The abundance, distribution and accumulation of plastic debris in Table Bay, Cape Town, South Africa

Annerie Lamprecht

Submitted in partial fulfilment of the requirements for the degree of Master of Science (by coursework and dissertation) in Applied Marine Science

Department of Biological Sciences, University of Cape Town,

April 2013

Supervisors:

Coleen L. Moloney

Peter G. Ryan

Photo: John Kieser

DECLARATION

1. I know that plagiarism is wrong. Plagiarism is to use another's work and to pretend that it is one's own. This includes copying phrases and sentences from another's writing, and inserting these into one's own work.
2. I have use a standard convention for citation and referencing. Each significant contribution to, and quotation in, this report from the work, or works, of other people has been attributed, and has been cited and referenced. Where exact wording is used, this is placed in quotation marks, and the page number is included in the citation.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE ……………………………………………………………………………….

DATE ……………………………………………………………………

NAME ………………………………………………………………….

STUDENT NUMBER ………………………………………………….

ABSTRACT

Stranded debris and beach litter were examined at two sites in Table Bay, South Africa, repeating a survey made at the same two beaches in 1994. One beach (Milnerton) is a popular recreational beach 12 km from the city centre, whereas the other (Koeberg) is situated in a nature reserve, with limited access by the general public, and is 27 km farther from the city. Daily accumulation rates of manufactured items (>1 cm diameter) were measured at both beaches for ten days in October, November and December 2012. Of the 124,646 items collected, 93% were made of plastic, but these items comprised only 59 % of the total weight. There was generally consistent but large within-site variability in accumulation rate; the within-site coefficients of variation (CVs), which range from 23.7 % to 101.5 %, respond in the same way across months. There was also considerable daily variation (CVs range from 13.6 % to 92.8 %). The mean density of items decreased with distance from Cape Town. Since 1994, the composition, abundance and accumulation rate of debris has changed on these two beaches. The mean (s.e) accumulation rate of plastic articles at Milnerton increased 257 %, from 378 (72.3) plastic items.day^{-1}.100 m^{-1} of beach to 1350 (126.7) items.day^{-1}.100m^{-1}. The increase at Koeberg was from 44 (2.7) items.day^{-1}.100 m^{-1} to 100 (17.3) items.day^{-1}.100 m^{-1}. Evidence of increased input during the peak holiday season (December) was recorded at both beaches. The mean accumulation rates of most materials had increased at Milnerton since 1994 and the composition of the materials had also changed. The non-plastics were numerically dominated by cloth, paper and wood in 1994 but cigarette butts dominated in 2012. In contrast, at Koeberg the accumulation rates of most non-plastic materials decreased since 1994 and there were small differences in composition. No correlation was found between total weights and total counts of plastic items on the beaches. Daily variability (accumulation rate and accumulating weight) was generally not correlated with weather conditions. Since 1994, the accumulation rate of small, unidentified plastic fragments increased by more than 200- fold at Milnerton and by a factor of 80 at Koeberg. To improve our understanding of the vertical distribution, abundance and composition of microplastics (articles < 10 mm), samples were taken at 5 cm depth intervals (0 to 25 cm) on Milnerton. The number of microplastics, sized 2 mm- 10 mm, found in each layer decreased with depth. Smallest plastic items (0.5 - 2 mm) were randomly distributed in the surface layers (top 10 cm) but had low densities in the bottom layers. Plastic pellets had the same decreasing trend with depth. Amounts of plastic litter have increased by two orders of magnitude over an 18-year period, reflecting both accumulation of plastic debris in coastal environments and increased use of plastics during the past decades.

ACKNOWLEDGEMENTS

Dr P.G. Ryan and Dr. C.L. Moloney for their guidance throughout the project and for useful comments made on the report and assistance with data collection; Tamryn and Jacque Oosthuizen, and Miekie Lamprecht for assistance with data collection; Jurina Le Roux for issuing a permit that allowed the study in the Koeberg Private Nature Reserve; John Kieser and his team for help with initial beach cleanups and for supplying dustbin bags; SA Weather Services for providing weather data which include rainfall, wind speed, tides and cloud cover; and the National Research Foundation for funds to cover petrol expenses and consumables for field work and bursary support to cover my student fees for 2013.

Table of Contents

Chapter 1

The effects of plastic marine debris on the marine environment

Marine debris is human-created solid waste material that enters the marine environment from various sources (Santos *et al.* 2009). The sources can be land or sea based and their origin can be local or distant. There are major issues of various kinds of pollution derived from marine debris contamination (Santos *et al.* 2005). Buoyant litter can travel long distances with currents and can contaminate the most remote islands (Otly & Ingham 2003). Buoyant litter tends to accumulate in coastal and convergence areas where abundance and diversity of marine life are greatest (Santos *et al.* 2009). Population growth and rapid urbanization can cause damage to coastal regions, which are susceptible to litter accumulation. Marine debris, especially plastic, poses numerous threats to terrestrial and marine animals, human activities, health and tourism (Oigman-Pszczol & Creed 2007). Well known environmental threats are choking and starving wildlife, distributing non-native and potentially harmful organisms, adsorbing toxic chemicals and degrading to microplastics that may later be ingested by fauna (Barnes *et al.* 2009). Litter also decreases the aesthetic value of tourist beaches, risks beach users' health and damages ships (Santos *et al.* 2005).

MARINE PLASTIC DEBRIS

Over the past five or six decades since the start of mass production of plastics, accumulation of plastics has been observed in terrestrial and marine environments (Barnes *et al.* 2009). These synthetic organic polymers (plastics) are contaminants whose effects have gone beyond the visual. Their low cost, longevity and disposable nature have made plastic debris a universal problem. What was simply seen initially as an aesthetic problem has become a threat not only to animals and the environment but for humans too (Barnes and Milner 2005). The attractive qualities of plastics make them suitable for the production of numerous products. Unfortunately the same properties are the cause of many environmental problems (Derraik 2002). Because most plastics are buoyant and persistent in sea water, they have the ability to disperse longer distances than high density articles such as glass and metal and last longer than low density articles such as paper (Ryan *et al.* 2009).

For centuries humans have disposed of their waste into the sea, where it eventually accumulates along coastlines or on seabeds (Ng & Obbard 2006). This has become an ever-increasing problem around the world as the lifetime of plastics at sea is largely unknown (Barnes *et al.* 2009). Most types of plastics are not biodegradable and can persist in the environment for years and even decades. Depending on environmental conditions, even degradable plastic can persist in the environment for many years, as the degradation rate depends on levels of ultraviolet (UV) light exposure, oxygen and temperature, whereas biodegradable plastics require certain micro-organisms to be present (Hopewell *et al.* 2009). Degradation rates can therefore vary from place to place, depending on the physical and chemical properties of the polymer (Ng & Obbard 2006) and environmental conditions. A rising concern is the presence of plastic pellets and plastic fragments in the marine environment. These can be found all over the world. Plastic pellets are raw plastic material from which larger plastic items are made. These enter the environment from plastic industries, by stormwater and deliberate or accidental spills (Ivar do Sul *et al.* 2009). Prolonged exposure to UV light and physical abrasion makes plastic fragile and leads to fragmentation (Barnes *et al.* 2009). Both plastic pellets and fragments have been recorded as having affected wildlife (Kusui & Noda 2003). Globally the average size of plastics is decreasing, although the environmental consequences of these small plastics are still largely speculative (Barnes *et al.* 2009).

Andrady and Neal (2009) describe the societal benefits of plastics. Plastic can improve consumers' health and safety, save energy and conserve other raw materials (Andrady and Neal 2009). Over - packaging is a problem as packaging normally sells a product, but because plastics are so persistent in the environment, compared with other discarded material (paper, metal, glass), it is difficult to determine the sources of plastic litter (Andrady & Neal 2009).

An important environmental concern, especially on beaches and in metropolitan areas, is the issue of littering. This can be overcome by stricter laws and education programs as littering is mostly described as a behavioural issue (Andrady & Neal 2009). The existence of litter on beaches and in waterways can have a number of impacts: it can decrease the aesthetic value, it can pose a potential health risk for humans, aquatic animals are in danger of getting entangled, suffocating or ingesting litter while searching for food, pathogenic organisms and toxins can be taken up through the food chain, poisoning animals and impacting humans (Armitage & Rooseboom 2000), invasive species can be transported, economic threats can increase (Gregory 2009), and large amounts of cash are spend every year for regular beach clean-ups (Barnes *et al.* 2009).

WASTE MANAGEMENT

Plastic manufacturers use around 7 – 8% of the world's petroleum (non-recycled resource) production to manufacture various plastic products (Hopewell *et al.* 2009). Almost half of it is used to make single-use items such as packaging (especially fast food packaging), which are disposed of within a year (Hopewell *et al.* 2009). Rochman *et al.* (2013) state that if the current rate of plastic consumption continues the planet will hold another 50 billion tonnes by 2050. The waste stream can be reduced by decreasing the use of materials in products, designing products for re-use purposes and ensuring repair and re-manufacturing of products is possible (Hopewell *et al.* 2009). Once material enters the waste stream, environmental impacts can be lessened by recovering plastics from landfills or littering. These can be recycled to produce other products. Incineration of plastic can also recover energy but it does not reduce the demand for new (virgin) material. Both recycling and incineration reduces the quantities of discarded plastic accumulating in landfills and natural environments (Hopewell *et al.* 2009). Rochman *et al.* (2013) believe that if plastic waste is classified as hazardous the production of plastics will decrease.

SINKS AND SOURCES

Debris can enter the marine environment either accidentally or deliberately. The sources of these polluting materials can be both land-and sea-based and their origin can be local or distant (Gregory 2009). Coastal tourism, recreational and commercial fishing, marine vessels and marine industries can be direct sources of plastic entering the marine environment (Cole *et al.* 2011). The fishing industry is the marine source that contributes most to ocean pollution by dumping (Otley & Ingham 2003) although the main contributors overall come from land-based sources which are responsible for up to 80% of marine debris (Cooper & Corcoran 2010). Land-based plastics include improperly disposed of "user" plastic and leachate from refuse sites. With almost half of the world's population living within 80 km from the coast, the possibility that litter will end up in the ocean via rivers, wastewater systems or being blown offshore increased (Cole *et al.* 2011). Fishing industries mostly affect shores with adjacent fishing ground (Otley & Ingham 2003). Martinez-Ribes *et al.* (2007) found on 32 beaches on the Balearic Islands that in the peak tourist seasons litter mostly derives from beach users, but drainage and outfall systems are the main sources in non-peak seasons.

Brown *et al. (*2011) believe that an important new source of micro plastic (articles < 1 mm) is through sewage contaminated by fibres from washing clothes. Experiments conducted on waste water of a domestic washing machine revealed that a single garment can produce more than 1900 fibres. Many governments have installed sewage treatment plants that remove large debris but none of them are designed to capture microplastics (Cole *et al.* 2011). Another overlooked source is small fragments of plastic derived from hand cleaners, cosmetic preparations and air-blast cleaning media. After use, these fragments can be contaminated by heavy metals as they are used in air-blasting technologies to clean motor engines or strip paint from metal surfaces. Once discarded, these particles end up in sewage systems and eventually in the sea (Deraik 2002; Cole *et al.* 2011). The most common micro-plastics found are acrylic, alkyd, poly (ethylene: propylene), nylon, polyester, polyvinyl- alcohol, methylacrylate, polypropylene and polyvinyl – alcohol (Thompson *et al.* 2004).

Another source of plastics is from industries that use virgin plastic pellets as raw material to manufacture larger plastic items. The pellets can enter the marine environment through accidental spillage on land and at sea, direct outflow from processing plants and inappropriate packaging materials (Cole *et al.* 2011). These plastic pellets are found in great concentrations in harbours (Claessens *et al.* 2011, Cole *et al.* 2011) but they are by no means localised. Evidence suggests that they can now be found anywhere in the world's oceans and coastal environments (Ivar do Sul *et al.* 2009). Concentrations of these pellets are variable (Claessens *et al.* 2011). Some American plastic manufacturers voluntarily committed to preventing or recapturing spilled pellets, an act that will automatically decrease quantities of resin pellets in the marine environment (Cole *et al.* 2011).

In South Africa litter mostly consists of single - use items and packaging such as paper and plastic food wrapping, cans, plastic bottles, cigarette packets and cigarette butts (Armitage & Rooseboom 2000). These items accumulate in public places such as public parks and gardens, shopping centres, car parks, railway and bus stations, public bins, landfill sites and recycling depots. It remains there until local authorities remove it or, if not regularly removed, is transported by wind and stormwater runoff into the drainage systems (Armitage & Rooseboom 2000). Once in the drainage system, the debris has the potential to travel long distances via rivers, stormwater conduits, streams and estuaries and eventually ends up in the sea. Some of the debris gets caught in vegetation along river and stream banks or strewn along beaches (Armitage & Rooseboom 2000). As the public puts pressure on local authorities, some of the litter is removed, often at great expense, but most will be buried in river and beach sediment over time. There, some litter, especially plastics, can persist for many years (Armitage & Rooseboom 2000). Almost all solid debris in rivers is derived from urban areas in South Africa although urban areas comprise only 5.6% of the land area.

THREATS FROM PLASTIC POLLUTION TO MARINE BIOTA

Invasion

The impact of invasive species on indigenous species has been identified as one of the primary reasons for biodiversity loss around the world (Lewis *et al.* 2005). Over the last few decades opportunities have increased for invasive organisms, especially fouling organisms, to travel long distances. Natural transport for marine organisms is being supplemented by plastic debris and shipping activities (Lewis *et al.* 2005, Barnes 2002). In contrast to shipping activities, transport routes via plastic debris are passive, dependent on ocean currents and are already established through natural drift. For this reason shipping activities (mostly not ocean or wind current dependent) have been identified as the main source for introducing species to other locations (Lewis *et al.* 2005). Plastic has doubled (Barnes & Milner 2005) the opportunities for organism dispersal in the tropics but humans, with their amazing travelling ability, have increased potential dispersal at sub-polar latitudes (Barnes & Milner 2005). The Southern Ocean has high levels of endemism in many taxa and few known introduced species. The Atlantic section of Antarctica is a fast warming region, which reduces the possibility of temperature acting as a barrier to exotic organisms transported on debris (Barnes & Milner 2005).

Barnes (2002) investigated drift items colonized by marine animals deposited on shores of 30 remote islands. He found that distance from mainland to each island played no role in the proportion of debris colonised. Latitude was a good indicator as no colonised items were found poleward of 60˚ (Barnes 2002). Numerous animals use marine debris as a vehicle, particularly barnacles, polychaete worms, hydroids and molluscs (Barnes & Milner 2005). Of the most abundant species found were animals with a cosmopolitan distribution. Masó *et al.* (2003) found harmful dinoflagellates on buoyant plastic along the Catalan coast. They believe that buoyant plastic debris can be a potential vector for microalgal dispersal.

Ingestion

The incidence of plastic in seabirds was first recorded in 1960 (Gregory 2009) and has since increased (Mallory 2008). Plastic ingestion can have a wide range of harmful effects on seabirds, including reduced appetite, growth and dietary efficiency, as well as increased levels of polychlorinated biphenyls (PCBs) and other organochlorine assimilations (Provencher *et al.* 2010). These can have negative impacts on bird populations, particularly when stressed by changing environmental conditions and altered prey abundance (Provencher *et al.* 2010). Azzarello & Van Vleet (1987) found that plastics affect different seabirds on different levels depending on their foraging methods, distribution, breeding and moulting periods.

Seabirds that ingest plastic are good indicators of the composition and amount of plastic debris at sea (Ryan *et al.* 2009). They forage over large areas at different trophic levels (Mallory 2008) and they can be cost effective sampling tools, providing samples from stomach contents of beached birds, birds killed accidentally by fishing activities or by examining predators feeding on seabirds (Ryan *et al.* 2009). Ryan (1988) did an experiment on domestic chickens to determine whether ingested plastic impaired feeding activity of birds. He found that plastic-loaded birds reduced food intake and grew slower. He concluded that reduced intake of food lessened their ability to store fat and thus reduced fitness. According to Azzarello & Van Fleet (1987), planktivores, are more likely than piscivores to mistake plastic pellets for their prey, therefore the former have a higher incidence rate of ingested plastics. Provencher *et al.* (2010) also found that surface feeders ingest more plastics than birds feeding in the water column. Kenyon & Kridler (1969) examined the gut contents of a 100 Laysan albatross *Diomedea immutabilis* and found that 99.4% was buoyant, of which 30% was plastic. These scrap plastics are regularly found on beaches. At first Kenton & Kridler (1969) thought the main sources of indigestible items in young albatrosses were beaches, but this is unlikely as albatrosses rarely feed on items from shore. It is more likely that these are retrieved from sea by adults and fed to their young by regurgitation.

Ingestion of plastic by numerous species of animals is a well known problem worldwide (Gregory 2009). Carpenter *et al.* (1972) found white, opaque polystyrene spherules in various species of fish while examining their guts, which indicates that they feed selectively on these spherules. The ingestion of microplastics by fish can be an unexpected impact on fisheries as Possatto et al. (2011) have found that three catfish species from the Gioana Estuary (Northeast Brazil), which ingest plastics, are important prey for large, economically valued species. Laboratory experiments have shown that mussels (*Mylitus edulis*) can ingest microplastics and incorporate them in their tissues where they can persist for at least 48 days (Claessens *et al.* 2011). Laboratory trials had found that detritivores, deposit feeders and filter feeders can ingest microscopic plastics (Thompson *et al.* 2004). No negative effect was found, most likely because of short exposure times in experiments (Claessens *et al.* 2011).

Some of the main threats to turtle survival are oil spills and persistent plastics, which can affect their breeding and foraging grounds (Bugoni *et al.* 2001). A study done by Tourinho *et al.* (2010) along the southern Brazilian coast concluded that marine debris contamination had increased because, for the first time, plastic was found in the digestive systems of all stranded juvenile green turtles. In previous studies plastic debris was only found in a portion of the total juvenile turtles. No preference was found in colour of plastic ingested. Sub-lethal effects for the turtles included reduction of food intake, decreased growth rates and increased time to reach sexual maturity (Tourinho *et al.* 2010, Bugoni *et al.* 2001). Plastic bags are often consumed by sea turtles as they are mistaken for jellyfish (Moore 2008). In general ingestion of plastics reduces fitness by altering food intake and thus reducing most animals' ability to store fat (Derraik 2002).

Adsorption power of plastics

Plastic pellets serve as a carrier of toxic chemicals in the marine environment (Brown *et al.* 2011). Plastics are known to adsorb hydrophobic compounds (Moore 2008). Field experiments have shown adsorption of polychlorinated biphenyls (PCBs) and dichlorodiphenyldichloroethylene (DDE) on polypropylene virgin pellets increased steadily over a six day experiment, indicating that the source of PCBs and DDE is ambient in seawater (Mato *et al*. 2001). There is evidence that ingestion of micro-plastics provides a vehicle for the transfer of pollutants, monomers and plastic-additives to organisms with likely negative consequences (Browne *et al.* 2011). Substances desorbed from plastic can have a negative physiological effect on biota, because there is a positive relationship between the mass of ingested plastic and PCB concentrations in fat tissue of Great Shearwaters *Puffinus gravis* (Mato *et al.* 2001, Moore 2008, Andrady 2011). Teaten *et al.* (2007) also showed that plastics can be important agents in the transport of hydrophobic contaminants to sediment - dwelling organisms, because the adsorption of these contaminants to plastics greatly exceeds adsorption to natural sediments.

Entanglement

In early years, rope and cordage used in marine activities was made of natural fibre (Gregory 2009). Today it is largely replaced by plastic because of its low cost and physical and biological durability. Fishing industries can thus spend more time fishing than repairing equipment (Page *et al.* 2004). However the increased use of plastics in the fishing industry has resulted in environmental problems in the oceans and on beaches (Page *et al.* 2004). Although most marine debris originates from land - based sources, maritime debris poses a risk to ecosystem health because fishing equipment is made to persist in the marine environment (Donohue *et al.* 2001). Entanglement affects numerous species, including turtles, penguins, albatrosses, petrels, shearwaters, shorebirds, skuas, gulls, auks, coastal birds other than seabirds, baleen whales, toothed whales, dolphins, earless or true seals, sea lions, fur seals, manatees, dugongs, sea otters, fish, crustaceans (Gregory 2009) and even coral reefs (Donohue *et al.* 2001).

Boren *et al.* (2006) suggest that high entanglement rates are mostly found where marine animal populations reside in close proximity to human settlements or fishing activities. Entanglement rates are often underestimated as entanglements at sea are often excluded

(Boland & Donohue 2003). A study done by Walker *et al.* (1997) found that the growing effort in long-line fishing activities increased the risk of entanglement of the Antarctic fur seal *Arctocephalus gazelle,* in areas where direct sources of man-made marine debris were relatively scarce. Off South Georgia entanglement had lessened over a two year period, not just because of improved waste disposal management, but also because fishing activities had decreased in that area at the same time (Arnould & Croxall 1995).

Animals are either attracted to (e.g. curious animals like young fur seals) or accidentally entangled in floating debris (Derraik 2002). Entangled animals find it difficult to escape and they can drown, have impaired ability to catch food or avoid predators, or incur wounds from abrasive or cutting actions of attached debris (Laist 1987). The highest incidence rate for entanglement was recorded in Bass Strait and off southern Tasmania, where in a period of four years (1989 - 1993) approximately 1.5 – 2% of Australian fur seals (*Arctocephalus pusillus doriferus*) were found with plastic collars (Jones 1995). Over a period of 23 years, Cliff et al. (2002) found 53 sharks along the coast of KwaZulu-Natal, South Africa with polypropylene strapping around their bodies of which the dusky shark was most impacted. Laboratory investigations showed that entangled sharks were significantly underweight. This shows that entanglement can influence feeding behaviour and reduce fitness (Cliff et al. 2002; Derraik 2002).

Abandoned nets, webbing and monofilament lines have the ability to capture fish and other species continuously for lengthy periods of time. Termed “ghost fishing”, this phenomenon has environmental and economic consequences. Death rates of fish, birds and mammals caused by ghost fishing are unknown but estimated at millions annually (Moore 2008). Once a trapped animal has died and decomposed, the plastic in which the animal got entangled has the ability to entangle another animal.

Impacts of microplastics on physical properties of beaches

A study done by Carson *et al.* (2011) found that coarse-grained, permeable beaches contained more plastic than fine-grained beaches. Laboratory trials on artificially-constructed cores that mimicked different mean grain sizes were unable to show what causes the increased permeability of plastics in coarse versus fine grained beaches, but possible reasons are a combination of reduced friction from smooth plastic surfaces and increased average grain size. This can have a variety of impacts on beach fauna (Carson *et al.* 2011), affecting a number of taxa and their eggs, including crustaceans, molluscs, polychaetes, fish and various interstitial meiofauna (Carson *et al.* 2011). Biogeochemical and trace element cycling in beach sediments can also be altered by changing permeability of beach sediment. Other processes that can change or increase with greater permeability in beach sediments are the volumes of water flushed through the sediment, fluxes of organic matter and biological activity (Carson *et al.* 2011). There is a possibility that thermal insulation properties of plastic fragments can reduce evaporation, balancing some of the effects of increased permeability. Reduced subsurface temperatures could influence temperature – dependent sex – determination of organisms such as sea turtles (Carson *et al.* 2011).

Smothering

Plastics are generally positively buoyant in sea water, with only a small proportion having a specific gravity greater than that of sea water (Andrady 2011). Despite this, there are several reports of marine debris settling on the seafloor (Gregory 2009). Once these items reach the seafloor they will probably be buried and last indefinitely (Gregory 2009). This can have major environmental consequences; many consider the seafloor as a permanent sink for marine debris (Gregory 2009). Accumulation patterns of debris on the seafloor are still poorly understood. Acha *et al.* (2003) found that bottom salinity fronts can act as debris accumulation barriers. Other studies found that debris has the tendency to accumulate in areas of low circulation and high sedimentation rates (Acha *et al.* 2003). Organisms settling on floating plastic can increase the density of the items so they sink. Grazing organisms can clean these surfaces from time to time and re-emergence of debris can occur (Gregory 2009).

Plastic debris on the seafloor can create hard bottoms. These attract sessile organisms and can alter sea floor communities and the composition of natural ecosystems (Gregory 2009). These blankets of debris can hinder gas exchange between overlying waters and the pore waters of the sediment, resulting in anoxia and hypoxia. This can seriously alter the normal functioning of sea life on the sea floor (Goldberg 1997).

QUANTIFICATION OF PLASTIC LITTER

With the increasing trend of plastic litter (Rochman *et al.* 2013) many efforts had been made to remove plastic waste from the environment (Ryan *et al.* 2009). The removal can occur before or after the persistent debris enters the environment. However, the most effective and economical solution is to reduce the trend of plastic entering the environment. By monitoring the trends it is possible to detect changes in the state of the system (Ryan *et al.* 2009).

Many efforts have been made to understand the dynamic system of plastic flux on beaches (Ryan *et al.* 2009). It is almost impossible to quantify the input of plastic in the marine environment due to the many different pathways for plastics to enter the ocean (Ryan *et al.* 2009). On the other hand, quantifying plastic litter that has already entered the marine environment is complicated because of the vastness of the ocean and the quantity of plastic debris being assessed (Cole *et al* 2011). Different methods of measuring plastic in the marine environment are used to meet different objectives, with some methods being more favourable than others. Depending on the goals set, there is a need to standardize methods to ensure that the results of different studies are comparable (Ryan *et al.* 2009).

Beach Surveys

Almost everything we know about the accumulation, distribution and abundance of plastic litter in the marine environment comes from beach surveys (Ryan *et al.* 2009). Comparisons of different beach surveys are difficult as different methodologies are used (Ryan *et al.* 2009). Nevertheless, there were some similarities found: plastic litter dominates marine debris in terms of numbers of articles (Derraik 2002) and litter loads are greatest close to population centres or/and pollution sources, increasing with the number of visitors to beaches (Ryan *et al.* 2009). Although beach surveys cannot determine where the debris comes from, they gives a rough indication of what is in the adjacent seas. With regular beach surveys, patterns of accumulation might indicate the sources of debris (Swanepoel 1995). Most studies report standing stocks of litter, as it is less labour intensive to measure than determining “accumulation rate” of litter.

De Araújo *et al.* (2006) emphasise the importance of determining the minimum width of transects needed to qualitatively characterize an area regarding plastic contamination.

Items collected were categorised according to their most probable sources/use (fishery, food packaging, hazardous, sewage/ personal hygiene, beach users and general home). They found that the ideal width to include all source-related categories on two beaches in Brazil (Tamandaré beach and Varzea do Una beach) was 15-20m. They also emphasize the importance of standardization of methods as it will allow comparisons of sampling results (De Araújo *et al.* 2006).

Most beach debris researchers realised that source identification is key to the solution of the beach debris problem but this can be difficult as one item can come from several sources (Santos *et al.* 2009). Different methods are used to determine these sources. Some studies classify marine debris in two broad categories, land- or sea- based origins (Santos *et al.* 2009). Others are more specific and classify the debris to their most probable source (De Araújo *et al.* 2006, Whiting 1998, Ribic 1998), assessing the presence of fouling organisms (Barnes & Milner 2005) and looking at the distance from probable sources (Swanepoel 1995). Santos *et al.* (2009) used a combination of methods to determine the origins of marine debris but found that it is difficult to assign a source to the most abundant articles, plastic fragments, as their origins can be from anywhere. Descriptions of the sampling areas are important as the sources of sample items can be determined from these descriptions. For example, sources can differ for sites with or without rivers, or the presence of a harbour or not, etc. Martinez - Ribes *et al.* (2007) did a study on the Balearic Islands and found that the main source of beach debris during the high tourist seasons was beach users but in the low tourist seasons, drainage and outfall systems contributed to the main debris income. The same was found at a beach near Cape Town, South Africa (Swanepoel 1995). A study on human behaviour showed that 70% of all beach users took food to the beach but most could not give clear answers on how they disposed of their waste (Claereboudt 2004). Education and stricter law enforcement are needed to overcome this problem (Claereboudt 2004).

Some studies on debris accumulation focus on the differences in quantity and type of debris between shorelines and strive to explain these differences by looking at weather patterns and/or possible sources (Whiting 1998, Swanepoel 1995, De Araújo *et al.* 2006, Santos *et al.* 2009). Thornton & Jackson (1998) looked at the differences in quantity and type of debris within reach of the shore. They found that the location and composition of debris was influenced by the spatial limits of wave and wind action, together with the physical properties of the beach profile. On a New Jersey beach, Ribic (1998) used indicator items (selected by the US Marine Debris Monitoring Program) to determine if the loading rates of marine debris changed over time. He found that indicator items did not change annually but non-indicator items did. Re-examination of the items on the indicator list was considered as a result of his study.

Swanepoel (1995) found that daily accumulation rates of plastic debris on two beaches near Cape Town, South Africa, were greater (in mass and number) than measures of accumulation rate from weekly sampling. The same was found on sub-Antarctic beaches (Eriksson *et al.* 2013). This means that the accumulation rate of items can be grossly underestimated depending on the frequency of the sampling intervals (Ryan *et al.* 2009). Variability in the results of short term accumulation rate studies can be linked to weather patterns. Frequent surveys fail to measure the loss of stranded litter, but are the best way to determine the abundance of litter in the adjacent seas (Ryan *et al.* 2009). Some of the dispersion routes can be explained by the characteristics of the debris itself, with plastics being very common in beach surveys (Derraik 2002, Kusui & Noda 2003, Claereboudt 2004, De Araújo *et al.* 2006, Santos *et al.* 2009). Local currents and circulation patterns, beach structure, recent weather conditions, associated beach dynamics and distance from local land based sources are all factors that play a role in the dispersion of marine debris (Ryan *et al.* 2009).

It is important to report debris size ranges in studies because they influence the type and size of collected debris during a survey. Ryan *et al.* (2009) divided plastics broadly into three categories: macrodebris (> 10 mm diameter), mesodebris (2 – 20 mm) and microdebris (< 2mm). Few studies mention size (Swanepoel 1995, Ribic 1998, Kusui & Noda 2003). Studies on macrodebris have been most common but recently there has been increased interest in microdebris. A problem that arises during studies done by volunteer cleanups is that volunteers mostly focus on large, more visible items (Moore *et al.* 2001). On California Coastal Cleanup Day, in 1999, volunteers picked up 8000 items of debris from two beaches: Salt Creek Beach and Sunset Beach. Afterwards Moore *et al.* (2001) estimated that 67795 items were left behind, mostly small items.

Sampling of Microplastics

The term microplastics has been define differently by variously researcher. Some define microplastic as debris that is barely visible (articles < 0.5mm) while others include all articles that are < 5mm in size (Andrady 2011, Hidago-Ruz *et al.* 2010). At presence there is no universal adopted measure in terms of size range for microplastics (Hidago-Ruz *et al.* 2012). According to Cole *et al.* (2011) microplastic debris (< 0.5 mm) is generally under-researched because of the difficulties in measuring its abundance, density and distribution within the marine environment. However, techniques have been developed to determine the presence of small plastic particles. These techniques differ depending on the goal of the study. Hidalgo-Ruz *et al.* (2012) reviewed 68 studies to compare methodologies used in the identification and quantification of microplastics from the marine environment. They identified three main sampling methods: selective sampling, volume reduction and bulk sampling. Selective sampling consists of direct extraction of items that are recognised by the naked eye from the environment. These extractions are normally done from the surfaces of the sediment. Bulk sampling is done when the entire volume of the sample is taken without reducing the sample. This method is used when particle samples are hard to identify with the naked eye. Volume reduced sampling is when the volume of the bulk sample is reduced, extracting only what is needed for further processing. This method can be used in both sediment and seawater samples (Hidalgo- Ruz *et al.* 2012). Further steps of processing include density separation, filtration, sieving and visual sorting of the microplastics (Hidalgo- Ruz *et al.* 2012).

Beach surveys done in South Africa

In 1994, Swanepoel (1995) examined stranded debris and beach litter on two beaches in Table Bay, South Africa. One of the beaches (Milnerton) is a popular recreational beach situated in a metropolitan area. The other (Koeberg), 39 km from the city centre, is situated in a private nature reserve and the beach is closed to the general public. Swanepoel (1995) measured daily accumulation rates for both beaches for 14 days each in October and December 1994. Most of the items she collected were plastic (81.7 %), of which half was polystyrene. Visitors to the beach were found to influence debris abundance and composition. Mean accumulation rate was twelve times greater at Milnerton than at Koeberg (Swanepoel 1995). Great within - site variability was recorded. Total article weight was positive correlated with total article number. Daily accumulation rate was, in general, not correlated with weather conditions (Swanepoel 1995).

The main aim of this study is to assess how the abundance, composition and accumulation rates of marine debris have changed on Milnerton and Koeberg beaches since 1994. Because of the increasing trend in marine debris, it was expected that accumulation and abundances should have increased compared with Swanepoel (1995) study and that composition of debris will changed over time. A second aim was to sample meso- and microplastic debris to establish a method and improve our understanding of its vertical distribution, abundance and composition.

Chapter 2

The abundance, distribution and accumulation of macroplastic debris (articles > 10 mm) in Table Bay, Cape Town, South Africa

INTRODUCTION

Plastic debris has become one of the most abundant global marine pollutants (Derraik 2002, Ivar do Sul *et al.* 2009), with environmental and economic consequences (Whiting 1998). In the Western Cape, South Africa, results from coastal cleanups confirmed that plastic waste is a major component of coastal pollution, most of which derived from local land-based sources (Marais *et al.* 2004). Surveys around the world found the same results (Derraik 2002). Surveys done between 1984 and 1989, on 50 beaches along the South African coast, show that the density of all types of plastic debris had increased (Ryan & Moloney 1990).

The durable, strong, cheap and persistent qualities of plastics make them suitable for the production of numerous items. Unfortunately, these same properties are the cause of problems in the environment (Derraik 2002). Degradation and fragmentation rates of different plastics under different conditions are largely unknown (Ryan *et al.* 2009), but estimates can vary depending if additives are added or not (Derraik 2002). The number of animals (marine or terrestrial) that can be affected by plastic increases through fragmentation and degradation because the end products are small (Cole *et al.* 2011). Threats include choking and starving wildlife, distributing non-native and potentially harmful organisms and adsorbing toxic chemicals that can be transferred to animals (Barnes *et al.* 2009). Plastic debris also decreases the aesthetic value of tourist beaches, risks beach users' health and has the potential to damage ships (e.g. through collisions with large items, entanglement of propellers with nets and ropes)(Santos *et al.* 2005).

In 2012 less than half of the plastic that was globally produced was recycled or discarded into landfills. Some of the remaining plastic may still be in use and the rest litters continents and oceans (Rochman *et al.* 2013). Rochman *et al.* (2013) estimate that, if countries classified plastics as hazardous and not as solid waste, environmental agencies would have the ability to restore affected habitats and prevent more plastics entering the environment.

In South Africa litter mostly consists of single - use items and packaging such as paper- and plastic food-wrapping, cans, plastic bottles, cigarette packets and cigarette butts (Armitage & Rooseboom 2000). These items accumulate in public places till local authorities remove them. If not regularly removed, litter can be transported by the wind or stormwater runoff into drainage systems or rivers that will eventually end up in the sea (Armitage & Rooseboom 2000). Litter has been described as a social behaviour problem since the 1970s (Marais *et al.* 2004).

The combination of various land- and sea- based sources and point- source inputs with the non- random transportation of litter by wind and ocean currents can cause great temporal and spatial variability in litter loads (Ryan *et al.* 2009). In Table Bay, the “flushing potential” is limited as the currents are generally weak throughout the year. In summer these currents are supplemented by high local wind velocities (Van Ieperen 1971). The path of pollutants in Table Bay thus depends on the characteristics of the pollutant and on the strength and direction of the wind (Van Ieperen 1971).

The Rietvlei area, Diep River and Black River (Figure 2.1) are potential polluting sources in Table Bay. The Diep River drains the Rietvlei area which is near Milnerton’s township and the Black River Runs are canalised through a metropolitan area between Milnerton and Cape Town into the Bay. Other potential polluting sources are the municipal sewage discharge from the Harbour and Green Point area. Investigators found that the municipal waste discharge at Green Point is carried into Table Bay by prevailing currents (Van Ieperen 1971).

In 1994 Swanepoel (1995) determined the daily accumulation of litter on two beaches in Table Bay, South Africa: Milnerton and Koeberg. In the Intervening 18 years, marine debris has increased globally, and this project aims to quantify the increase on these beaches by repeating the methods of Swanepoel (1995). Temporal and spatial patterns of accumulating debris will also be investigated and discuss in relation to available weather data.

MATERIALS AND METHODS

Study sites

Stranded debris and beach litter were examined from two beaches in Table Bay, South Africa (Figure 2.1) repeating a survey made on the same two beaches in 1994 (Swanepoel 1995). Table Bay is a shallow bay, located on the west side of Cape Town. The coast is mostly sandy and the coastal areas to the north consist largely of sand dunes covered with scrub bush (Van Ieperen 1971). Urban development is rapidly taking place south of Koeberg Private Nature Reserve. Surface currents in the area are weak and in summer are mostly driven by south easterly winds, with the consequence that the general direction of the water flow is northwards (Van Ieperen 1971).

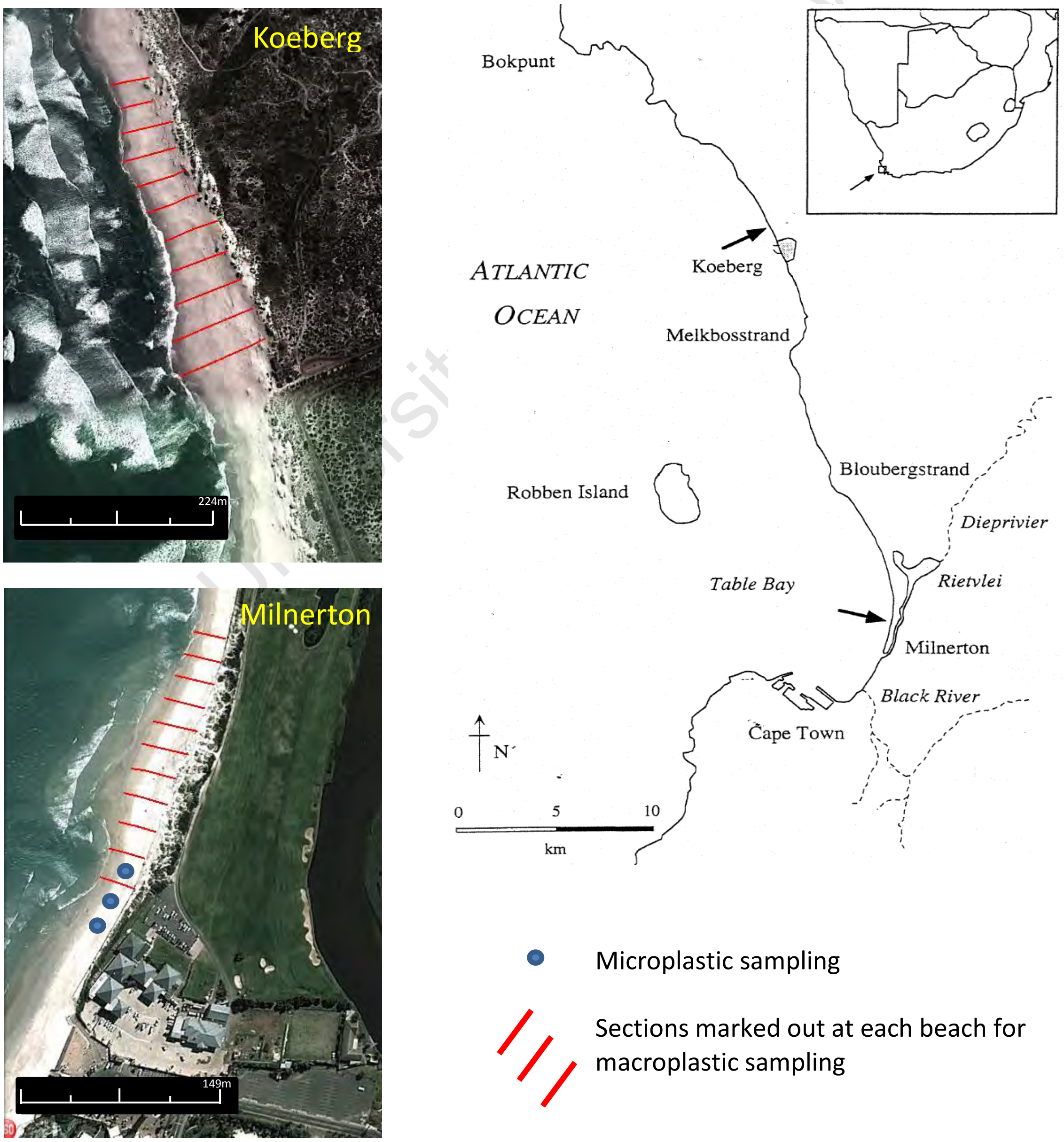

Figure 2.1: Map of Table Bay showing study areas (after Swanepoel 1995)

Milnerton Beach is a popular recreational beach 12 km from the city centre. Koeberg beach is situated north of Milnerton in a nature reserve, with limited access by the general public, and is 27 km farther from the city. Recreational use at Koeberg is restricted to hiking and cycling and the beach (study site) is a no-entrance zone for visitors. Neither of the two study sites (the parts of the beaches that were sampled) was cleaned by local authorities. However, one of the neighbouring areas of both study sites was cleaned; at Milnerton, the neighbouring site was cleaned daily and at Koeberg four- monthly. The last cleanup for Koeberg was in September 2012.

Data Collection and Analysis

The study period extended from October to December 2012. Daily accumulation rates were measured for ten days each at the beginning of October and November and the middle of December 2012. Daily sampling periods were chosen to include a holiday (December) season and a non-holiday season (October and November).

A 250 m stretch of beach was marked out at Milnerton in ten adjacent 25 m-wide sections (Figure 2.1). At Koeberg, a 500 m stretch of beach was marked out in ten adjacent 50 m-wide sections (Figure 2.1). The day before sampling, all accumulated macrodebris (articles > 10 mm) was removed. Beaches were cleaned between the low water- and vegetation- line. All debris "arriving" thereafter was recorded. This included debris washed ashore recently, left by beach users, re-emerging from previous burial and drifting laterally from un-cleaned areas.

Debris was taken back to the University of Cape Town and counted and weighed under laboratory conditions. Articles were cleaned of sand before weighing. Each debris item was identified and categorised by type and function (Table 2.1).

Rainfall, wind and tide data were obtained from the South African Weather Services to test for correlations between daily debris accumulation rates and weather conditions.

Data matrices with rows representing functional groups of plastics and columns representing samples were constructed and contained abundance data of each functional group for each site. Counts of the ten transects on each beach were pooled and expressed as numbers per section. Two matrices were formed: 1) Data obtained 2012, to examine differences between Milnerton and Koeberg and 2) daily data obtained in 1994 and 2012 from each beach to examine differences between beaches and years. To reduce the large differences in counts among the functional groups, the data were fourth-root transformed. A resemblance matrix was obtained using Bray-Curtis dissimilarity measures. Principle coordinate analysis (PCO) based on the resemblance matrix was carried out to show differences between sites and years. Statistical analyses were carried out using the PERMANOVA + add on of PRIMER V6 multivariate data analysis package (Anderson *et al.* 2008).

Table 2.1: List of type of debris and sub - categories of plastic, identified on the basis of function

Type	Plastic: Functional types
Cigarette butts	Bags
Cloth	Bottles
Glass	Lids
Metal	Cigarette wrappers
Paper	Earbuds
Plastic	Fishery items
Rubber	Foam
Wax	Food wrappers
Wood (worked wood)	Medical waste
	Packaging
	Unidentified plastic fragments
	Styrofoam
	Sweet wrappers
	User Items

Data matrices with rows representing types of debris and columns representing sites (Koeberg and Milnerton) were constructed and contained the proportions of different types of debris collected at each site. Two matrices were formed: 1) proportions of different types of debris in terms of mass, 2) proportions of different types of debris in terms of numbers. Data (Y) were arcsine transformed (Y_{tr}, Zar 2010).

$$Y_{tr} = \arcsin\sqrt{Y + 0.5}$$

Chi-Square tests were carried out on the arcsine- transformed proportions to test if the same proportions of litter types were collected both at Milnerton and Koeberg beach.

One – way Analysis of Variance (ANOVA) was used to test if 1) there were differences in accumulation rates between each section of beach length and 2) if there were differences in daily accumulation rate. A separate ANOVA was applied to each beach and month. Abundance data (Y) were square- root transformed (Y_{tr}, Zar 2010) before analyses were carried out to improve homoscedasticity and normality.

$$Y_{tr} = \sqrt{Y + 0.375}$$

Statistical analyses were carried out using STATISTICA version 11.

RESULTS

In total, 124,646 (147 kg) items and fragments were collected during the daily surveys. The most abundant materials collected were plastics (93.3 %) (Figure 2.2). The non- plastics comprised wood (14 %; only human-modified wood was collected), glass (15 %) and cigarette butts (52 %) by number. The majority of items in the plastic category consisted of unidentified fragments (43.5 %), polystyrene (12.1 %), sweet wrapper (11.5 %), lids (10.9 %) and cotton buds (7.5 %).

Debris composition in terms of mass differed from that in terms of numbers (Figure 2.2). Plastic only comprised 58.9 % of the total mass. Wood (21.9 %), glass (12.7 %) and cloth (2.1 %) made up most of the remaining mass. All of the other categories each comprised less than 1 % of the total mass. Bottles (11 %), cotton buds (7.9 %), lids (13.1 %), unidentified plastic fragments (29.6 %) and user items (10.4 %) made up most of the total mass of the plastic category. The proportions of types of debris found both on Milnerton and Koeberg were compared with each other. All were significantly different in terms of numbers and mass. The most noticeable were wood ($Z = -21.55$, $p < 0.05$), rubber ($Z = -13.92$, $p < 0.05$) and cloth ($Z = -32.35$, $p < 0.05$) that were greater at Koeberg than Milnerton, which had relatively greater proportions of cigarette butts ($Z = 15.53$, $p < 0.05$), glass ($Z = 12.01$, $p < 0.05$) and metal ($Z = 5.73$, $p < 0.05$) (Figure 2.3B). Wood ($Z = -8.49$, $p < 0.05$) dominated mass at Koeberg but glass ($Z = 7.76$, $p < 0.05$) and wood ($Z = -8.49$, $p < 0.05$) dominated at Milnerton (Figure 2.3A).

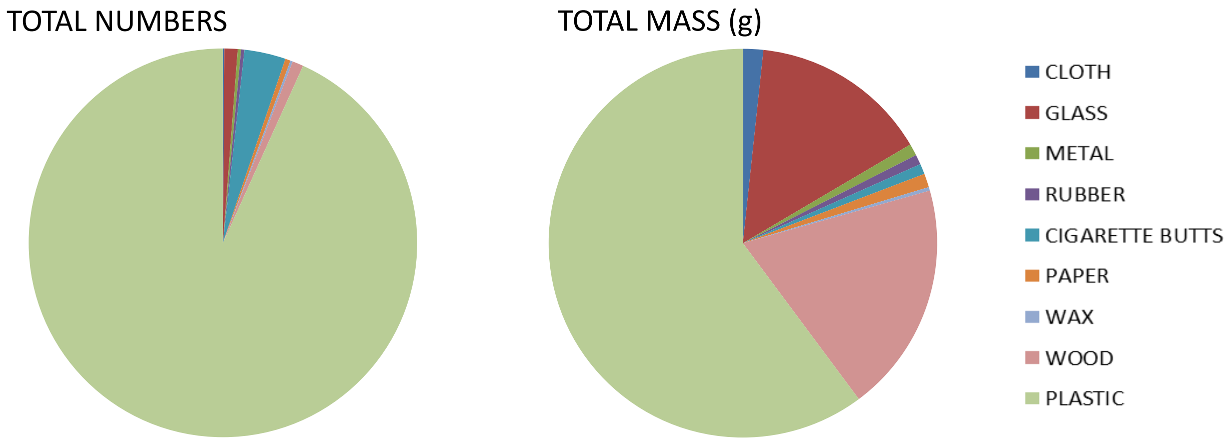

Figure 2.2: The proportion (total number or total mass (g)) of different types of litter found during the sampling period. Data of both beaches are combined

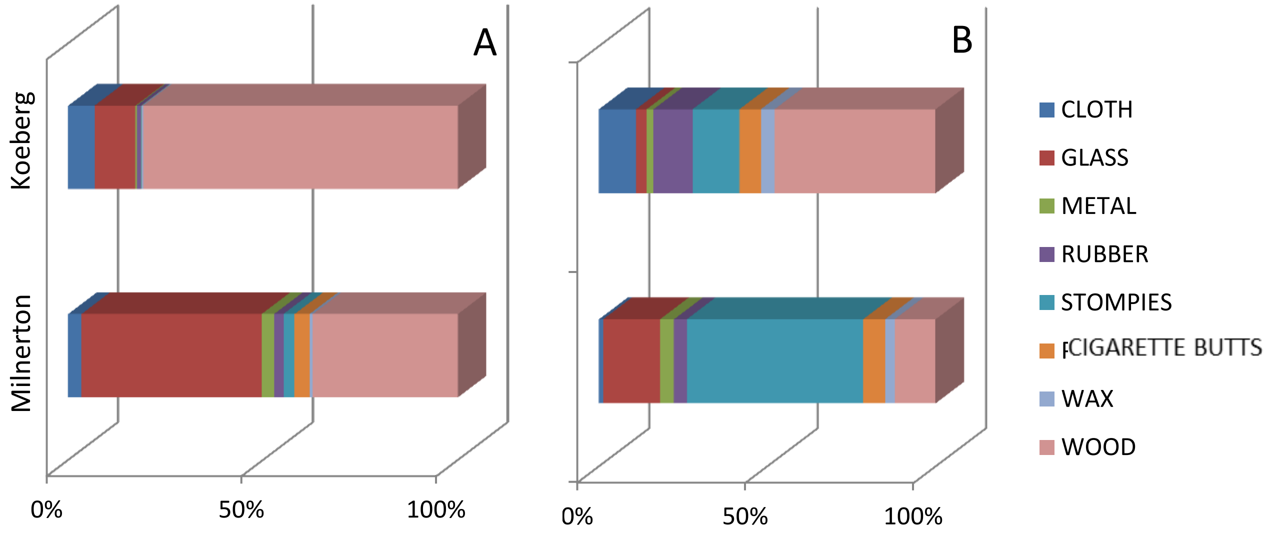

Figure 2.3: The proportions A) mass (gram.day^{-1}.100 m^{-1}) and B) numbers (items.day^{-1}.100m^{-1}) of non-plastic litter types found stranded at Milnerton and Koeberg.

There was clear separation of debris types and abundances at Milnerton and Koeberg (figure 2.4). The three sampling months were separated along PCO 2. At both sites October was clearly separated from November and December, which were mostly clustered together. The first axis (PCO 1) accounted for most of the variation, which was caused by differences in abundance of plastics. The accumulation rate at Milnerton was clearly more than at Koeberg.

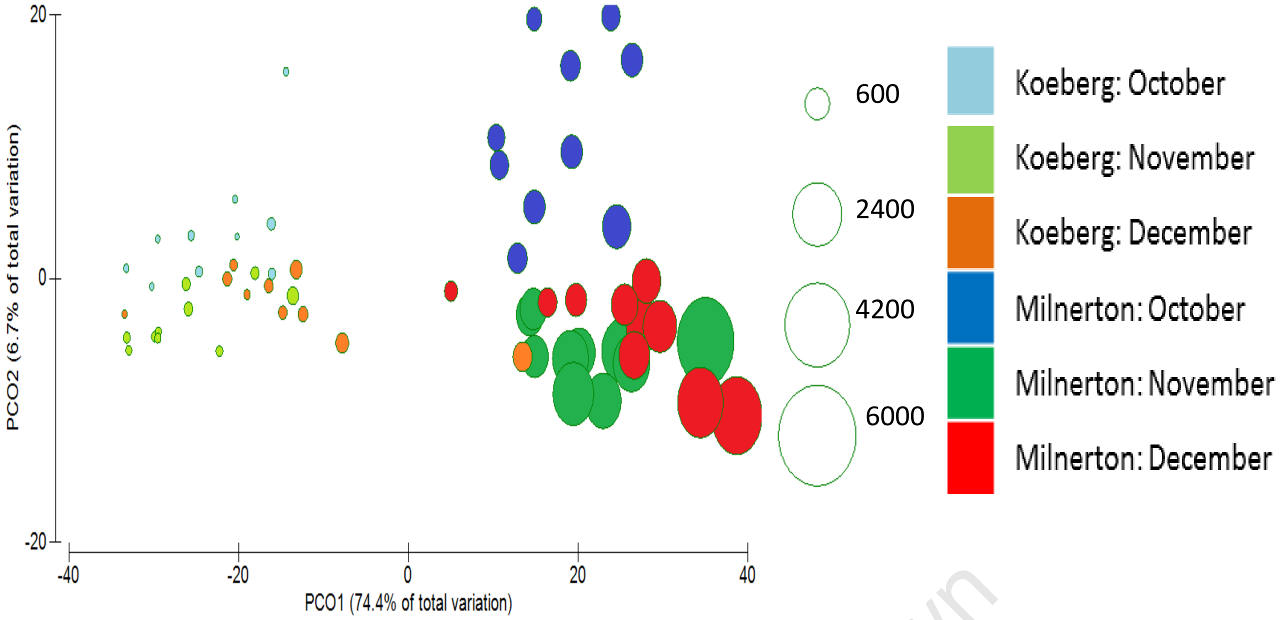

Figure 2.4: Results of PCO showing differences among daily samples in fourth-root transformed abundances of plastic functional types. The sizes of the circles represent the relative amounts of unidentified plastic fragments.

The mean accumulation rate of plastic articles decreased with distance from Cape Town. The mean ± s.e. accumulation rate of plastics was greater than 100-fold more at Milnerton (1350 ± 126.7 items.day^{-1}. 100 m^{-1}) than Koeberg (100 ± 17.3 items.day^{-1}.100 m^{-1}). There was generally consistent but large within-site variability (Figure 2.5) in accumulation rates; the within-site CVs, which ranged from 23.7 % to 101.5 %, responded in the same way across months. There was also considerable daily variation (CVs ranged from 13.6 % to 92.8 %). At Milnerton, more debris accumulated in section five (M5) than the other nine sections (Figure 2.5B). Section one, the closest section to the point of access to the beach, had an increase in plastics during December. In some months the uncleaned areas might have affected the border sections (sections one and ten), especially at Koeberg, although section ten at Koeberg was considered a high depositing section (Figure 2.5A).

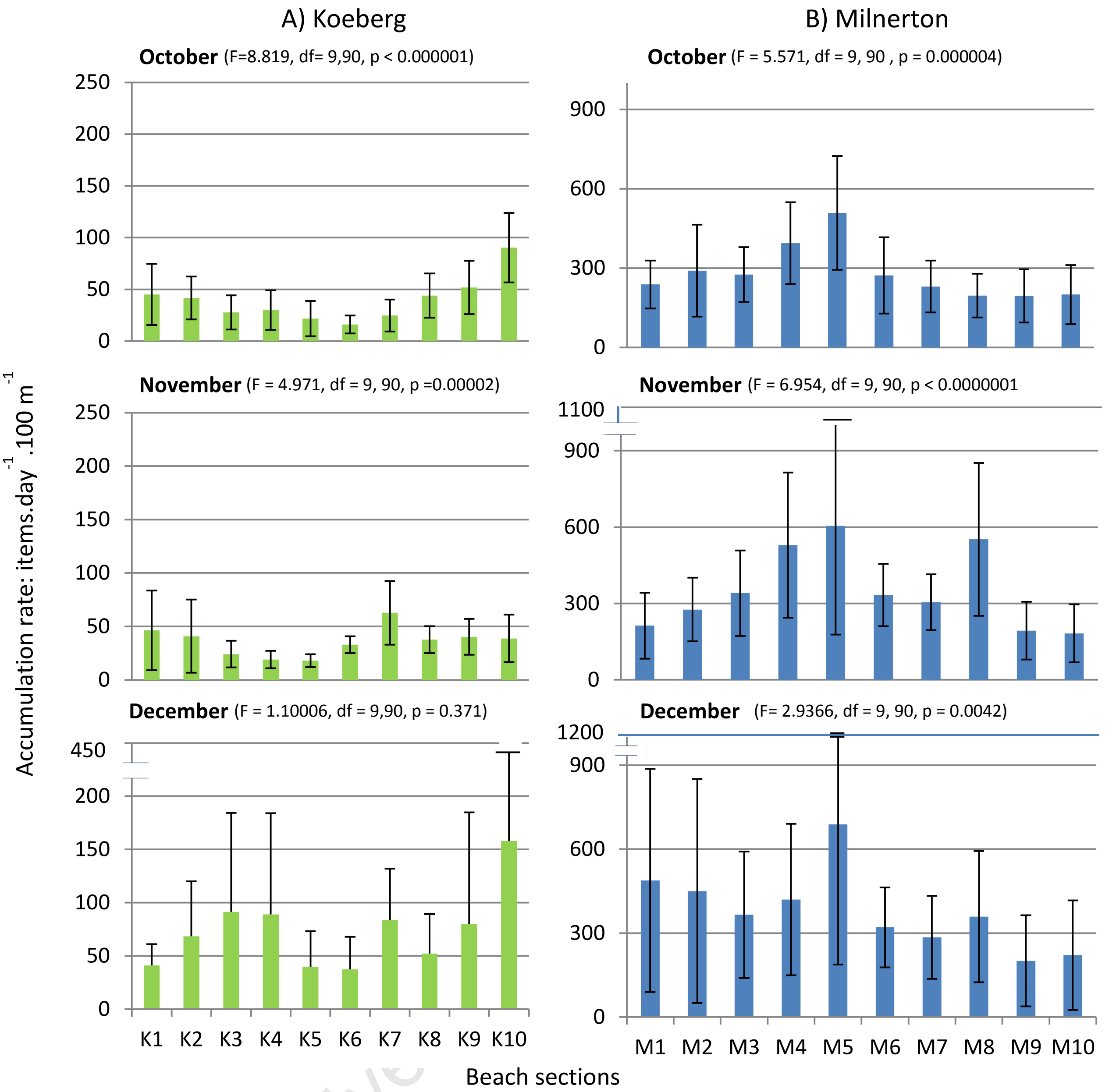

Figure 2.5: Differences in mean (± standard deviation) accumulation rate (items.day^{-1}.100m^{-1}) for each section of beach length over the 30 sampling days. A) Koeberg B) Milnerton

Daily accumulation rates varied (Figure 2.6). Within-site variation contributed to daily variability which did not correlate with rainfall or wind data, although in December at Koeberg there was some correlation with the tides (n = 10, r = -0.556, $p < 0.05$)(Figure 2.6A). There were a few days that were significantly different from others but mostly they were consistent (Figure 2.6). Certain functional groups of plastics were more abundant than others in each month. Food wrappers and sweet wrappers were more abundant in October than the other two months. Polystyrene and unidentified plastic pieces increased towards December (Figure 2.7).

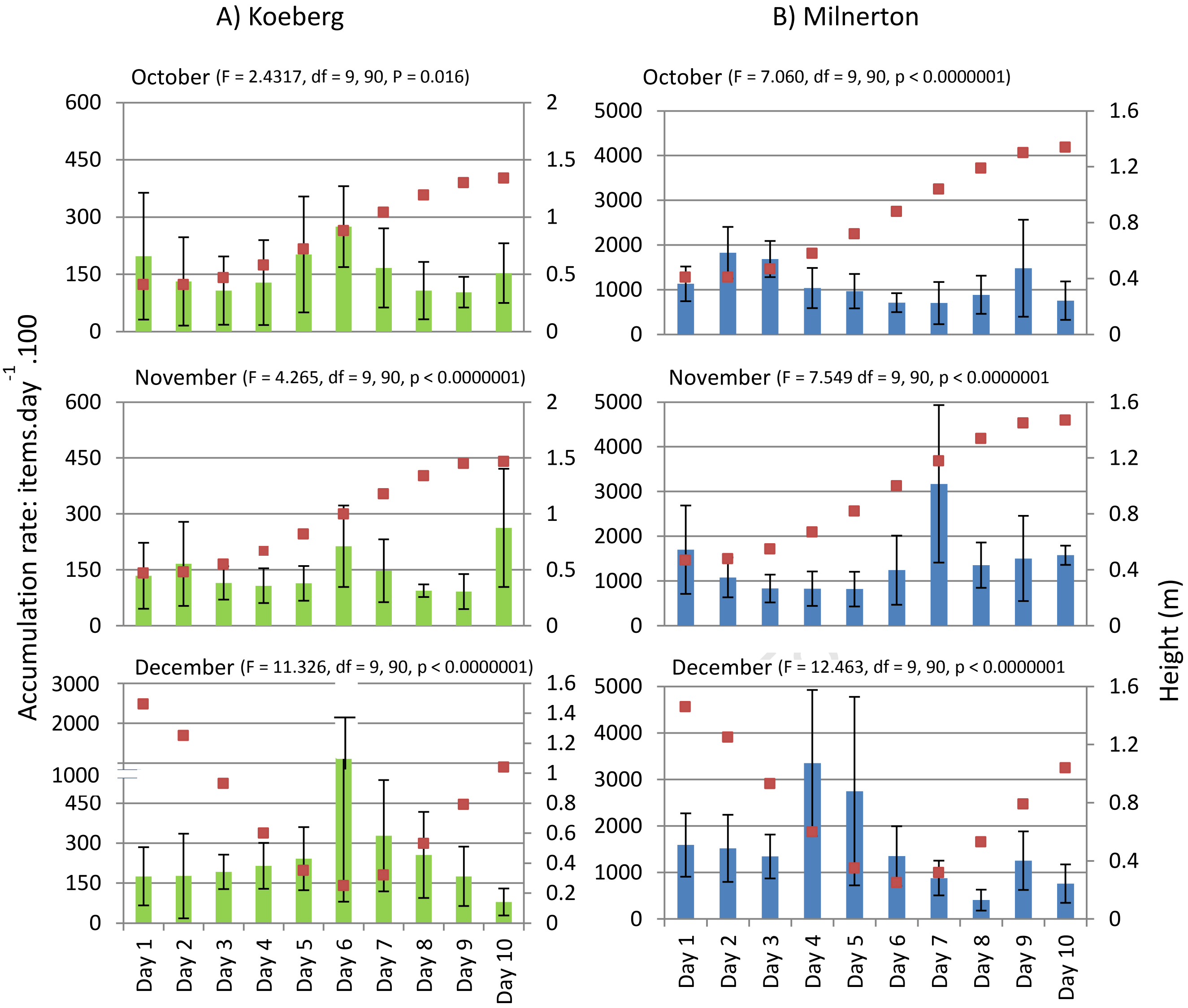

Figure 2 6: Daily changes in mean (± standard deviation) accumulation rate (items.day^{-1}.100m^{-1}) for each 10 days sampling period average over the 10 sections of beach length. Red dots represent heights of tides.

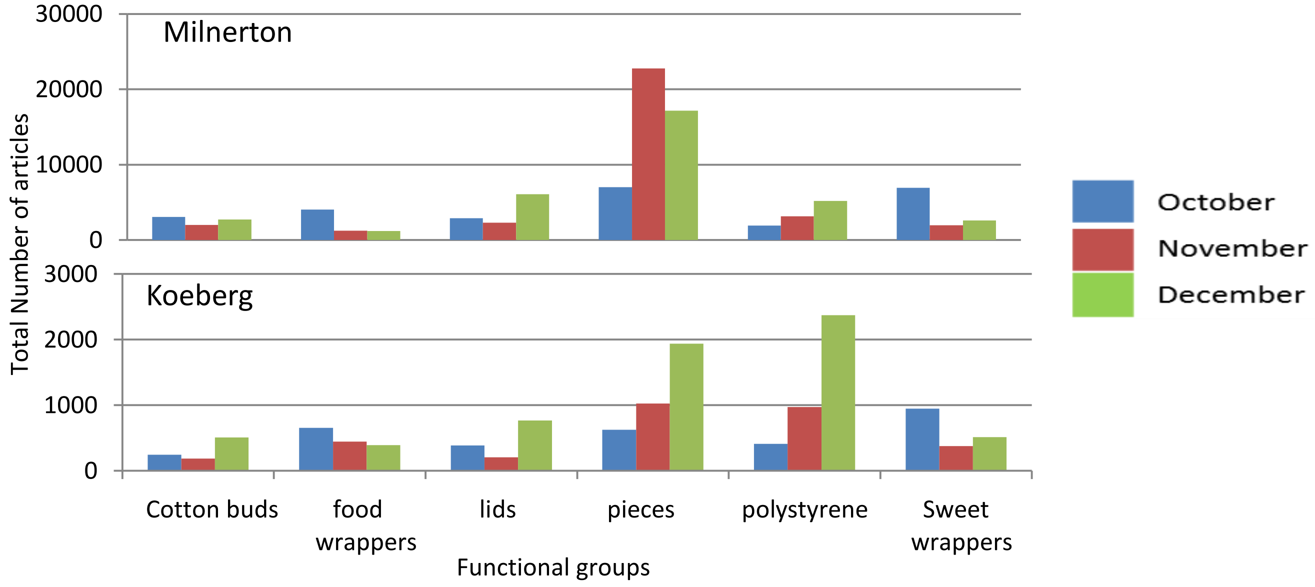

Figure 2.7: Abundance data of each functional group per month for each site (Koeberg and Milnerton). Only groups in which there were at least 2000 items at Milnerton and 500 items at Koeberg collected in one of the three surveyed months are shown.

The composition, abundance and accumulation rates of debris were different on the two beaches between 1994 and 2012. The mean (s.e) accumulation rate of litter items increased threefold at both beaches, from 464 (91) to 1458 (140) items.day^{-1}.100m^{-1} at Milnerton and from 34 (2.9) to 102 (17.1) items.day^{-1}.100m^{-1} at Koeberg. Most of this accumulating litter was plastic (Figure 2.8 & 2.9). At Milnerton, mean (s.e.) plastic numbers increased 257 %, from 378 (72) to 1350 (127) items.day^{-1}.100 m^{-1} and the increase at Koeberg was from 44 (3) to 100 (17) items.day^{-1}.100m^{-1}. The two beaches are clearly distinguished on PCO 1 in terms of accumulation rates of plastics (Figure 2.10). Data collected in different years are separated along PCO 2. The non-plastics were dominated by cloth, paper and wood in 1994 but cigarette butts dominated in 2012 at Milnerton (Figure 2.8). In contrast, at Koeberg the accumulation rates of most non-plastic materials decreased since 1994 and there were small differences in composition (Figure 2.9). No correlation was found between total weights and total counts of plastic items on the beaches. Since 1994, the mean accumulation rate of small, unidentified plastic fragments increased by more than 200 fold at Milnerton and by a factor of 80 at Koeberg (Figure 10: sizes of the circles). Another abundant item found on these beaches was cotton buds. Since 1994, the mean accumulation rate of cotton buds increased by more than 100 fold at both sites.

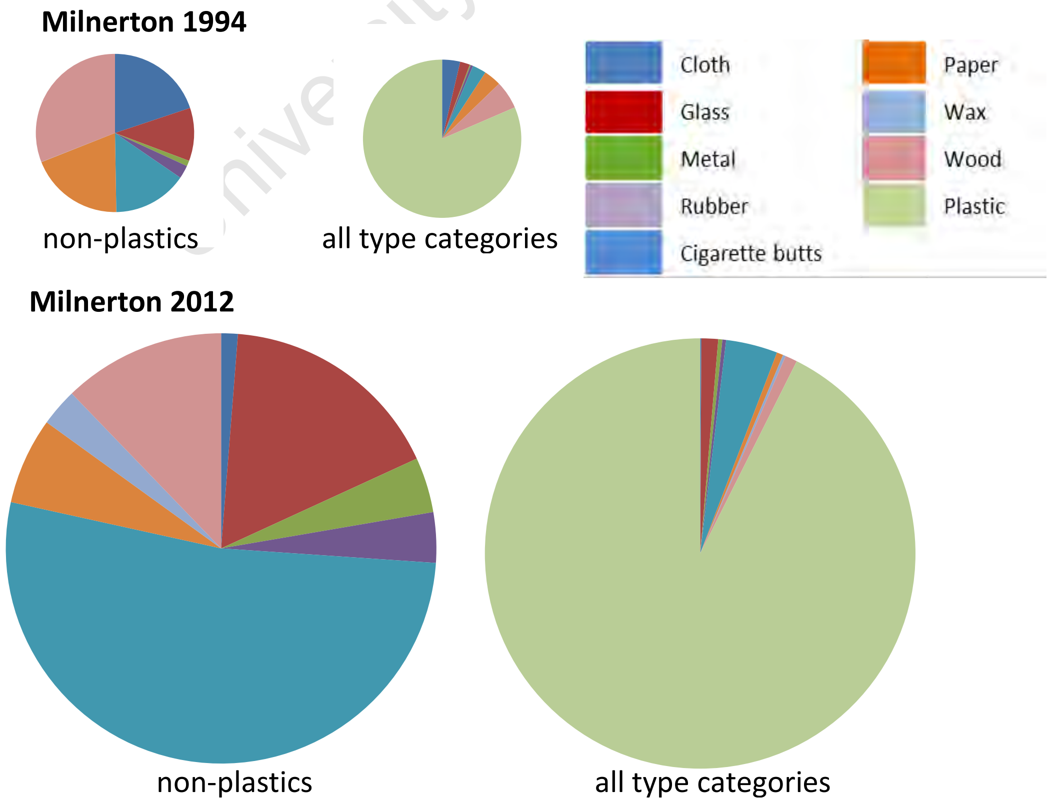

Figure 2. 8: The proportions of litter types (non-plastics and all types combined) accumulating at Milnerton in 1994 and 2012. The sizes of the circles indicate the relative amounts of litter collected.

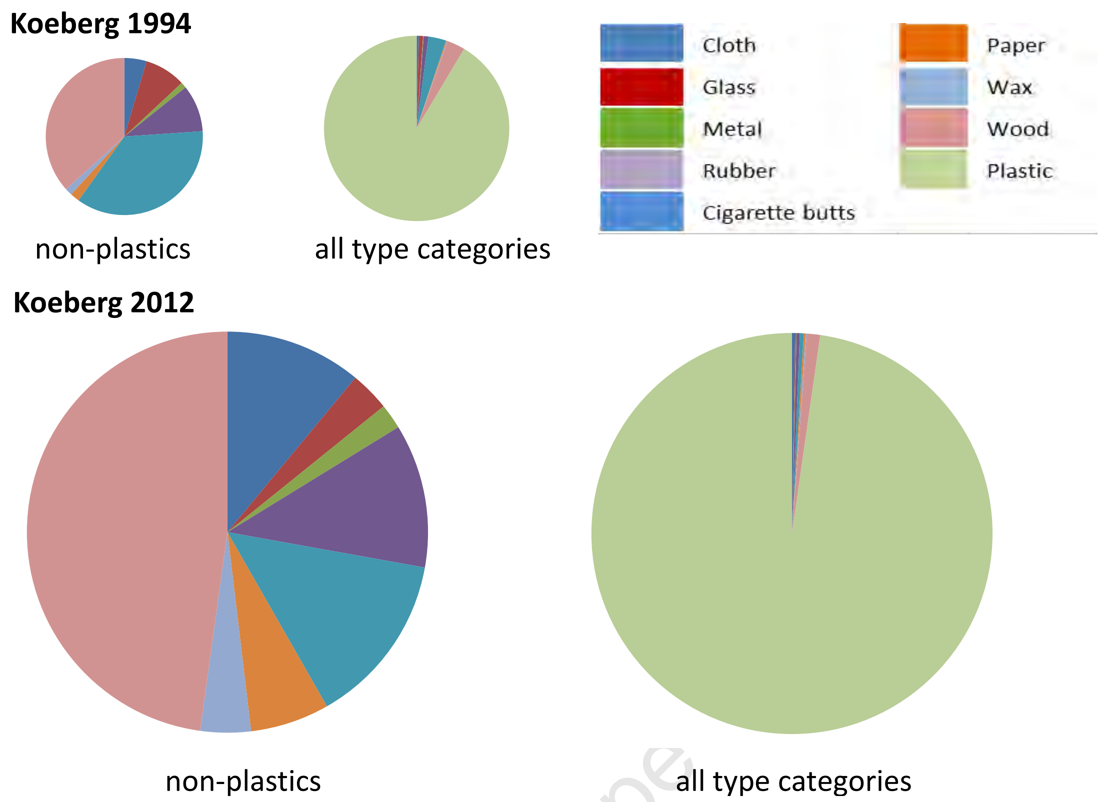

Figure 2.9: The proportions of litter types (all types combined and non-plastics) accumulating at Koeberg in 1994 and 2012. The size of the circle indicates the relative amount of litter collected.

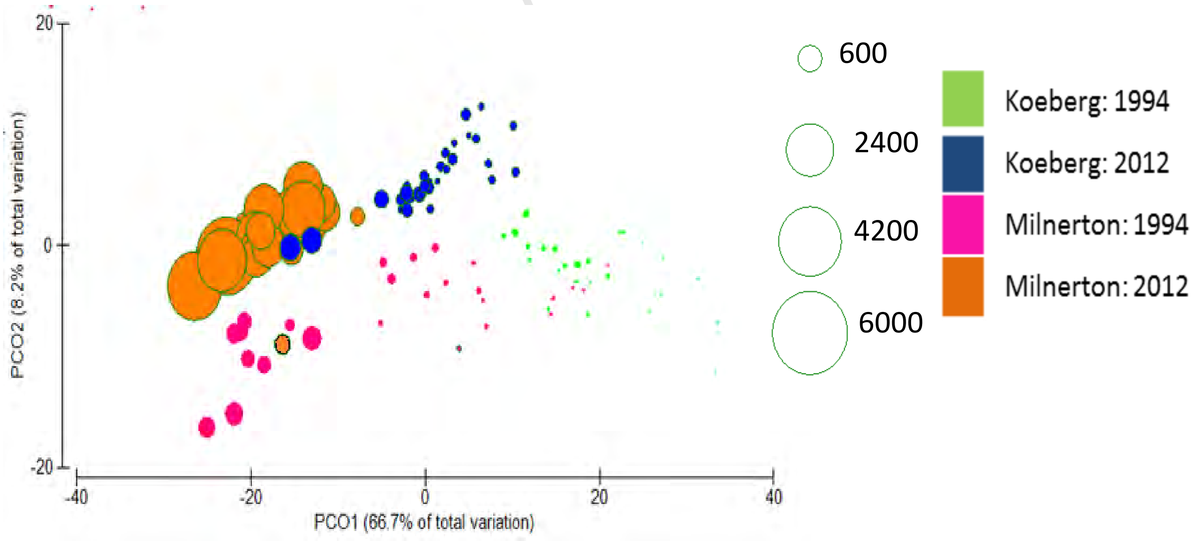

Figure 2.10: Comparison of daily samples in terms of plastic types and fourth-root transformed abundances from 1994 (Swanepoel 1995) and 2012. The sizes of the circles demonstrate the relative quantities of unidentified plastic fragments collected daily.

DISCUSSION

The majority of the litter found in 2012 on Milnerton and Koeberg beach was made of plastics. Most of the literature on marine debris found the same result with the proportions of plastic consistently varying between 60 – 80 % by number (Derraik 2002). In this study, plastics accounted for 58.9 % of the litter by mass and 93.3% in number. A study done on a beach in Brazil found that plastics were the most abundant submerged marine debris observed (Oigman-Pszczol & Creed 2007). Of the other litter types (Table 2.1), mean accumulation rate at Koeberg mostly decreased. Reasons for this could be because plastics are starting to replace other more expensive materials such as metal, paper, cloth, etc. The same results were not found at Milnerton, but public beaches are more susceptible to litter pollution.

Of the non-plastics, cigarette butts dominated in counts and wood dominated in weight. On 32 beaches on the Balearic Islands, cigarette butts comprised up to 46 % of the total debris in the holiday seasons (Martinez-Ribes *et al.* 2007). Oigman-Pszczol & Creed (2007) found that paper (which represents mostly cigarette butts) was the most abundant item on a popular recreational beach in Brazil. In this study, more than half of the non-plastic marine debris consisted of cigarette butts at Milnerton beach.

Differences in the mean densities of litter between the two sites (Koeberg and Milnerton) can mostly be explained by their different distances from potential pollution sources and population centres, local and land-based sources and shoreline orientation to dominant winds (Thornton & Jackson 1998). Van Ieperen (1971) studied the morphology of Table Bay, and speculated that an onshore wind will result in beach pollution (oil or litter pollution) while an offshore wind will blow the pollutants seawards. No correlations were found between the mean daily accumulation rate and weather conditions (wind speed and precipitation) and tides.

Spatial differences over beach length are controlled by the spatial limits of wave and wind action, combined with beach morphology (Thornton & Jackson 1998). Some sections will be high depositing areas and others low depositing areas, as found in this study (Figure 2.5). Evidence of an increased input during the peak holiday season (December) was recorded at both beaches. These results were similar to those of other beach surveys (Swanepoel 1995, Martinez-Ribes *et al.* 2007).

Eriksson *et al.* (2012) summarised the abundances (standing stock) of marine debris found on northern and southern hemisphere beaches. The abundances of marine debris on these beaches ranged from 0.008 to 253 items.m^{-1}. From these standing stocks, Eriksson *et al.* (2010) also calculated accumulation rates (items.day^{-1}.km^{-1}) although the beaches had been sampled at different sampling periods (daily, weekly, monthly and sometimes only once). In the northern hemisphere, accumulation rates ranged from 0.001 to 69.1 items.day^{-1}.100m^{-1}, and in the southern hemisphere from 0.003 to 4.13 items.day^{-1}.100m^{-1}. Both Milnerton and Koeberg can be considered as high depositing beaches with daily accumulation rates of 1458 items.day^{-1}.100m^{-1} at Milnerton and 102 items.day^{-1}.100m^{-1} at Koeberg.

Direct comparisons of accumulation rates are difficult because of differences in sampling methodology (Swanepoel 1995), litter concentration units and classification categories (Kusui & Noda 2003). Most studies preferred to sample standing stocks as it is easier, requires less effort and is cheaper to accomplish than accumulation studies. But irregular sampling can be misleading. Swanepoel (1995) found that daily accumulation rates (from daily sampling) of all of debris at Milnerton and Koeberg beach was 100 – 600 % greater in number than weekly sampling.

Unidentified plastic fragments made up most (43.5 %) of the plastic category. A similar result was found by Topcu *et al.* (2013), which slightly more than half of the marine debris sampled along sandy beaches of the Turkish Western Black Sea coast consisted of unidentified plastic fragments. The fragmentation of plastic items makes it difficult to evaluate plastic litter precisely, even though plastics are so persistent in the environment (Kusui & Noda 2003). Since 1994, small plastics have become much more abundant on the two beaches in Table Bay. In the North Pacific, 96% of the plastics found were small pieces of plastic (McDermid & McMullen 2004). On the beaches of Kauai, Hawaii, debris was collected over a small area (1 x 5 m) for eleven days, resulting in a mean accumulation rate of plastic fragments of 484 pieces.day^{-1} (Cooper & Corcoran 2010). At Milnerton the mean accumulation rate of plastic fragments was 626 pieces.day^{-1}.100m^{-1}, much lower than that of Cooper and Corcoran (2010) although comparisons are difficult because of different sampling methods.

The mean accumulation rate of litter on the two beaches in Table Bay had increased since 1994. Debrot *et al.* (2013) calculated the mean debris concentration on a beach in Bonaire, Southern Caribbean, and compared his results with a study done 20 years previously on a nearby Island (Curacao). He found that the mean (± approximately 70% confidence limits) debris contamination levels can be considered as high (115 ± 58 items.m^{-1}) compared with the contamination levels in Curacao (60 ± 62 items.m^{-1}). The contamination levels had increased by 91 % at Bonaire, if it is assumed that the debris contamination levels on Curacao and Bonaire were the same 20 years ago. This estimated percentage increase in Bonaire was less than that found in this study, but the contamination levels were much higher. Other repetitive studies found different results. The mean density of litter sampled on beaches around the northern South China Sea (China) decreased from 41.59 items.km^{-1} in 2009 to 24.05 items.km^{-1} in 2010 (Zhou *et al.* 2011).

Most litter types found at Koeberg, was also found at Milnerton. Thus items found are not necessarily bound to the site but more to the month of sampling. The abundance of food wrappers and sweet wrappers were the highest in October. For other items (polystyrene and lids), abundaces increased towards the holiday season (December), whereas others decreased (food wrappers). The reasons for the variability in litter found in each month is unknown, but storms can uncover old litter that was buried a long time ago.

Chapter 3

Abundance, vertical distribution and composition of meso- and microplastics on Milnerton Beach, Cape Town, South Africa

INTRODUCTION

The accumulation and concentrations of marine debris in the marine environment have been widely recorded (Derraik 2002) and their negative impacts on marine animals are comprehensively documented (Gregory 2009). The raw material from which plastic items are manufactured is in the form of virgin pellets, approximately 5 mm in diameter (Ivar du Sul *e al.* 2009). These pellets are often noticed on beaches around the world and enter the marine environment by accidental spillage during transport, inappropriate used of packing material and direct outflow from processing plants (Cole *et al.* 2011). These virgin plastic pellets, together with other microplastics, have been accumulating in the world's oceans for at least the last four decades (Andrady 2011).

Plastic items in the environment eventually undergo degradation to smaller fragments that ultimately form microscopic articles or microplastics (Ng & Obbard 2006), defined here as items that go through a 2mm – mesh sieve. In addition some plastics are manufactured to be microscopic size. These plastics are used in facial-cleansers and cosmetics, or in air-blasting technology. The use of microplastics in exfoliating cleansers had increased since the patenting of microplastic scrubbers within cosmetics in the 1980s (Cole *et al.* 2011). Microplastics used in air-blasting technology can be recycled up to 10 times before being discarded. After use, these plastics can be contaminated by heavy metals as they are used for stripping paint from metal surfaces and cleaning engine parts (Derraik 2002). Once discarded these microplastics end up in sewage systems, where some are retained during sewage treatment but most are discharged into marine waters (Derraik 2002, Cole *et al.* 2011).

Threats posed to marine biota by microplastics are still uncertain. Their small size makes microplastics available to a wide range of marine organisms, including small filter feeders (Cole *et al.* 2011). In the marine environment filter feeders interact with natural, nonnutritious, micro- particles with no ill effects (Andrady 2011). Marine fauna do not have the ability to digest plastics, so ingested plastics will never get digested or absorbed and will be bio-inert. However, there are concerns about the potential of microplastics to deliver concentrated persistent organic pollutants (POPs), mainly adsorbed from sea water, to organisms. The risks posed by these high concentrations of POPs are significant (Andrady 2011). Microplastic ingestion can also cause other harmful effects to small animals, such as internal blockages of the intestinal tract, reduced nutrition uptake and internal injury (Cole *et al.* 2011). Ingestion of plastic fragments has been reported in certain seabirds (Mallory 2008), fish (Possatto *et al.* 2011) and various planktivores (McDermid & McMullen 2004).

Most studies done on microplastic used sediment samples. Hidalgo-Ruz *et al.* (2012) reviewed 68 studies to compare methodologies used in the identification and quantification of microplastics from the marine environment. Forty four of these studies were done in sedimentary environments (mostly sandy beaches). Like beach combing, it is probably the cheapest way to do quantitative analysis of microplastics. The specific tidal zone sampled varied but most of the studies (28) focussed on the most resent flotsam (high tide line). Of these studies only two sampled different depth strata using corers. Three of the studies reduced their bulk samples by density separation and sieving. In all of these studies, visual examination of concentrated remains is an obligatory step (Hidalgo- Ruz *et al.* 2012). The aim of this study was to establish an appropriated sampling method for microplastics and improve our understanding of their vertical distribution, abundance and composition on an urban beach in Cape Town, South Africa. It was hypothesized that the abundance of microplastic should increase with sediment depth, as small plastics are easily covered with sand by the wind.

MATERIALS AND METHODS

One sample was collected per week for three weeks in November-December 2012 at Milnerton beach (Figure 2.1). All articles ≥ 10 mm in diameter were removed from the surface before sampling. Sediment samples were taken from the high tide mark (storm swash). Each sample consisted of sand scooped out of a 30 x 30 x 30 cm corer. Five depths were sampled: 0 - 5 cm, 5 - 10 cm, 10 – 15 cm, 15 – 20 cm and 20 – 25 cm.

In the laboratory, each sample was dry-sieved separately through a 2 mm-mesh sieve to remove large articles (mostly plastic fragments and plastic pellets). The rest of the sediment was mixed with NaCl solution (35g.L^{-1}) and stirred for one minute. The sediment quickly settled to the bottom while the low density articles remained in suspension or floated to the surface. The supernatant was removed and suspended articles (mostly plastics) were separated by wet-sieving through two nested sieves with mesh sizes respectively of 1mm and 0.5mm. Samples were oven dried in the sieves for 5 - 10 hours at 30˚C. All articles < 10 mm were sampled.

Materials retained in the sieves were collected and sorted under a dissecting microscope at 400X magnification. Natural material was discarded. All articles were counted and weighed on an analytical GH-202 scale to the fourth decimal of a gram. Virgin plastic pellets were weighed separately but all other identifiable plastic articles were weighed in separate categories (e.g. plastic fragments) but not individually. All articles retained by the 0.5 mm-mesh sieve were weighed together.

RESULTS

An average (±s.d.) of 696 (± 388) articles was collected on the three days, giving a mean density of 30.9 (±17.2) articles. L^{-1}. All debris found was plastic. Composition of the plastics was predominantly virgin plastic pellets (39 %), unidentified plastic fragment (29 %) and styrofoam (28 %). Most of the articles (86 %) were found in the top 10 cm of the sediment (Figure 3.1). In general, numbers of articles decreased with depth (Figure 3.1) but when the numbers were separated into size categories the trends for articles sized 1 – 2 mm and 0.5 – 1 mm varied (Figure 3.2). The main differences were found in the top 10 cm of the sediment, where the number of articles varied between the first (top 5 cm) and second layers (top 5 – 10 cm). Deeper layers had low densities. Virgin plastic pellets had the same decreasing trend (in numbers and mass) as articles > 2 mm (Figure 3.3). More than half of the collected articles (57%) fell in the size category 2 mm - 10 mm.

There mean (± standard deviation) mass of one pellet was 0.0248 ± 0.0053 g with an average size ranging from 3 – 5 mm.

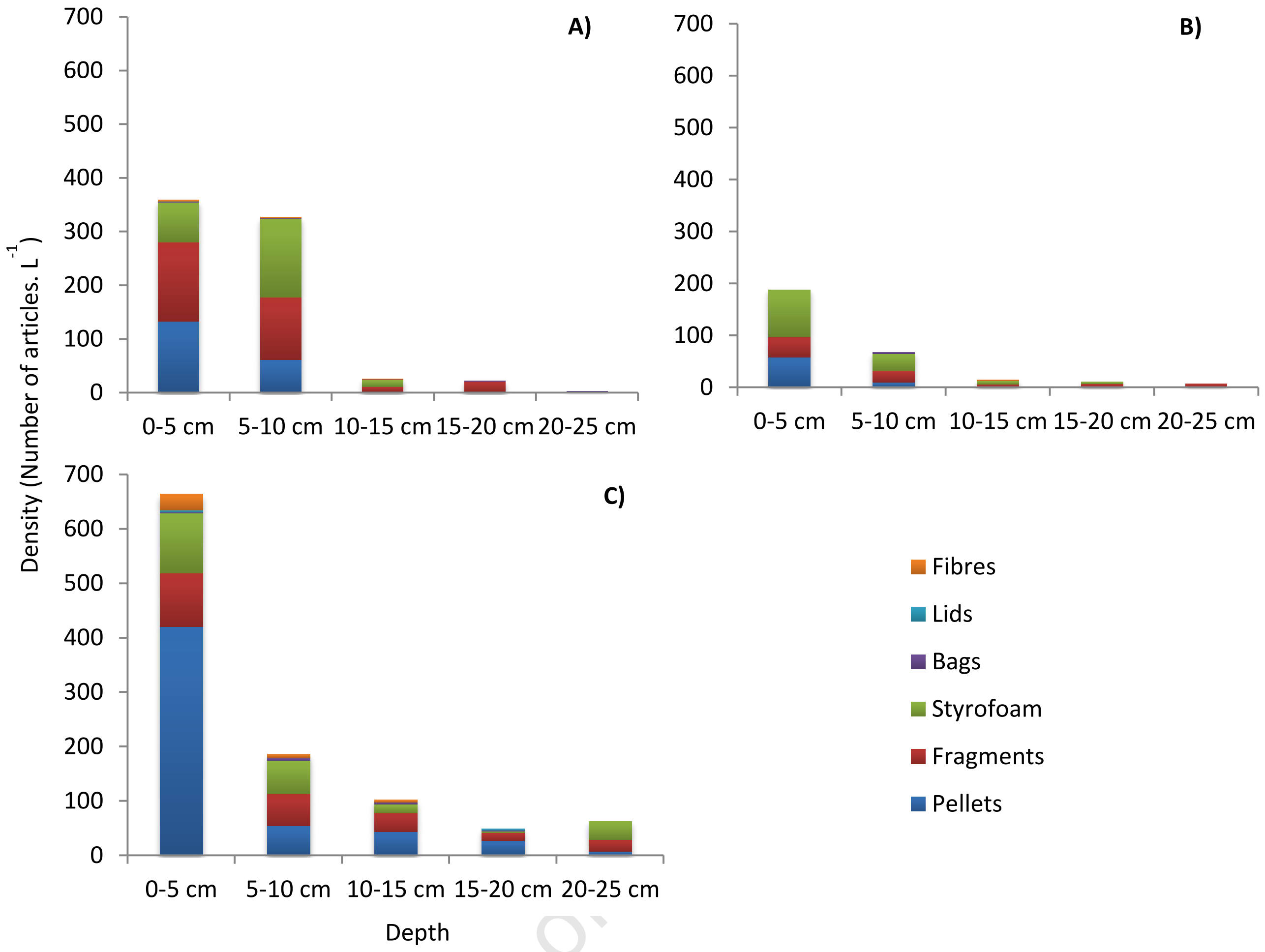

Figure 3.1: The density (number.L^{-1}) of plastic litter types sampled at different depths. A) 18 November 2012 (Total articles: 737), B) 25 November 2012 (Total articles: 289) and C) 2 December 2012 (Total articles: 1063)

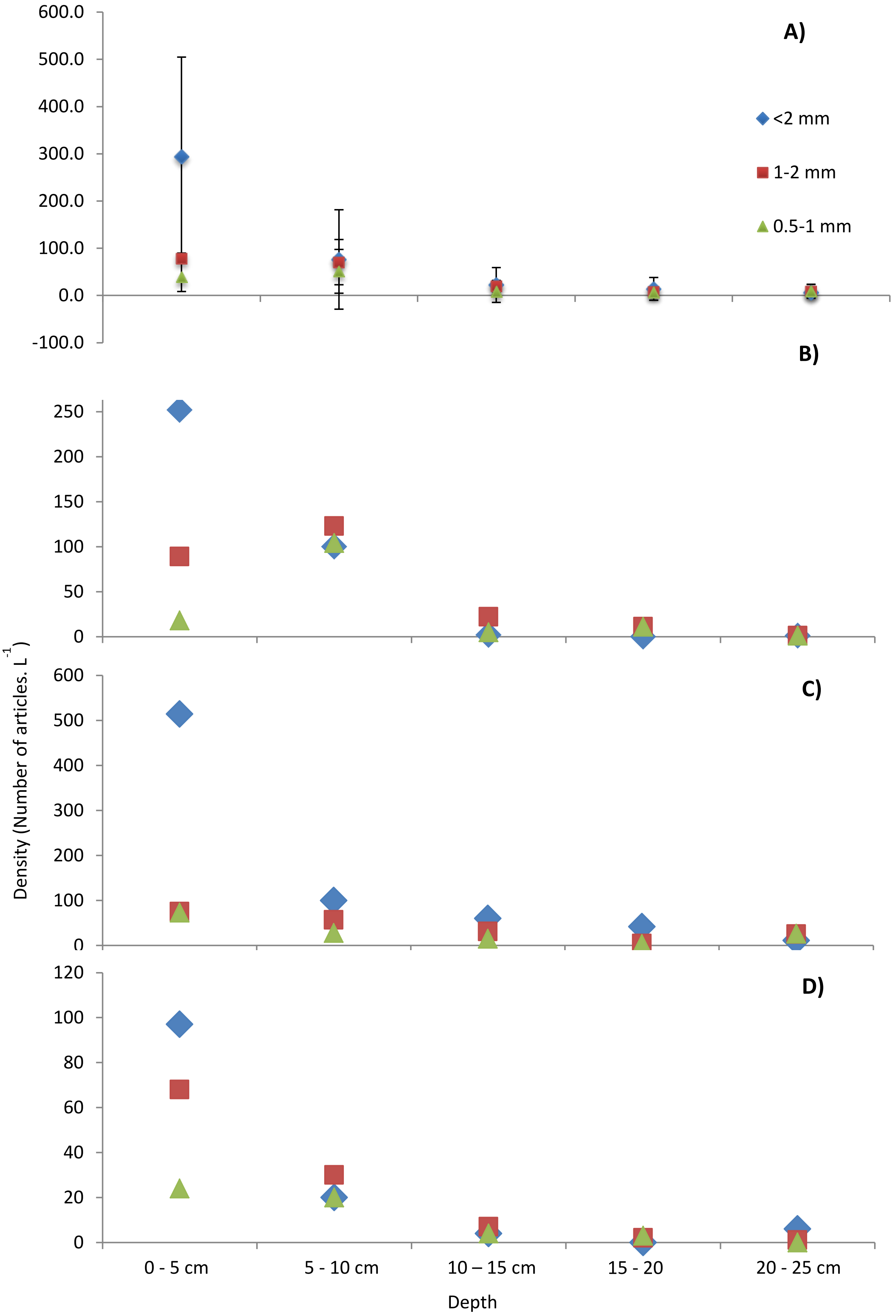

Figure 3.2: The distribution of plastic articles with depth in different size classes. A) Mean (± s.d.) density of articles collected at each depth. Density of plastics collected on B) 18 November 2012, C) 25 November 2012 and D) 2 December 2010

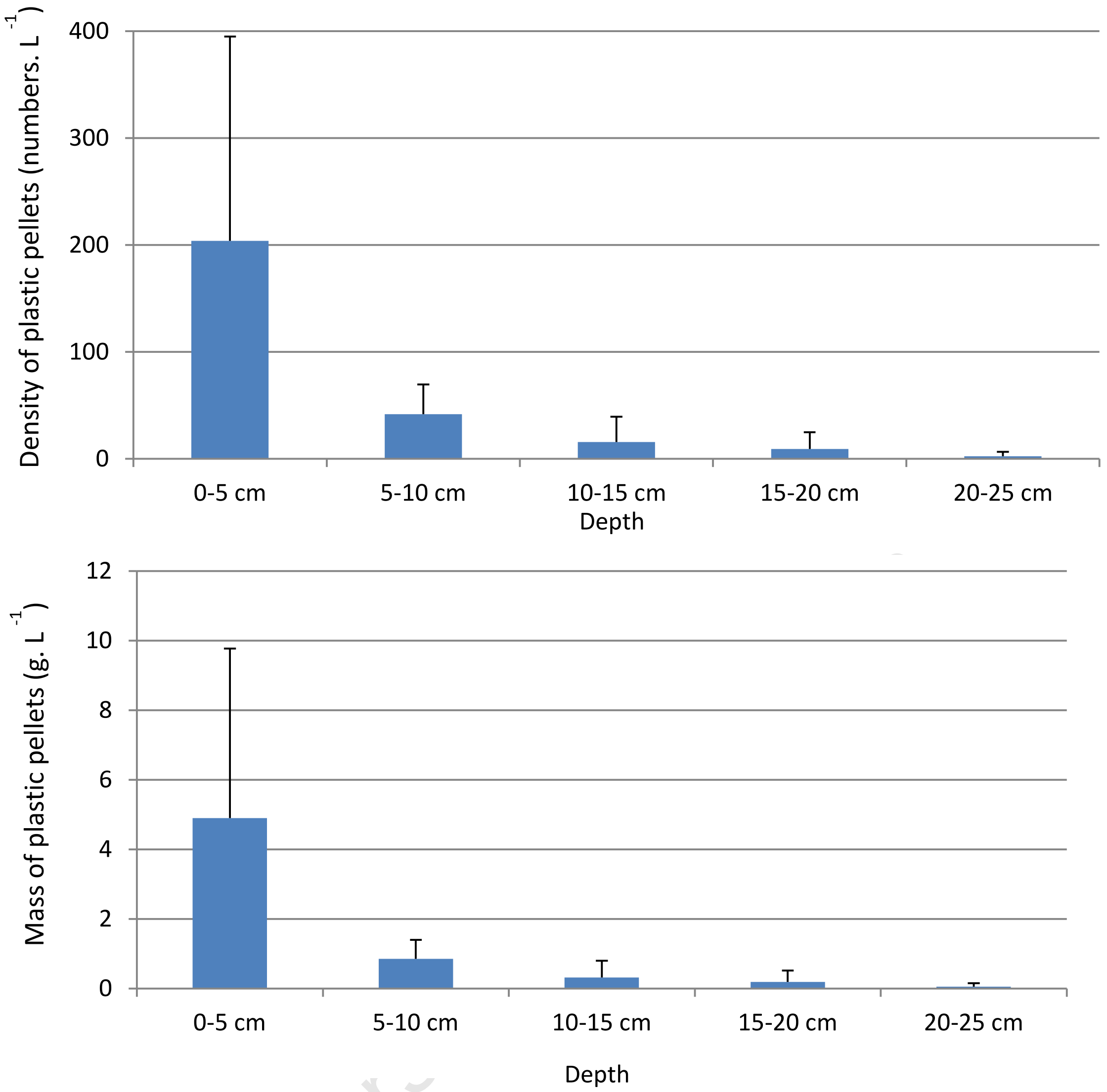

Figure 3.3: Mean A) number and B) mass of virgin plastic pellets collected from different sediment depths. Error bars represent standard deviation

DISCUSSION

Virgin plastic pellets have been noticeable in the marine environment for some time (Gregory 1978, Ivar do Sul *et al.* 2009) and, together with small plastic fragments, are present almost everywhere in the world's oceans and coastal environments (Ivar do Sul *et al.* 2009). A study by Ivar do Sul *et al.* (2009) on beaches of Fernando de Noronha (Equatorial Western Atlantic) found that 65%, 23% and 0.5% of the marine debris found in sediment samples consisted of plastic fragments, pellets and polystyrene respectively, although only 39% of the sample debris could be considered as microplastics. Kusui & Noda (2003) studied buried litter on beaches along the Sea of Japan and found that 10.6%, 1.8%

and 87.1% consisted of plastic fragments, pellets and polystyrene respectively. Most items found were < 10 mm. In this study 29%, 39% and 28% of the total articles collected were respectively unidentified plastic fragments, plastic pellets and polystyrene. Although these studies are not easily compared because of the different methodologies used, the same three broad groups feature in all of them and can be considered regular items found in microplastic surveys.

Plastic pellets are found floating on the sea surface and accumulating on beaches or on sea bottoms (Costa *et al.* 2010). They are generally more abundant on beaches in areas near plastic manufacturers, cargo loading docks and shipping lanes for raw plastic materials (McDermid & McMullen 2004). Milnerton Beach is close to Cape Town Harbour and an industrial area. In this study the number of plastic pellets decrease with depth of the sediment. Debris within the same size class followed the same pattern. Most studies only sample a single depth layer of 5 cm, whereas others do not mention the sampling depth and on rare occasions they follow a stratified sampling approach (Hildago-Ruz *et al.* 2012). In this study, deeper layers of sand from the sampling areas were denser than the surface layers, which might mean that some of the deeper layers were thus not as regularly replaced as the upper layers. The distribution of particles on beaches is controlled by a number of natural, physical and anthropogenic factors (Abu-Hilal & Al-Najjar 2009). In this study, the distribution of meso- and microplastics were probably influence by prevailing winds and incoming tides.

Gregory (1978) found that many pellets sampled on a New Zealand beach had fine cracks, which is a sign of progressive embrittlement. He also illustrated the deterioration of plastic pellets, ultimately leading to complete disintegration. Size and weight alteration can be explained by the degrading process. Sizes of plastic items are frequently reported in ingestion studies (Costa *et al.* 2010). For this reason, the size of items should be considered as a real threat to wildlife and even children (Costa *et al.* 2010). The smaller the item, the bigger the possibility that the item can affect an animal (Cole *et al.* 2011). Coloured plastic fragments and pellets, especially those that look edible, are likely to be ingested by marine animals. Microplastics can potentially affect filter feeders that live on or in the sand or other substrata (Costa *et al.* 2010). McDermid & McMullen (2004) found in their study on Hawaiian beaches that 43% of the plastic pieces collected could be ingested by planktivores, filter-feeding salps and surface- feeding seabirds. These plastic pieces fell in a size range of 1 – 2.8 mm in size. In this study 42% of the debris fell in that size category (0.5 – 2 mm).

Hidalgo-Ruz *et al.* (2012) distinguished four steps during sample processing: density separation, filtration, sieving and visual sorting of microplastics. Of these four steps, three were used in my study: density separation, sieving and visual sorting. Density separation and sieving was fairly easy to do but problems started to arise during visual sorting. Most of the items > 1mm were fairly easily distinguished by the naked eye or with the help of a dissecting microscope, but identification difficulties were found with items between the sizes of 0.5 - 1 mm. With an untrained eye, natural matter and plastic at such small sizes seems to look like the same thing under a dissecting microscope. Other methods to identify microplastics and methods to separate microplastics from natural debris need to be developed for more accurate results.

Chapter 4

Conclusion

Variability among the sections on the beaches (Koeberg and Milnerton) was found. The transect of the two studied beaches (250m at Milnerton and 500m at Koeberg) were long enough to cover high and low depositing areas. Differences between the 2 beaches are thus not simply caused by where the samples were taken. In daily variation, there are a few days that differ from others, but mostly they are consistent showing that the accumulation rates are quite robust.

A rising concern is the increase of small plastics in the environment. In this study, mesoplastics, sized 2 mm – 10 mm, found in each layer decreased in depth. Smaller Items (microplastics), sized 0.5 mm- 1 mm, were randomly distributed. Identification of mesoplastics is easier than microplastics. Other methods to identify microplastics are thus needed for more accurate results in the future.

Natural habitats from the poles to the equator are already polluted by plastic litter due to its persistent qualities (Thompson *et al.* 2009). In this study and most other studies on marine debris, plastic litter dominates (Derraik 2002). Accumulation rates of plastics are increasing. Monitoring represents a key step towards quantifying spatial and temporal trends in the abundance of all types of litter (Thompson *et al.* 2009). The increasing trend of plastic litter entering the marine environment is of concern all over the world.

People must change their attitudes and act to solve the problem. However, it is difficult to persuade people to change their lifetime habits without proper education, stricter laws and regulations. This study only focusses on the increase of plastic litter over an 18-year period on two beaches in Table Bay and not on where the litter comes from. For management purposes, more research is needed to determine the sources of urban litter. This could give an indication on how to manage urban litter. Source control of litter could lead to a cleaner environment. By working together (general public, governments and businesses) it is possible to make a change.

REFERENCES

ABU-HILAL, A.H. & ALJJAR, T.H. 2009. Plastic pellets on the beaches of the northern Gulf of Aqaba, Red Sea. *Aquatic Ecosystem Health & Management* **12:** 461 – 470.

ACHA, E.M., MIANZAN, H.W., IRIBARNE, O., GAGLIARDINI, D.A., LASTA, C. & DALEO, P. 2003. The role of the Rio de la Plata bottom salinity front in accumulating debris. *Marine Pollution Bulletin* **46:** 197 – 202.

ANDERSON,M.J., GORLEY, R.N. & CLARKE, K.R. 2008. PERMANOVA + for PRIMER: Guide to software and statistical methods. PRIMER-E: Plymouth, UK.

ANDRADY, A.L. 2011. Microplastics in the marine environment. *Marine Pollution Bulletin* **62:** 1596 – 1605.

ANDRADY, A.L. & NEAL, M.A. 2009. Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society B* **364:** 1977-1984.

ARMITAGE, N. & ROOSEBOOM, A. 2000. The removal of urban litter from stormwater conduits and streams: Paper 1 - The quantities involved and catchment litter management options. *Water South Africa* **26:** 181-188.

ARNOULD, J.P.Y. & CROXALL, J.P. 1995. Trends in entanglement of Antarctic fur seals (*Arctocephalus gazelle*) in man-made debris at South Georgia. *Marine Pollution Bulletin* **30:** 707-712.

AZZARELLO, M.Y. & VAN VLEET, E.S. 1987. Marine birds and plastic pollution. *Marine ecology – Progress Aeries* **37:** 295-303.

BARNES, D.K.A. 2002. Invasion by marine life on plastic debris. *Nature* **416:** 808-809.

BARNES, D.K.A. & MILNER, P. 2005. Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean. *Marine Biology* **146:** 815-825.

BARNES, D.K.A., GALGANI, F., THOMPSON, R.C. & BARLAZ, M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B* **364:** 1985 – 1998.

BOLAND, R.C. & DONOHUE, M.J. 2003. Marine debris accumulation in nearshore marine habitats of endangered Hawaiian monk seal, *Monachus schauinslandi* 1999 – 2001. *Marine Pollution Bulletin* **46:** 1385 – 1394.

BOREN, L.J., MORRISSEY, M., MULLER, C.G. & GEMMELL, N.J. 2006. Entanglement of the New Zealand fur seals in man-made debris at Kaikoura, New Zealand. *Marine Pollution Bulletin* **52:** 442 – 446.

BROWN, M.A., CRUMP, P., NIVEN, S.J., TEUTEN, E., TONKIN, A., GALLOWAY, T. & THOMPSON. 2011. Accumulation of micro-plastics on shorelines worldwide: sources and sinks. *Environmental Science & Technology* **45:** 9175-9179.

BUGONI, L., KRAUSE, L. & PETRY, M.V. 2001. Marine debris and human impacts on sea turtles in Southern Brazil. *Marine Pollution Bulletin* **42:** 1330-1334.

CARPENTER, E.J., ANDERSON, S.J. HARVEY, G.R. MIKLAS, H.P. & PECK, B.B. 1972. Polystyrene Spherules in Coastal Waters. *Science* **178:** 749-750.

CARSON, H.S., COLBERT, S.L., KAYLOR, M.J. & MCDERMID, K.J. 2011. Small plastic debris changes water movement and heat transfer through beach sediment. *Marine Pollution Bulletin* **62:** 1708-1713.

CLAEREBOUDT, M.R. 2004. Shore litter along sandy beaches of the Gulf of Oman. *Marine Pollution Bulletin* **49:** 770 – 777.

CLAESSENS, M., DE MEESTER, S., VAN LANDUYT , L., DE CLERCK, K. & JANSSEN, C.R. 2011. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution bulletin* **62:** 2199-2204.

CLIFF, G., DUDLEY, S.F.J., RYAN, P.G. & SINGLETON, N. 2002. Large sharks and plastic debris in KwaZulu-Natal, South Africa. *Marine and Freshwater Research* **53:** 575 – 581.

COLE, M., LINDEQUE, P., HALSBAND, C & GALLOWAY, T.S. 2011. Microplastics as contamination in the marine environment: a review. *Marine Pollution Bulletin* **62**: 2588 – 2597.

COOPER, D.A. & CORCORAN, P.L. 2010. Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island Kauai, Hawaii. *Marine Pollution Bulletin* **60:** 650-654.

COSTA, M.F., IVAR DO SUL, J.A., SILVA-CAVALCANTI, J.S., ARAÚJO, M.C.B., SPENGLER, A. & TOURINHO, P.S. 2010. On the importance of size of plastic fragments and pellets on the strandline: a snapshot of a Brazilian beach. *Environmental Monitoring and Assessment* **168:** 299 – 304.

DE ARAÚJO, M.C.B., SANTOS, P.J.P. & COSTA, M.F. 2006. Ideal width of transects for monitoring source-related categories of plastics on beaches. *Marine Pollution Bulletin* **52:** 957 – 961.

DEBROT, A.O., VAN RIJN, J., BRON, P.S. & DE LEÓN, R. 2013. A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean. *Marine Pollution Bulletin* http://dx.doi.org/10.1016/j.marpolbul.2013.01.027.

DERRAIK, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* **44:** 842 - 852.

DONOHUE, M.J., BOLAND, R.C. SRAMEK, C.M. & ANTONELIS, G.A. 2001. Derelict fishing gear in the Northwestern Hawaiian Island: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. *Marine Pollution Bulletin* **42:** 1301-1312.

ERIKSSON, C., BURTON, H., FITCH, S. & SCHULZ, M. 2013. Daily accumulation rates of marine debris on sub-Antarctic island beaches. *Marine Pollution Bulletin* **66:** 199 – 208.

GREGORY, M.R. 1978. Accumulation and distribution of virgin plastic granules on New Zealand beaches. *New Zealand Journal of Marine and Freshwater Research* **12:** 399 – 414.

GREGORY, M.R. 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B* **364:** 2013 – 2025.

GOLDBERG, E.D. 1997. Plasticizing the seafloor: an overview. *Environmental Technology* **18:** 195 - 202.

HIDALGO-RUZ, V., GUTOW, L., THOMPSON, R.C. & THIEL, M. 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science & Technology* **46:** 3060 – 3075.

HOPEWELL, J., DVORAK, R. & KOSIOR, E. 2009. Plastic recycling: challenges and opportunities. *Philosophical Transactions of the Royal Society B* **364:** 2115-2126.

IVAR DO SUL, J.A., SPENGLER, A. & COSTA, M.F. 2009. Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). *Marine Pollution Bulletin* **58:** 1236-1238.

JONES, M.M. 1995. Fishing debris in the Australian marine environment. *Marine Pollution Bulletin* **30:** 25 – 33.

KENYON, K.W. & KRIDLER, E. 1969. Laysan Albatrosses swallow indigestible matter. *The Auk* **86:** 399 – 343.

KUSUI, T. & NODA, M. 2003. International survey on the distribution of stranded and buried litter on beaches along the Sea of Japan. *Marine Pollution Bulletin* **43:** 175 – 179.

LAIST, D.E. 1987. Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine Pollution Bulletin* **18:** 319 -316.

LEWIS, P.N., RIDDLE, M.J. & SMITH, S.D.A. 2005. Assisted passage or passive drift: a comparison of alternative transport mechanisms for non-indigenous coastal species into the Southern Ocean. *Antarctic Science* **17:** 183-191.

MALLORY, M.L. 2008. Marine plastic debris in northern fulmars from the Canadian high Arctic. *Baseline/ Marine Pollution Bulletin* **56:** 1486 – 1512.

MARAIS, M., ARMITAGE, N. & WISE, C. 2004. The measurement and reduction of urban litter entering stormwater drainage systems: paper 1 – quantifying the problem using the City of Cape Town as a case study. *Water South Africa* **30:** 469-482.

MARTINEZ-RIBES, L., BASTERRETXEA, G., PALMER, M. & TINTORÉ, J. 2007. Origin and abundance of beach debris in Belearic Islands. *Scientia Marina* **71:** 305-314.

MASÓ, M., GARCÉS, E., PAGES, F. & CAMP, J. 2003. Drifting plastic debris as a potential vector for dispersing Harmful Algal Bloom (HAB) species. *Scientia Marina* **67:** 107 – 111.

MATO, Y., ISOBE, T., TAKADA, H., KANEHIRO, H., OHTAKE, C. & KAMINUMA, T. 2001. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environmental Science & Technology* **35:** 318-324.

MCDERMID, K.J. & MCMULLEN, T.L. 2004. Quantitative analysis of small-plastic debris on beaches in Hawaiian archipelago. *Marine Pollution Bulletin* **48:** 790 -794.

MOORE, C.J. 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. *Environmental Research* **108:** 131-139

MOORE, S.L., GREGORIO, D., CARREON, M., WEISBERG, S.B. & LEECASTER, M.K. 2001. Composition and distribution of beach debris in Orange County, California. *Marine Pollution Bulletin* **42:** 241-245.

NG, K.L. & OBBARD, J.P. 2006. Prevalence of microplastics in Singapore's coastal marine environment. *Marine Pollution Bulletin* **52:** 761 – 767.

OIGMAN-PSZCZOL, S.S. & CREED, J.C. 2007. Quantification and classification of marine litter on beaches along Armação dos Búzios, Rio de Janeiro, Brazil. *Journal of Coastal Research* **23:** 421 – 428.

OTLEY, H. & INGHAM, R. 2003. Marine debris surveys at Volunteer Beach, Falkland Islands, during the summer of 2001/02. *Marine Pollution Bulletin* **46:** 1534-1539.

PAGE, B., MCKENZIE, J., MCINTOSH, R., BAYLIS, A., MORRISSEY, A., CALVERT, N., HAASE, T., BERRIS, M., DOWIE, D., SHAUGHNESSY, P.D. & GOLDSWORTHY, S.D. 2004. Entanglement of Australian sea lion and New Zealand fur seals in lost fishing gear and other marine debris before and after government and industry attempts to reduce the problem. *Marine Pollution Bulletin* **49:** 33 – 42.

POSSATTO, F.E., BARLETTA, M., COSTA, M.F., IVAR DO SUL, J.A. & DANTAS, D.V. 2011. Plastic debris ingestion by marine catfish: an unexpected fishery impact. *Marine Pollution Bulletin* **62:** 1098-1102.

PROVENCHER, J.F., GASTON, A.J., MALLORY, M.L., O'HARA, P.D. & GILCHRIST, H.G. 2010. Ingested plastic in a diving seabird, the thick – billed murre (*Uria lomvia),* in the eastern Canadian Artic. *Marine Pollution Bulletin* **60:** 1406 – 1411.

RIBIC, C.A. 1998. Use of indicator items to monitor marine debris on a New Jersey beach from 1991 to 1996. *Marine Pollution Bulletin* **36:** 887 – 891.

ROCHMAN, C.M., BROWN, M.A., HALPERN, B.S., HENTSCHEL, B.T., HOH, E., KARAPANAGIOTI, H.K., RIOS-MENDOZA, L.M., TAKADA, H., TEH, S. & THOMPSON, R.C. 2013. Classify plastic waste as hazardous. *Nature* **494:** 169 - 171.

RYAN, P.G. 1988. Effects of ingested plastic on seabird feeding: evidence from chickens. *Marine Pollution Bulletin* **19:** 125–128.

RYAN, P. G., MOLONEY, C. L. 1990. Plastic and other artefacts on South African beaches: temporal trends in abundance and composition. *South African Journal of Science* **86**: 450–452.

RYAN, P.G., MOORE, C.J., VAN FRANEKER, J.A. & MOLONEY, C.L. 2009. Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of the Royal Society B* **364:** 1999 – 2012.

SANTOS, I.R., FRIEDRICH, A.C., WALLNER-KERSANACH, M. & FILLMANN, G. 2005. Influence of socio-economic characteristics of beach users on litter generation. *Ocean and Coastal Management* **48:** 742-752.

SANTOS, I.R., FRIEDRICH, A.C. & IVAR DO SUL, J.A. 2009. Marine debris contamination along undeveloped tropical beaches from northeast Brazil. *Environmental Monitoring Assessment* **148:** 455-462.

StatSoft, Inc. 2012. STATISTICA (data analysis software system), version 11. www.statsoft.com.

SWANEPOEL, D. 1995. An analysis of beach debris accumulation in Table Bay, Cape Town, South Africa. MSc thesis, University of Cape Town.

TEATEN, E., ROWLAND, S.J., GALLOWAY, T.S. & THOMPSON, R.C. 2007. Potential for plastics to transport hydrophobic contaminants. *Environmental Science of Technolo*gy **41:** 7759-7764.

THOMPSON, R.C., OLSEN, Y., MITCHELL, R.P., DAVIS, A., ROWLAND, S.J., JOHN, A.W.G., MCGONIGLE, D. & RUSSELL, A.E. 2004. Lost at sea: where is all the plastic? *Science* **304:** 838.

THORNTON, L. & JACKSON, N.L. 1998. Spatial and temporal variations in debris accumulation and composition on an estuarine shoreline, Cliffwood Beach, New Jersey, USA. *Marine Pollution Bulletin* **36:** 705-711.

TOPCU, E.N., TONAY, A.M., DEDE, A., ÖZTÜRK, A.A. & ÖZTÜRK, B. 2013. Origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. *Marine Pollution Bulletin* **85:** 21-28.

TOURINHO, P.S., IVAR DO SUL, J.A. & FILLMANN, G. 2010. Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? *Marine Pollution Bulletin* **60:** 396-401.

VAN IEPEREN, M.P. 1971. Hydrology of Table Bay. Final Report, University of Cape Town.

WALKER, T.R., REID, K., ARNOULD, J.P.Y. & CROXALL, J.P. 1997. Marine debris surveys at Bird Island, South Georgia 1990-1995. *Marine Pollution Bulletin* **34:** 61-65.

WHITING, S.D. 1998. Types and sources of marine debris in Fog Bay, Northern Australia. *Marine Pollution bulletin* **36:** 904-910.

ZAR, J.H. 2010. Biostatistical analysis, fifth edition. Pearson Prentice Hall, Upper Saddle River, NJ, USA, 944pp

ZHOU, P., HUANG, C., FANG, H., CAI, W., LI, D., LI, X. & YU, H. 2011. The abundance, composition and sources of marine debris in coastal seawaters or beaches around the northern South China Sea (China). *Marine Pollution Bulletin* **62:** 1998 -2007.