, the wind was predominantly from the north with a speed range of 20-29 km/h blowing 10 % of the time (Fig.4.24c). The results showed that summer was windier than autumn during the sample collection in Table Bay. In summer, the wind speed was most predominant on the 8^{th} day and least predominant on the 9^{th} day during the sample collection (Fig.4.25a). In autumn, the wind speed was most predominant on the fourth day and least predominant on the seventh day during the sample collection (Fig.4.25a). On Woodbridge Island beach, the wind was predominantly blowing from the south with a speed of 20-29 km/h blowing 30 % of the time, followed by >30 km/h blowing 10 % of the time and 10-19 km/h blowing less than 10 % of the time (Fig.4.24d). On Derdesteen beach, the wind was predominantly blowing from the south with a speed of 20-29 km/h 30 % of the time (Fig.4.24e). In addition, some wind of 20-29 km/h was also blowing from the north less than 10 % of the time. The results showed windier conditions at Woodbridge Island than Derdesteen during the sample collection. At Woodbridge Island, the wind speed was most predominant on the 1^{st} day and least predominant on the nineth day during the sample collection (Fig.4.25b). At Derdesteen, the wind speed was most predominant on the fifth day and least predominant on the second day during the sample collection (Fig.4.25b).

Spearman's rank correlation was computed to assess the relationship between wind speed versus litter count, and wind speed versus litter weight. There was a negligible correlation between wind speed and litter count (r= -.040, p=0.722) (Fig.4.26a) as well as wind speed and litter weight (r= .111, p=0.327) (Fig.4.26b).

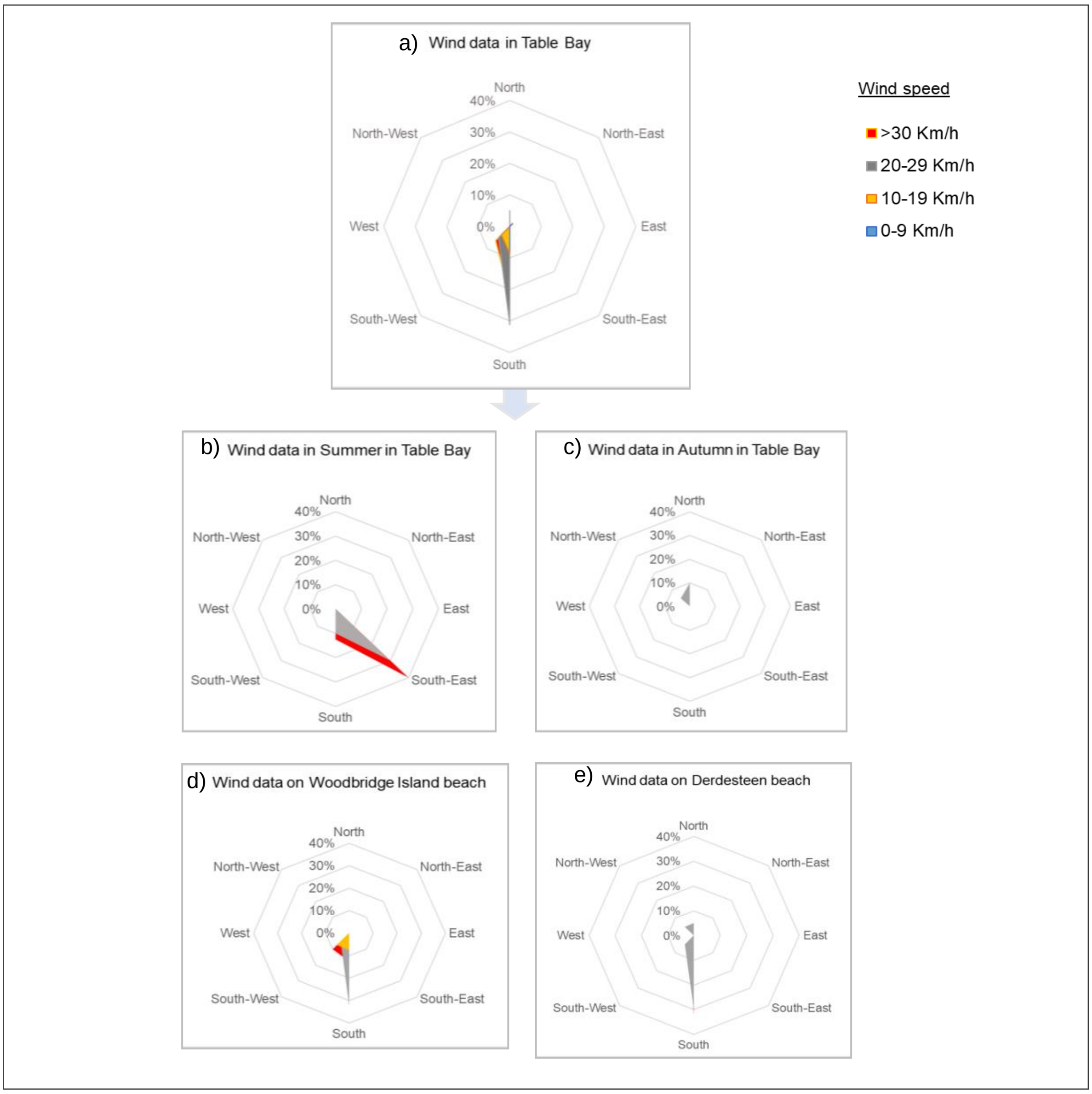

Figure 4. 24: Wind speed and direction in for both sites and seasons in Table Bay (a). Wind speed and direction for all sites in summer (b) and autumn (c). Wind speed and direction for both seasons in Woodbridge Island (d) and Derdesteen (e)

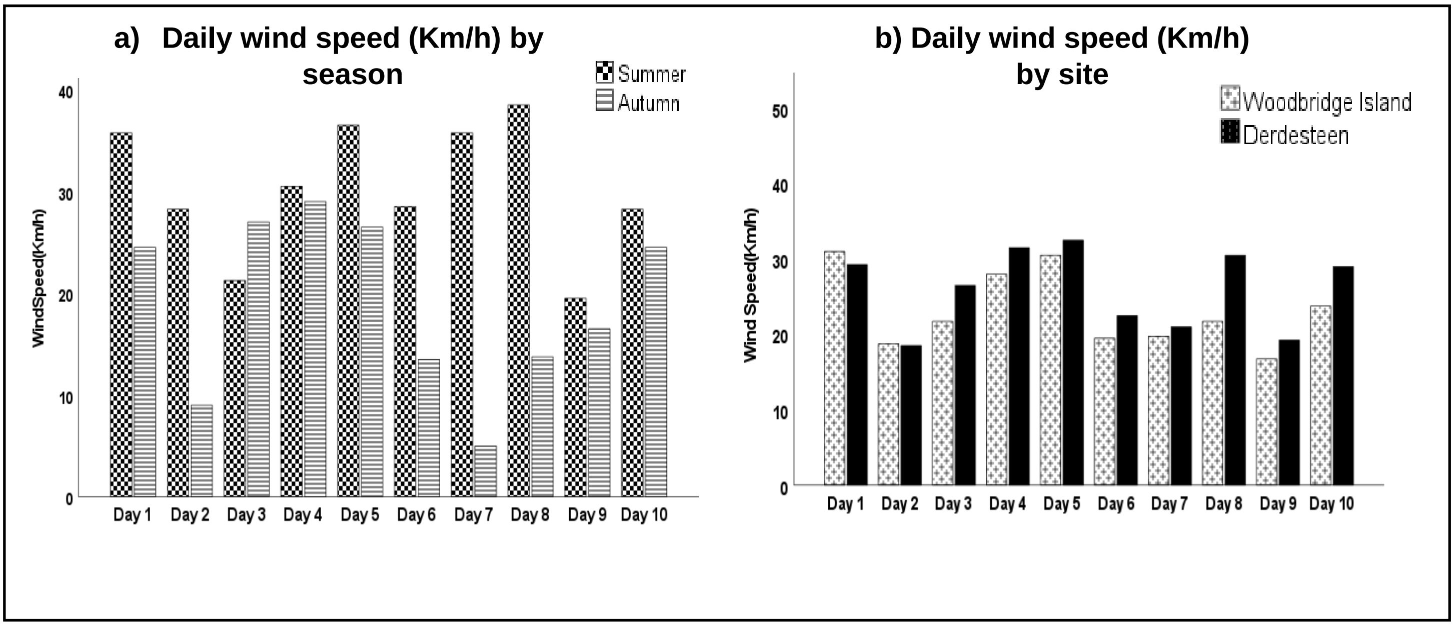

Figure 4. 25: Daily wind speed between summer and autumn on both sites combined (a) and between Woodbridge Island and Derdesteen in both seasons (b)

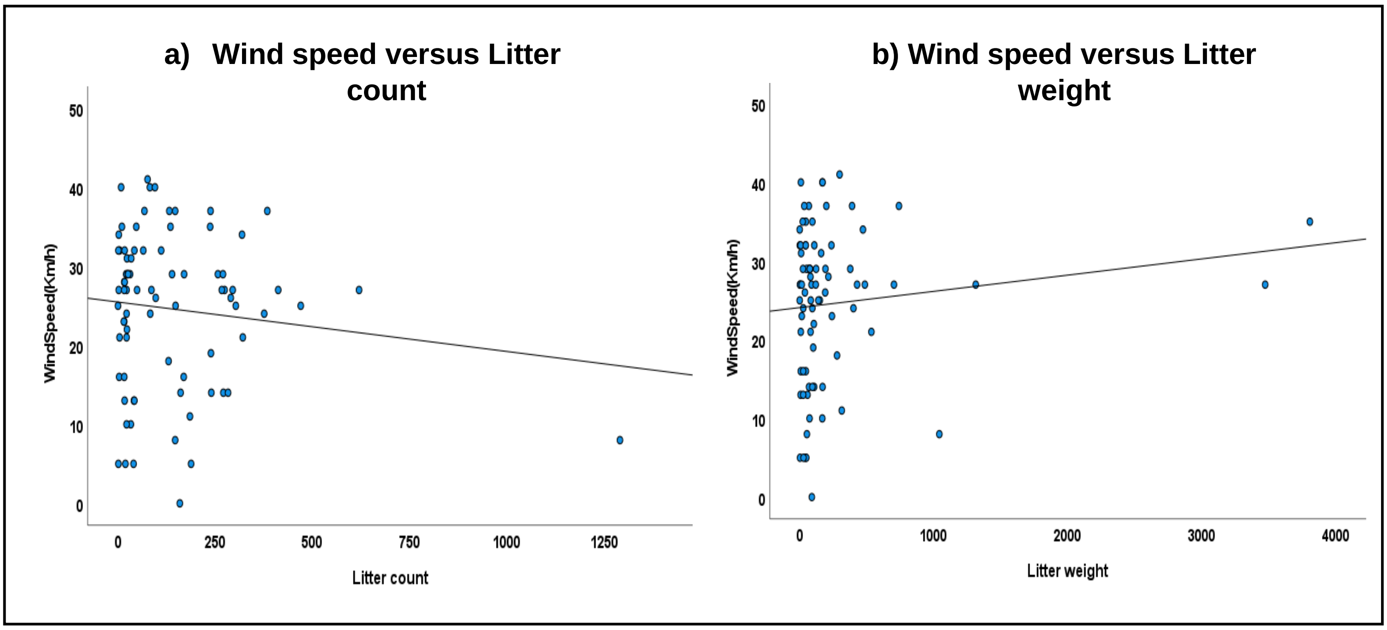

Figure 4. 26: Correlation between wind speed and litter count (a) and correlation between wind speed and litter weight in Table Bay (b)

CHAPTER 5

DISCUSSION

CHAPTER 5

DISCUSSION

5.1. Litter

Litter was found in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay where a total of 11 179 litter items weighing 20 028.07 g (20 kg) were collected. A similar study on Milnerton and Koeberg beaches in Table Bay found 39 602 items weighing 116.6 kg in 2019 (Opie et al, 2021). The values found in this study were considerably lower than those found by Opie et al (2021) and can be attributed to the difference in sampling methodologies. It is well documented that estimates of litter accumulation are influenced by sampling methodologies (Eriksson et al., 2013; Ryan et al., 2014; Smith and Markic, 2013). Opie et al (2021) sampled litter during winter, spring, and summer while the present study only sampled for summer and autumn. In addition, Opie et al (2021)'s survey was carried in 2019 pre-Covid19 pandemic while this survey was carried in 2021 during the pandemic. The finding of this study showed seasonal variations of litter between summer and autumn for both sites. Most of the litter count was found in autumn, with 5 883 items/100m (52.63%), while 5 296 items/100m (47.37%) was found in summer (Fig.4.1a). However, in terms of litter items by weight, most of the litter items were found in summer with 15 132.14 g/100m (75.55%), while 4 895.92 g/100m (24.45%) were found in autumn (Fig.4.1b). Opie (2021) also found seasonal variations in litter in Table Bay where more items were found in winter compared to the other seasons. In Chile, a total of 19,886 litter items were collected and seasonal variations between fall (11 894 items representing 59.8%) and winter (7 992 items representing 40.2%) was observed (Barría-Herrera et al., 2021). The present study was carried out during summer and autumn, when beach usage in the summer months (December-February) in Cape Town is quite intensive, potentially resulting in greater litter abundance. Due to the COVID-19 pandemic and the enforced restrictions on the movement of people, access to the beach for recreational purposes in South Africa was prohibited in November and December 2020 through to the end of January 2021, implying fewer visits during that period. It is important to note that beach clean-up resumed as soon as the beach reopened. The collection of litter for the summer was done in early February 2021, just as access to the beach was allowed. This explains why fewer items were collected in the summer compared to the autumn season. The low litter count observed in summer could be caused by the COVID-19 imposed restrictions during the summer season, resulting in fewer visits and a lower frequency of beach clean-ups compared to autumn. The influence of wind on the litter was evidenced in this study where summer was windier than autumn (Fig.4.24b and Fig.4.24c), which suggests that more lightweight items were blown away, leaving behind the heavier ones, as can be seen by the high weight observed in summer (Fig.4.1b).

The results of this study showed inter-beach differences in the litter collected in both summer and autumn. Most litter items by count were recorded at Woodbridge Island with 10 004 items/100 m (89.49%) compared to Derdesteen with 1 175 items/100 m (10.51%) (Fig.4.2a). More litter items per weight were found in Woodbridge Island, with 12 341.24 g/100 m (61.62%) compared to 7 686.83 g/100 m (38.38%) in Derdesteen (Fig.4.2b). This site related variation of litter items could be explained by: (a) the difference in land use between Woodbridge Island beach, which is in a residential area, and Derdesteen beach in a nature reserve (Fig.3.1 and A.2). Woodbridge Island beach is a popular recreational beach near the Cape Town harbour, surrounded by popular food establishments, and has a higher number and frequency of visitors than Derdesteen. Chitaka and von Blottnitz (2019) and Lamprecht (2013) identified public access and proximity to metropolitan areas as influential factors in marine litter occurrence. This could explain why Woodbridge Island had more litter than Derdesteen. (b) proximity to population centres, where the accumulation of beach debris is proportional to the number of beachgoers (Barnes et al., 2009). (c) the influence of wind as observed in this study, where the wind was more prevalent on Woodbridge Island compared to Derdesteen at the time of sample collection (Fig.4.23d and Fig.4.23e). Although statistical analysis showed a negligible correlation between wind speed and litter count ($r = -.040$, $p = 0.722$) (Fig.4.25a) as well as wind speed and litter weight ($r = .111$, $p = 0.327$) (Fig.4.25b) in Table Bay. Most studies have identified wind as a factor influencing debris transport (Ivar do Sul et al., 2014; Faure et al., 2015). Studies in South Africa such as Swanepoel (1995), Lamprecht (2013), and Opie (2021) have also reported on the variability of litter between sites. They surveyed Milnerton and Koeberg beaches in Table Bay in 1995, 2012, and 2019 and found that Milnerton beach repeatedly had more litter than Koeberg.

The results of this study also showed an intra-site variability in litter in Table Bay. Litter can enter the marine environment from various sources, including land-based activities such as stormwater runoff, littering, as well as marine-based activities such as fishing, shipping, and offshore oil, and gas production (Opie, 2021; Galgani et al., 2015; Ryan et al., 2009). However, once in the ocean litter can be deposited onshore through ocean current, tides, and wind. More litter items by count were collected in the dry zone, with 6 212 items/100 m representing 55.57% compared to 4 967 items/100m representing 44.43% (Fig.4.3a). The same trend was observed for litter weight. In the dry zone, 15 740.76 g/100m representing 78.59%, compared to 4 287.30 g/100m (106.80±28.10) representing 21.41% (Fig.4.3b). This could be attributed to displacement and exposure of buried items by wind. Leaving items behind by beach goers could also explain why more litter is found on the dry zone. Meakins et al. (2022) also found more litter items above the tide line (dry zone) in the eThekwini municipality. This, like in the current study was attributed to beach goers as well as wind transporting debris from the wet to the dry zone. In Kenya, Okuku et al. (2020b) collected litter in six beaches and reported higher litter count in the dry zone compared to the wet zone and higher litter weight in the wet compared to the dry zone. This was attributed to the presence of a few yet heavy items on the wet zone (shoes, fishing nets, clothes) which could easily be deposited when the wave energy is reduced while the dry zones had mostly lighter items (plastic fragments, food wrappers, cigarette butts, lollipop sticks and straws) which were mainly windblown (Okuku et al., 2020b). Okuku et al. (2022) also found that the dry zone had more litter than the wet zone in Kenya, caused by factors such as wind.

There was a moderate positive correlation between the weight and count of litter items in Table Bay ($r = .666$, $p<0.001$) (Fig.4.5). Chitaka and von Blottnitz (2019) also found a positive correlation between litter weight and count in Table Bay ($r = 0.95$, $p < 0.05$). In addition to the seasonal and site variabilities of litter observed in this study, a daily variability was also noted during the two sampling periods (summer and autumn) in Table Bay. This could be attributed to the effect of wind blowing litter items. This is no surprise given that wind was observed to vary throughout the sampling period. Similarly, daily variations in litter were observed on 5 beaches in Cape Town (Chitaka and von Blottnitz, 2019). Chitaka and von Blottnitz (2019) attributed this to some extent to varying weather patterns such as rainfall and wind. It was observed that on some sites, rainfall events increased the flow of litter via stormwater systems, while on other sites, the wind blew away accumulated litter (Chitaka and von Blottnitz, 2019). Lamprecht (2013) also observed daily litter variations in Table Bay in 2012. This confirms the findings of this study, with daily variations of litter potentially linked to the action of the wind blowing away the accumulated litter and uncovering previously hidden items. Other studies also highlighted that the transportation of litter via wind or water may be influenced by weather patterns (Li et al., 2018, Chitaka and von Blottnitz, 2019). Numerous studies have found a link between rainfall and litter loads (Lee et al., 2017; Rech et al., 2014). However, the results of this study cannot support or reject the impact of rainfall on litter loads because no rainfall events occurred during the collection period. But wind acted as a vector for litter transportation in Table Bay. The findings of this study are like those of Chitaka and von Blottnitz (2019), where the increased wind speed, coupled with the direction, resulted in a cleaning effect on the beach as litter was blown away from the site.

Of the 11 179 items weighing 20 028.07 g (20kg) found in this study and grouped into eleven litter types, plastic was the most abundant type by count (90.27%) and weight (43.45%). This is to be expected as most studies on marine litter worldwide have shown that plastic accounts for 50 to 90% of all marine litter (Agamuthu *et al.*, 2019). Lamprecht (2013) surveyed Milnerton and Koeberg beaches in Cape Town in 2012 and found that plastic was the most abundant marine litter with 93.3% by count and 58% by weight. The latter compared to this study indicates that plastic litter has decreased both by count and weight since 2012. This can be attributed to beach clean-up efforts, the presence of trash bins on the beaches, and the increased value of plastic recycling. Chitaka and von Blottnitz (2019) similarly found plastic to be the most abundant litter type during a survey of five beaches in Cape Town in 2017. Plastic items accounted for 94.5–98.9% of the total count and 57.0%–83.4% by average weight (Chitaka and von Blottnitz, 2019). Furthermore, items such as glass, wood, metals, clothing, rubber, paper, and marine objects were found during this survey. As anticipated, the results support the fact that there are varied litter types in Table Bay. The types of litter found in this study mostly align with the global characteristics of litter as mentioned in Galgani *et al.* (2015). Of the plastic litter, foam (Styrofoam) was the most abundant both by count and weight, with 41.74% and 48.32% of all the plastic litter collected. Polyethylene (PET) accounted for 69.23% of polymer types, followed by polypropylene (PP) and cellulose acetate (CA), both at 14.10%, and polystyrene at 2.56% (Fig.4.12). Similarly, Schwarz et al. (2019) also found polyethylene to be the most dominant polymer type.

The brand audit showed that most identified items in Table Bay were from local origin. This supports Ryan et al. (2020) who indicated that most marine debris in South Africa come from local sources. This further suggests that most land-based plastics does not disperse far from the source areas (Ryan et al., 2020). This brand audit also showed that most identified items were on-the-go snacks and beverages that were left behind by beach goers. In Kenya, Okuku et al. (2020b) also found that most of the litter collected was of local origin, making up to 88% of all collected items. In addition, the result of the clean cost index (CCI) categorized both Woodbridge Island (0.329) and Derdesteen (0.004) within the “very clean” category. This could be attributed to the clean-up efforts from the municipality as observed during the survey as well as the clearing effect of wind as identified in other studies (Chitaka and von Blottnitz, 2019). In Chile, the overall CCI was 4.9 which categorized the area as clean.

5.2. Mesolitter

Mesolitter was found in the summer of 2021 on Woodbridge Island and Derdesteen in Table Bay with a total of 1428 weighing 12.20 g collected during the survey. The recorded mean count was 4.46±0.60 items/m of meso-size (5–25 mm) with a mean weight of 0.04±0.01 g/m in 2021. These results support the point raised by Arabi and Nahman (2020) about the poor and inadequate state of waste management in South Africa resulting in waste being leaked in the environment. In 2015, Ryan et al. (2018) found an average density of mesolitter of 708 items/m, which is higher than what was found in this study. Meakins et al. (2022) found mesolitter items of size between 0.5 and 2.5 cm weighing an average of 2 g in the eThekwini municipality. Because of their small size, cleaning mesolitter during surveys is quite challenging.

Inter-beach differences in mesolitter collection were found, with Woodbridge Island accounting for 1 406 items/m, representing 98.46% of the mesolitter count, compared to Derdesteen with 22 items/m, representing 1.54% (Fig.4.13a). In terms of weight, the totality of weight was found on Woodbridge Island with 12.20 g/m (0.06±0.02) representing 100 % of the total weight (Fig.4.13b). Like litter, the inter-beach variation of mesolitter could be attributed factors such as public access, proximity to population centre, and wind. Woodbridge Island beach is in a residential area, near the Cape Town harbour, and Derdesteen beach in a nature reserve (Fig.3.1 and A.2). Tourism and the number of beach goers have been reported to influence the occurrence of mesolitter (Okuku et al, 2020a; Poeta et al., 2016; Leite et al., 2014). A similar pattern was observed in Kenya where mesolitter count was higher on sites near populated areas compared to those near semi populated, and remote ones (Okuku et al., 2020a).

Furthermore, intra-beach variability was observed in this study where more mesolitter items by count were collected in the in the wet zone (4.68 ± 0.94 items/m/day) compared to the dry zone (4.25 ± 0.76 items/m/day) (Fig 4.14a). However, no clear variability was observed for the mean weight of mesolitter items, with approximately 0.04 ± 0.02 g/m/day in both the wet and dry zones (Fig 4.14b). In addition, there was no significant differences in mesolitter count (U= 14 021 p = 0.093) and weight (U = 12 727, p = 0.756) between the two zones. The observation in this study is different to that of a similar study, where the backshore (designated as the dry zone in this study) had the highest mesolitter count (Lee et al., 2017).

The intra-beach variabilities of mesolitter items could be attributed to factors such as wind and amounts of items entering the marine environment as well as land use and proximity to metropolitan areas (Chitaka and von Blottnitz, 2019). This trend also supports the assumption that most mesolitter derives from local, land-based sources.

In addition to inter- and intra-site variability, daily variability was observed in this study. The highest daily mean count of mesolitter was observed on day 9 (12 ±4 items/m), while the lowest was on day 2 (0.8±0.4 items/m) (Fig 4.16a). The highest daily mean weight of mesolitter was observed on day 9 (0.17±0.09 g/m) while the lowest was on days 2, 3, 4 and, 6 (0 g/m) (Fig 4.16b). The daily variation of mesolitter could be attributed to the action of wind influencing the deposition of mesolitter in the different sections of the beach, as was observed on site, and the uncovering of formerly hidden or buried items, as observed on-site as well as the uncovering of buried items. Lee et al. (2017) also concluded that wind causes the displacement of litter on the beach according to the wind direction and uncovers previously hidden items (Okuku et al., 2020a). Galgani et al. (2015) mentioned prevailing winds and currents as vectors for mesolitter movement.

The composition of mesolitter showed that plastic items were the most abundant type found in this study, making up 99.05% by count and 78.69% by weight, with metals accounting for 21.31% of the remaining weight. This is understandable given that metal items are heavier than plastic ones. The same trend was observed in Kenya, where plastic was the most abundant meso-litter type on all the beaches surveyed (Okuku et al., 2020a). A similar trend was observed in South Africa from a survey of 82 beaches in 1994, 2005, and 2015, with plastic count accounting for 99% by count and 95% by weight (Ryan et al., 2018). In this study, pellets accounted for 69.75 % of all meso-plastics by count, followed by foam (18.49 %) and fragment (10.78 %) (Fig. 4.17a). The effect of wind during the sample collection potentially influenced the occurrence of the different mesolitter types in Table Bay. It is likely that given the small density and size of mesolitter items, the wind played a significant role in displacing and uncovering previously buried items. The results of this study highlight the ubiquitous nature of plastics of varying size in the marine environment and points to the already observe trend of plastic entering the environment (Agamuthu et al., 2019; Borrelle et al., 2020). Polymer identification showed that polyethylene (PET) was the most abundant polymer type, accounting for 59.52%, followed by polypropylene (PP) at 27.38%, polystyrene (PS) at 12.50%, and cellulose acetate with 0.60% (Fig.4.18). Pellets were also found to be the most dominant meso-plastic on 82 beaches in South Africa in 1994, 2005, and 2015, with 55.1% of all meso-litter, followed by rigid plastic fragments (33.7%) and foamed plastics (8.3%). In another survey in Korea, Lee et al. (2017) found that hard plastic and Styrofoam were the dominant material types.

5.3. Microplastics

The results from microplastics extraction from water and sediment in Table Bay showed that 688 microplastics (MPs) were found in summer and autumn of 2021 on both sites. The presence of microplastics in Table Bay was expected as the occurrence of this ubiquitous contaminant in the marine environment is well documented (Lamprecht, 2013). Statistical tests showed a significant difference in microplastics between the Woodbridge Island and Derdesteen ($U = 258.5$, $p = 0.002$). This inter-beach variability observed in this study (Woodbridge Island: 75.66% and Derdesteen 24.34% of total microplastics) can be attributed to factors such as proximity to river mouth, public access, and land use. The higher abundance of microplastics in Woodbridge Island clearly reflects the beach's proximity to the Diep River's discharge point (within 1 km vicinity), high accessibility and presence of renowned food establishments, and proximity to residential area. This is the opposite for Derdesteen beach, which is in a nature reserve, far from residential area as well as a river's mouth. Like this study, Sparks and Awe (2022) reported site specific variations of microplastics in the coastal sediment of a marina in Cape Town. Out of the six sites sampled, site 1 had the highest concentration of microplastics in sediment. Karthik et al. (2018)'s survey showed inter-beach variabilities of microplastics along the beaches of southeast coast of India. Karthik et al. (2018) found that beaches adjacent to rivers exhibited higher microplastics abundance compared to those influenced by tourism and fishing activities. On the Coast of Belgium, Claessens et al. (2011) reported the presence of microplastic in sediment and attributed their presence to the proximity to rivers, sewage outfalls, and combined sewers. The current study showed that summer accounted for 57.81 % of microplastics and autumn 42.19 % however, no significant difference was found between the two seasons ($U = 525$, $p = 0.861$). The same was observed in the coast of Hengchun in Taiwan, where Chen and Chen (2020) found no significant difference in microplastics between seasons but found a spatial one. The lack of clear seasonal distribution of microplastic in Taiwan could indicate the complex interactions between tourism activity level, ocean currents, wind, and precipitation (Chen and Chen, 2020).

Fibre was the most abundant type of microplastics collected from water and sediment samples (97.37 %) (Fig. 4.20a, Fig. 4.23) while blue was the most common colour, accounting for 46.46 % of all microplastics collected. The presence of fibre could be attributed to the presence of people on the beach. The results of this study are like those found by Nel and Froneman (2015) along the south-eastern coastline of South Africa (fibres: 90 % and blue/black colour: 90 %), and Claessens et al. (2011) in the Belgian coast (fibre: 59 %). Chen and Chen (2020) also found fibre to be the most prevalent microplastic type in Taiwan (fibre: 97-99%). In contrast to this study, Chen and Chen (2020) found white/transparent as the most prevalent colour. It is reported that the variation of microplastic colours point to the origin of the particles in the environment (Dhineka et al., 2022; Bimali Koongolla et al., 2018; Stolte et al., 2015). Although fragment was the most dominant along the beach sediments in the southeast coast of India, it was followed immediately by fibres (Karthik et al., 2018). However, this suggests that the type of microplastics found is influenced by the methodologies used. Karthik et al. (2018) used the lower limit of 0.3 mm while this study used 0.1 mm. It has been reported that differences in collection methods, lab methodologies, and quantitative units make it difficult to establish direct and meaningful comparison of results between studies (Nel et al., 2017). In the size category, microplastics between 0.1 and 0.5 mm were the most abundant, accounting for 50.32%.

The research on the three categories of contaminants (litter, mesolitter and microplastics) provided evidence of the complex and dynamic systems in the coastal environment. The three categories of contaminants varied by site and seasons, indicating the effects of anthropogenic activities in Table Bay. Furthermore, the dominance of plastics as the main type of marine litter and mesolitter, as was expected is in line with other studies (Opie 2021; Chitaka and Von Blottnitz, 2019). The presence of mesolitter also indicate that beach clean-up activities do not target meso-sized items. In addition to anthropogenic activities, factors such as wind play a noticeable role in displacing and uncovering debris on the beach (Ivar do Sul et al. 2014; Faure et al. 2015, Li et al. 2018). For microplastics, fibre was the most abundant type found reflecting the proximity to river, and wastewater treatment discharge. The distribution of litter and microplastics between sites and seasons was observed and attributed to variables such as wind, site accessibility, and items left behind by visitors. Mesolitter, sampled in summer only, showed site variations attributed to the same variables affecting litter and microplastics. The presence of the three contaminant categories (litter, mesolitter, and microplastics) in Table Bay reflects the state of waste management in South Africa. The results of this study support Arabi and Nahman (2020) observation that waste management in the country is characterised by poor and inadequate waste collection and disposal eventually leaking into the environment.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

CHAPTER 6

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6.1. Conclusion

This section offers the conclusive statements formed from the discussion of the results. The aim of the research was to investigate the characteristics and distribution of litter and microplastics in Table Bay, Cape Town, South Africa. The following objectives: (1) To determine the characteristics and distribution of litter in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay; (2) To determine the characteristics and distribution of meso-litter on Woodbridge Island and Derdesteen beaches in Table Bay; (3) To determine the characteristics and distribution of microplastics form water and sediment in summer and autumn on Woodbridge Island and Derdesteen beaches in Table Bay guided the research towards achieving the aim of the study.

The results of this study provide evidence of the occurrence of litter, mesolitter, and microplastics in the coastal environment of Table Bay in Cape Town. The study highlighted the seasonal, and site variabilities of litter and mesolitter in Table Bay. Most litter items were found in autumn, but most of the litter weight was found in summer, potentially due to wind displacement in summer. The study also found inter-beach differences in litter and mesolitter collected, with Woodbridge Island beach having higher numbers of items and weight due to proximity to residential area and ease of access. Both sandy beaches were very clean based on the clean coast index (Woodbridge Island: 1.67; Derdesteen: 0.19). This could be attributed to the clean-up efforts from the municipality as observed during the survey as well as the clearing effect of wind. Intra-site variability of litter and mesolitter in Table Bay was also observed, with more litter found in the dry zone, possibly due to displacement by wind and leaving items behind by beachgoers. Factors such as wind, land use, proximity to metropolitan areas, and public access contributed to litter and mesolitter occurrence in Table Bay. Furthermore, the action of wind displacing, and uncovering previously buried litter and mesolitter items was observed in this study. The brand audit showed that most of the identified items were of local origin, with on-the-go snacks and beverages being the most found litter. The presence of plastic as the dominant litter and mesolitter type in Table Bay clearly reflects the increase in plastic production and adoption coupled with poor waste management. The occurrence of litter in Table Bay aligns with the global composition of litter where plastic litter accounts for 50 to 90% of all litter types. Additionally, items such as metal, textile, glass, hygiene, and rubber reflect the varied litter characteristics of waste found in Table Bay.

Microplastics were found in Table Bay with fibre, a type of secondary microplastic making up the most of all microplastics collected. The occurrence of microplastics in Table Bay also showed seasonal and site variabilities. Seasonal variabilities of microplastics were observed (summer: 57.81 %; autumn: 42.19 %) although no significant difference was found between the two seasons (U = 525, p = 0.861). This inter-beach variability of microplastics in this study (Woodbridge Island: 75.66% and Derdesteen 24.34% of total microplastics) was observed, with statistical tests showing a significant difference between the two sites. This was attributed to factors such as proximity to residential area and river mouth, public access, and land use.

To sum it up, the aim and objectives of the study were met in this study. The findings of this study lay the groundwork for a better understanding of the spatial and temporal variations and characteristics of litter, mesolitter and microplastics. They contribute towards historical data of litter, mesolitter, and microplastics in Table Bay and serve as baseline for future research. The findings of this research provide a comprehensive understanding of the characteristics and distribution of litter and microplastics which will inform regional and international strategies for mitigating the impact of waste on the environment. The context of the study also highlights the importance of addressing root causes of the issue, such as poor waste management and weak policies, in addition to mitigating the immediate impacts of litter and microplastics in the environment.

6.2. Recommendations

- Establish management strategies to monitor litter, mesolitter, and microplastics contaminants from source level.
- Engage governments, public and private sectors, institutions of learning, and community on separation at source programmes to minimize leakage into stormwater drains.
- Improve waste management and strengthen waste policies.
- Beach clean-up programme should also include meso-sized items.
- Conduct annual accumulation surveys to get more detailed information on litter, mesolitter, and microplastic in Table Bay.
- Develop a uniform methodology for litter, mesolitter, and microplastics to allow for easy comparison of results.

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APPENDICES

Appendix A: Sampling site

Figure A.1: Woodbridge Island Beach in Table Bay

Figure A.2: Derdesteen beach in Table Bay

Appendix B: Sample collection

Figure B. 1: Collection of sediment samples from the backshore for MPs analysis

Figure B. 2: Collection of sediment samples from the most recent water mark (strandline) for MPs analysis

Figure B. 3: A 0.5mX0.5m sieve with 2mm mesh used for the collection of mesolitter

Appendix C: Collected items

Figure C. 1: Glass bottles found on the beach

Figure C. 2: Litter items collected in Table Bay

Figure C. 3: Cotton buds

Figure C. 4: Cigarette lighter and litter items such as plastic spoon in Table Bay

Figure C. 5: Aluminium can collected in Table Bay

No	Brand name	Item
1	Amajoya	Candies
2	Bar One	Chocolate
3	Bigga Naks	Chips
4	Black Label	Beer
5	Coca Cola	Soft beverage
6	Coffee	Candies
7	Endearmints	Candies
8	Fizpop	Candies
9	Go-slo's	Chips
10	Gold label	Tomato sauce
11	Lays	chips
12	London Dry gin	Liquor
13	Maynards	Sweets
14	Mentos	Candies
15	Sasko	Bread packaging
16	Seepo	Iodated salt
17	Simba	Chips
18	Smoothies	Candies
19	Strongbow	Apple Cider

Figure C. 6: Names of brands and items found in Table Bay

Appendix D: Laboratory work

Figure D. 1: Digestion of sediment samples with 10% KOH solution

Figure D. 2: Filtration of samples through a 20 μm mesh for microplastic extraction

Figure D. 3: FTIR station