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Sea-surface microplastic concentrations along the coastal shelf of KwaZulu–Natal, South Africa

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ABSTRACT

Ocean pollution is a global issue; yet limited quantitative data on microplastic concentrations are available for the South African coastal shelf. Estuarine outlets within industrial areas that are found along the coastline serve as conduits for plastics and other pollutants to the ocean. This study investigated coastal plastic concentrations around KwaZulu–Natal. Forty–three manta trawl samples were collected and analysed over a period of one year. An average of 4.01 ± 3.28 plastic particles/100 m^2 was found in surface trawls. Plastic concentrations in winter were significantly higher than those in summer (5.54 ± 3.26 and 2.96 ± 2.94 particles/100 m^2 respectively). The highest concentrations of plastics were found south of the city of Durban, with the highest concentration at Isipingo winter with 12.2 particles/100 m^2. Among the summer samples, the highest concentration of particles was off Amanzimtoti (9.54 particles/100 m^2). The main plastic forms were fragments, films and fibres that were commonly white, clear, opaque, blue and black in colour. High plastic concentrations in the Durban area and sites close-by were expected due to the high levels of urbanization in the area, however, the difference in concentrations found between winter and summer was not expected and may have been due to the prevailing wind and/or current conditions on the sampling date.

1. Introduction

From the onset of production, 8300 million metric tonnes of plastic has been produced with ≈ 59% being discarded (Geyer et al., 2017). The trillions of plastic particles now afloat in our oceans are a global issue that cannot be overlooked (Eriksen et al., 2014). Rivers and estuaries are the major conduits, especially in urban settings (Bakir et al., 2014; Wagner et al., 2014) and collectively account for a large proportion of plastics entering the oceans annually (Lebreton et al., 2017). Moore et al. (2011) estimated that 2.3 billion plastic particles, consisting mainly of foams, fragments and pre–production pellets, weighing 30 t, flow out from the Los Angeles and San Gabriel rivers in California over a period of 72 h. Estuarine sediments are also inundated with plastic, such as in the Yangtze Estuary, which is considered one of the largest plastic dischargers, and holds an average of 4137 ± 2461 plastic particles/m^3 of sediment (Zhao et al., 2014; Lebreton et al., 2017). Other 'hotspots' are the Ganges, Mississippi and Nile rivers (Lebreton et al., 2012), the Laurentian Great Lakes (Eriksen et al., 2013) and Singapore's coastal systems (Mohamed Nor and Obbard, 2014). South African urban estuaries are no exception (Naidoo et al., 2015), but the quantity and fate of plastics that are discharged from them, and are thereafter subsequently afloat along our local currents, are not well known. Quantifying this is important, since high plastic concentrations can result in frequent interactions with marine life, especially when plastics closely resemble the size and colour of prey items (Clark et al., 2016; Di Mauro et al., 2017; Ory et al., 2017). These interactions often result in negative effects leading up from the cellular level (von Moos et al., 2012) to affecting organism's overall health (Rochman et al., 2013).

The South African coastline is 3400 km long and has 300 river outlets which are located in areas that vary in their level of urbanization, making it ideal for an investigation into the impacts of urban development on ocean plastic concentrations (Harrison, 2004; Nel et al., 2017; de Villiers, 2018). It has been estimated that South Africa (SA) discharges 0.09–0.25 million metric tonnes of plastics to the ocean annually and is ranked as one of the top 20 countries of mismanaged waste (Jambeck et al., 2015). Small plastic items, including industrial pellets, seem to aggregate around the industrial centers around South Africa (Ryan et al., 2018). The city of Durban, located in the KwaZulu–Natal (KZN) province, is one of the largest industrialised centers along the coast of SA and has sixteen estuaries in close proximity to the city (Forbes and Demetriades, 2008; Ryan et al., 2012). Since plastics transported through estuaries can accumulate chemical pollutants associated with industrialised centers (Ogata et al., 2009; Bakir et al.,

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2014).

Quantitative data on plastic concentrations in SA has been limited to estuaries (Naidoo et al., 2015), surf-zones (Nel and Froneman, 2015), beaches (Ryan and Moloney, 1990; Madzena and Lasiak, 1997; Lamprecht, 2013; de Villiers, 2018; Ryan et al., 2018) and beach clean-ups, whilst data on coastal and oceanic plastic concentrations are dated (Ryan, 1988) or from the African sector of the Southern Ocean (Ryan et al., 2014). Quantification on the east coast of SA will therefore add value to the existing data on coastal plastic pollution in the country and will clarify how, and in what concentration, plastic travels along local currents. For instance, the shelf around Durban is narrow and can slope down to 100 m within 7 km from the coastline in some areas (Roberts et al., 2010). South–westward currents are the norm within this part of the shelf (Schumann, 1986), but the shape of the coastline can create north–eastward countercurrents giving rise to a semi-permanent cyclonic eddy (Roberts et al., 2010) termed the 'Durban Eddy' (Guastella and Roberts, 2016), which may influence particle concentrations and transport. Identifying the sources of plastic in the Durban eddy would help to understand the distribution of plastic particles in the province's coastal waters. There is also a seasonal precipitation difference, with more rain and run–off generally in summer, possibly influencing coastal plastic concentrations (Forbes and Demetriades, 2008). The city of Durban has been developed around an industrialised harbour and many storm water channels run into it (Forbes and Demetriades, 2008). These channels may act as vectors for pollutants, including plastic. We therefore aimed to (1) investigate ambient plastic concentrations along the KwaZulu–Natal coastal shelf and to (2) determine if there are seasonal differences in plastic concentrations. The objectives were to collect and analyse water samples along the KwaZulu–Natal coastal shelf, using a manta trawl. It was hypothesised that plastic concentrations are higher in the Durban area and at coastal sites further south, since southward movement may be aided by the Agulhus current. Since there is higher rainfall in summer, it was further hypothsised that would result in greater run–off and therefore higher plastic concentrations in the coastal ocean.

2. Material and methods

Five sites along the KwaZulu–Natal coastal shelf were sampled from 02/09/2016 to 30/11/2016 which coincided with the spring/summer season (Fig. 1). The following year, samples were collected at the same sites starting from the winter season (03/08/2017), with the exception of Sodwana. Sampling encroached into spring at the last site of iLovu (15/09/2017), therefore summer and winter were termed nominally. All samples were collected with a stainless steel manta trawl with nylon mesh typically used to collect surface plastics. A buoy was fitted to the top of the net to keep the net afloat and for recovery in the case of rope or knot failure. The trawl net was a 333 μm mesh, which conformed to most studies (Clark et al., 2016), and the cod end was fitted with a stainless steel collecting jar. The width of the net opening was 45 cm. The net was towed parallel to the coastline, northward, for 6 min and GPS co–ordinates were recorded. Trawls were generally around 500 m in distance and were done at the side of, and 25 m behind a research vessel traveling at 2–3 knots. The rope attached to the net was held at approximately 1.5 m above sea level during tows. These tows were outside of the swash zone of the vessel. Plastic concentrations were calculated as the number of plastic particles/100 m^2 according to Brunner et al. (2015) and Viršek et al. (2016). Five replicate tows were done along a single transect at each site during each season, except during the winter sampling for Isipingo where only three replicates were collected due to equipment failure. Water depth at each site was 35–40 m (which was within 5 km from the shore). Surface tows collected plastics from an approximate depth of 0–15 cm.

After each sample, the mesh was rinsed from the outside to ensure that all visible material moved down to the cod end. Each sample was decanted into hard plastic 1 L polyethylene bottles and kept out of direct sunlight, for transport to the laboratory. At the laboratory, 1000, 500 and 250 μm stacked sieves were rinsed and examined directly under a dissecting microscope for contamination (Kyowa Optical, model SD–2PL), under 4 × magnification. Water samples were then sieved into these, covered with foil to prevent airborne contamination and left to dry. Thereafter, the contents of each sieve were analysed under a dissecting microscope to isolate and enumerate any microplastics present. Plastic particles were classed into morphotypes such as plastic fragments, fibres, films, line, polystyrene and pellets, according to Hidalgo-Ruz et al. (2012). The class 'other' was plastic that did not fall within the common categories. Plastic colour was also noted, in this case the class 'other' was given to a particle that did not fall into the common colour but were either a mixture of colours or had two colours that covered and equal area on a particle. Opaque particles were

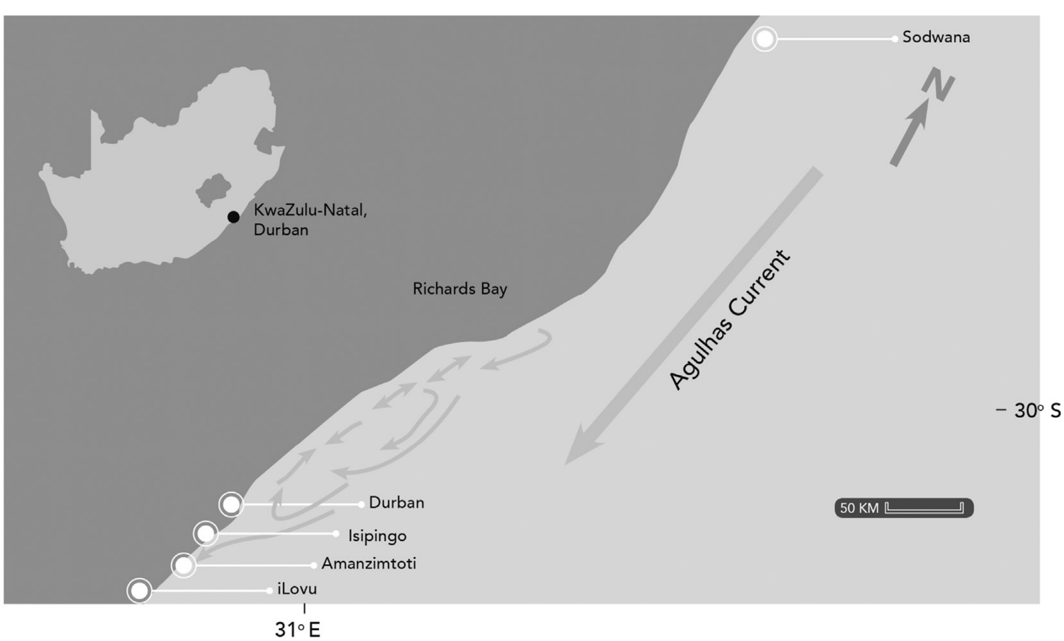

Fig. 1. Sampling sites along the KwaZulu–Natal coastline, South Africa. Current lines were adapted from deLecea (2012) and Roberts et al. (2016).

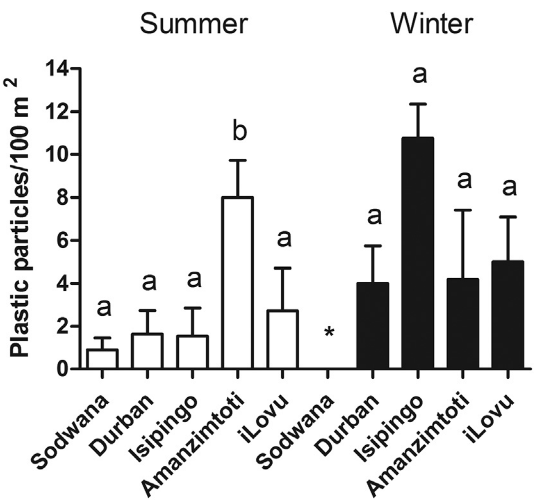

Fig. 2. The average number of plastic particles/100 m^2 for surface samples at five sites along the KwaZulu–Natal coastline. Bars represent the standard deviation (+S.D.) and letters in lower case represent post–hoc tests within each season. * – Not sampled.

particles that were found that were not transparent and not clearly white, but had started to turn colour as a result of being in the environment (Gregory, 1978). Plastics that were present in the sieves were removed using a pair of forceps and placed in 4.5 × 4 cm zip sealed bags. A close eye was kept when analysing samples for any particles that may resemble fragments of the new green rope that was used to pull the net or white paint flakes of the boat hull and none were found.

A two-way ANOVA was run on *R* to compare average plastic concentrations between seasons and among sites. Plastics quantified from all three sieves, used to distinguish size classes, were combined within each replicate. Plastic concentrations were $\log_{10}$ (x + 1) transformed and the residuals of the ANOVA resembled that of a normal distribution ($W = 0.976$, $p = 0.485$), using a Shapiro–Wilk normality test. Bartlett tests showed homogeneity of variance of the residuals by season ($K^2 = 0.012$, $df = 1$, $p = 0.914$) and site ($K^2 = 0.427$, $df = 4$, $p = 0.980$).

3. Results

3.1. Plastic concentrations

Plastic particles were found at all sites except for a single replicate each from Isipingo and Sodwana, in summer. Plastic concentrations varied considerably and an average of 4.01 ± 3.28 particles/100 m^2 were found for surface trawls. Winter plastic concentrations were significantly higher than those in summer (5.45 ± 3.26 and 2.96 ± 2.94 particles/100 m^2 respectively, $F = 19.088$, $df = 1$, $p \leq 0.001$). No major difference in rainfall was observed between seasons on the days prior to sampling events, from historical rainfall data (www.dbnrain.co.za). There was a significant interaction between season and sites ($F = 10.422$, $df = 3$, $p \leq 0.001$). Maximum concentrations were found at Amanzimtoti, in summer (9.55 particles/100 m^2), and at Isipingo, in winter (12.2 particles/100 m^2, Fig. 2). Amanzimtoti was the only site that had a significantly different plastic concentration within summer, while plastic concentrations did not differ among sites in winter (Fig. 2). When particles were found, Sodwana had the lowest surface plastic concentrations (0.91 ± 0.56), yet this did not significantly differ from other sites except for Amanzimtoti, additionally Sodwana was not sampled in winter.

3.2. Plastic morphotypes, colour and sizes

Overall, fragments, fibres and film contributed the largest portions to the total plastic pool (Fig. 3). This ranged from 23.3 to 72.7% for

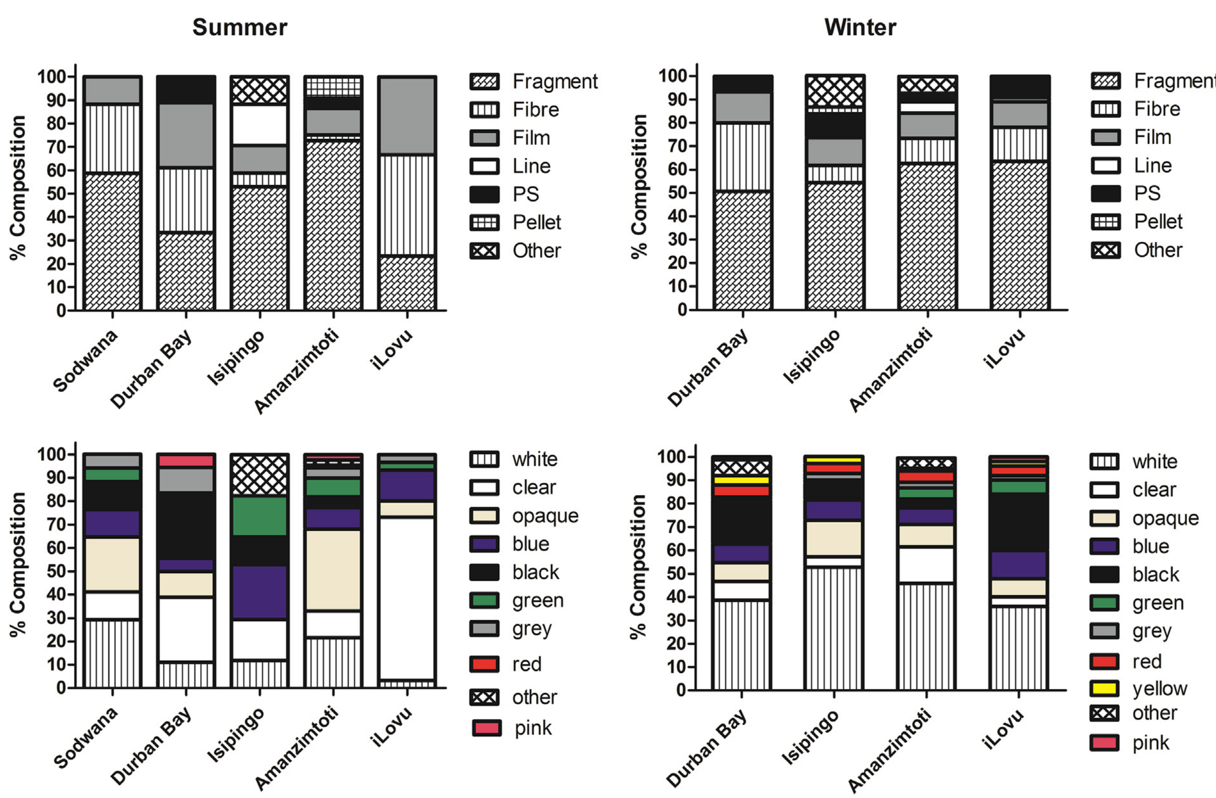

Fig. 3. The proportion of plastic types and colours found in coastal samples along KwaZulu–Natal. PS – Polystyrene. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

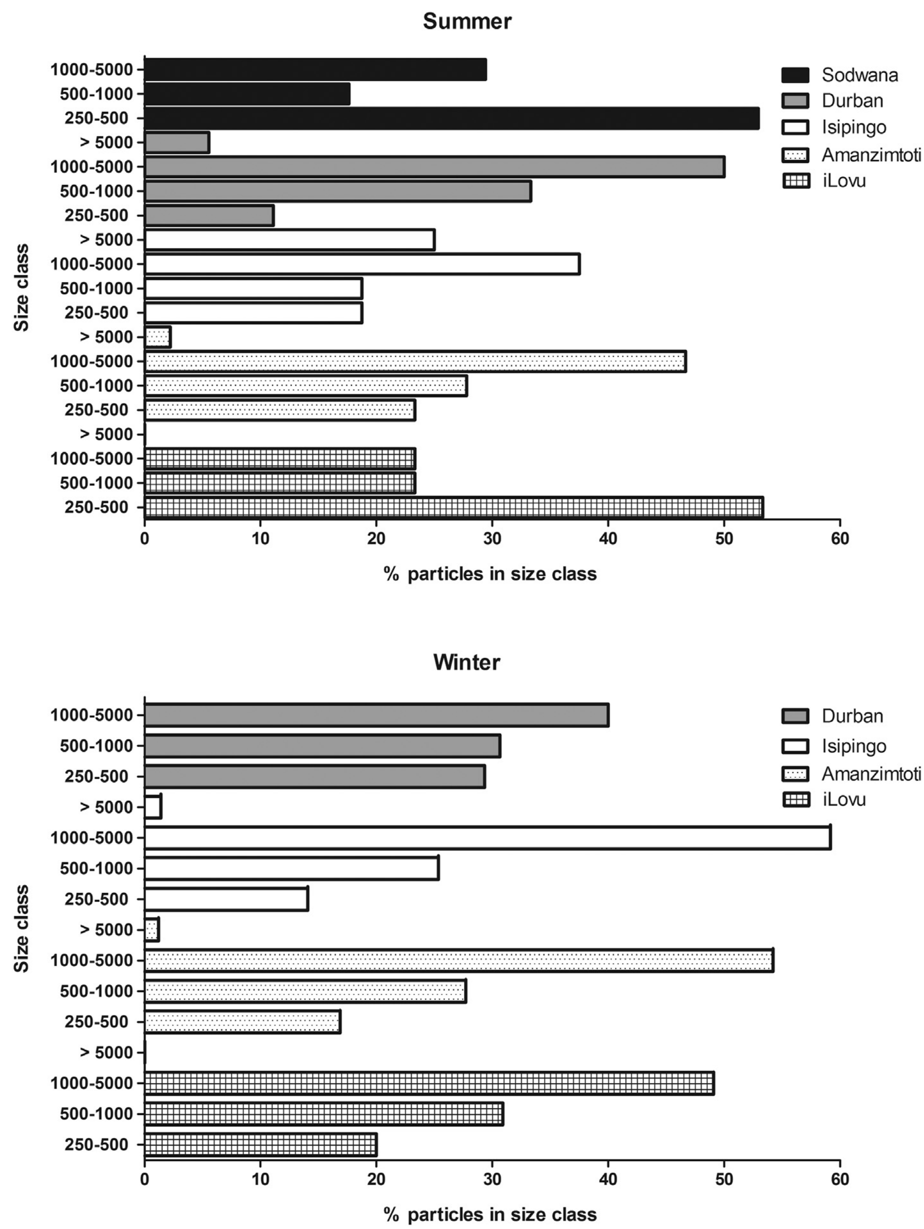

Fig. 4. The size distribution of plastic particles collected in manta trawls along the KwaZulu–Natal coastline. Summer and winter data are presented.

fragments, 2.3–43.3% for fibres and 10.8–33.3% for film. In summer, Amanzimtoti had the highest proportion of pellets and fragments, while Isipingo had a higher proportion of line compared to the other sites (Fig. 3). Polystyrene was more prominent during winter sampling and all sites also displayed similar ratios of film. The main plastic colours found were white, clear, opaque, blue and black. Higher proportions of clear, green and pink plastics were found in summer, whilst white was dominant in winter (Fig. 3). Red and yellow particles also featured during winter (Fig. 3). Plastics at iLovu were composed of a larger variety of colours in winter compared to mainly clear particles during summer (Fig. 3).

During summer, Sodwana and iLovu had higher proportions of particles < 1000 μm in length, which accounted for 71% and 77% of the total particles, respectively; while Durban, Isipingo and Amanzimtoti, had mainly particles > 1000 μm, accounting for 56%, 63% and 49%, respectively (Fig. 4). Particles that were > 5000 μm were found only at Durban, Isipingo and Amanzimtoti, with the largest proportion occurring at Isipingo and accounting for 25% of the particle size range (Fig. 4). During winter, plastic particles > 1000 μm contributed > 40% to each site (Fig. 4). Particles > 5000 μm were found only at Amanzimtoti and Isipingo during winter (Fig. 5), although at low proportions of 1.2 and 1.4%, respectively (Fig. 4).

4. Discussion

Plastic particles were found at all sites, with Amanzimtoti and Isipingo having the highest concentrations in summer and winter, respectively. These sites have high levels of urbanization and may also receive plastic particles from the nearby Durban area. Alternatively, Sodwana was expected to have the lowest plastic concentrations, which it did, but it did not significantly differ from the urban sites situated further south. Since this site is relatively free from major urbanization, it implied that some degree of long range inflow of microplastics may have occurred into the Sodwana area. This movement could be either via the Agulhas Current flowing along Mozambique or an inshore counter–current from further south along the KwaZulu–Natal coastline. Ryan (1988) noted that the Agulhas Current is a major conduit for plastics transport toward the Western Cape, but accumulation points

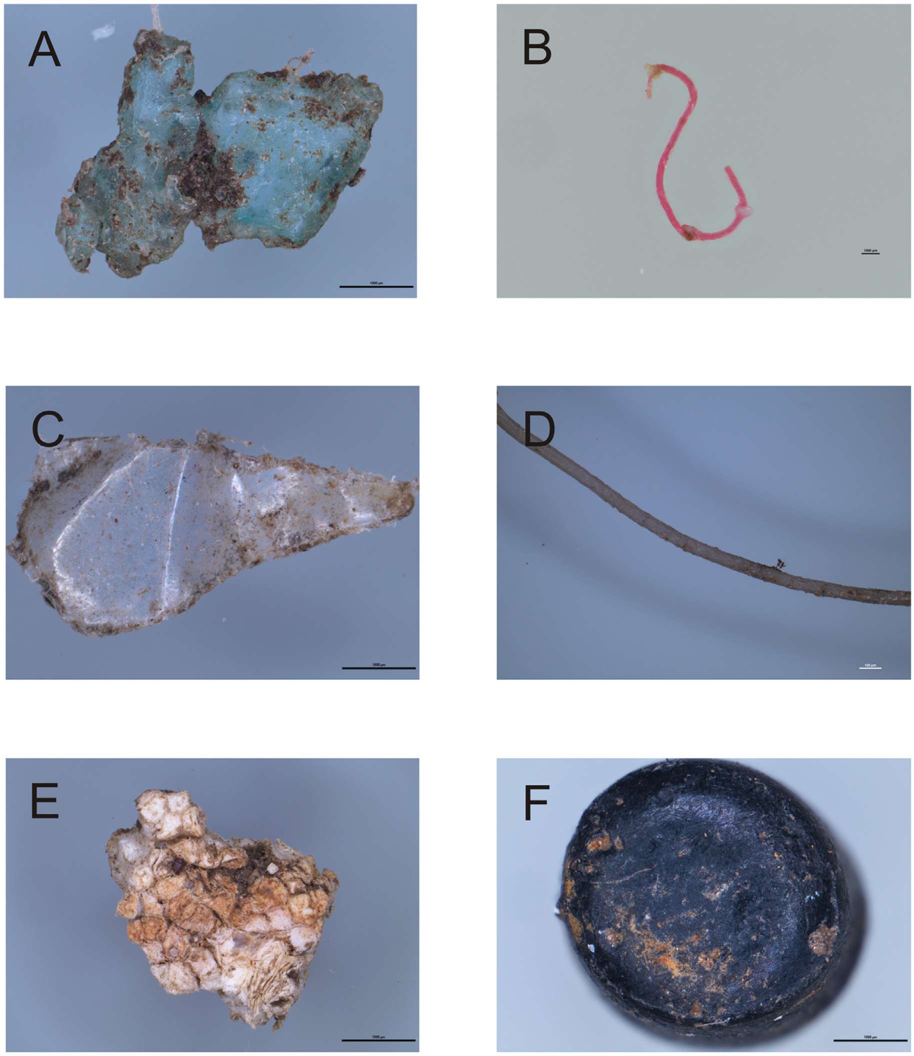

Fig. 5. Example of the plastic types that were found. A – fragment, B – fibre, C – film, D – line, E – polystyrene, F – pellet. Scale bars are 1 mm, except for D which is 100 μm.

Table 1
Plastic concentrations in decreasing order from studies reporting particles collected using similar mesh size (300–335 μm). The exception is van Cauwenberghe et al. (2013), who used 1 mm mesh.

Area of study	Average	Maximum	Reference
	Plastic particles/100 m^2		
Arabian Gulf		146	Abayomi et al. (2017)
Baltic Sea – Near Stockholm	42		Gewert et al. (2017)
North Pacific Central Gyre	33		Moore et al. (2001)
North Atlantic Subtropical Gyre		> 20	Law et al. (2010)
Mediterranean	12	89	Collignon et al. (2012) & Eriksen et al. (2014)
Baltic Sea – Offshore	5		Gewert et al. (2017)
Laurentian Great Lakes	4	47	Eriksen et al. (2013)
KwaZulu–Natal Coastal Shelf	**4**	**12**	**This study**
Belgian Continental Shelf	0.43		van Cauwenberghe et al. (2013)
Tasman Sea – Offshore	0.07		Rudduck et al. (2017)

further north of the coastline than sampled here is not well known. Possible pollution sources to the Sodwana area could be located in Richards Bay, Kosi Bay and Maputo. Plastics have also been shown to be transported into this area from Durban via a northward moving inshore counter–current (Steinke and Ward, 2003). Steinke and Ward (2003) showed that plastic drift cards dropped inshore at Durban could travel as far north as Sodwana or even south and to the west coast of the country. Since the northward flowing counter–current can reach speeds of 1 m/s, it has the possibility of transporting plastics far from their source rapidly (Guastella and Roberts, 2016). Guastella and Roberts (2016) found a similar type of movement when deploying satellite drifters to track currents along the coast from Durban. Two of the five drifters deployed in the Durban Eddy moved northward with the counter–current while three followed the southwestward flowing Agulhas Current. Plastic particles may also spend some time in the cyclonic rotating Durban Eddy, as surface drifters have done (Guastella and Roberts, 2016). Complicating particle movement even further is the presence of another rotating current just north the Durban Eddy, the Durban Swirl, which may also help move plastic particles northwards, and even back into the Agulhas Current (Roberts et al., 2016). This intricate pattern of currents along the coastline could be a possible reason as to why Nel et al. (2017) did not find clear trends of plastic pollution and population densities in the area, and proposed that long range transport of plastics is dominant in the area. In addition, the relatively high variability within some sites was likely due to low overall abundances and patchiness at the scale of sampling.

Ryan (1988) also noted that the Agulhas Current was responsible for distributing both macro and microplastics toward the South Western Cape of South Africa and found it to hold an average of 0.36 plastic particles/100 m^2, 30 years ago. On the KwaZulu–Natal coastline, we found eight times the amount of plastics, composed of similar types as found by Ryan (1988), which included foams, fragments, pellets and fibres. Film material now features more prominently than in the study by Ryan (1988), which could suggest that proportion of packaging material now used and discarded in South Africa is higher (Malikane et al., 2000). The sources of fragments are difficult to track but fibres are commonly produced by the degradation of textiles (Browne et al., 2011).

Compared to other parts of the world, including major oceanic gyres, the plastic concentrations found on the KwaZulu–Natal coastline, which included macro and microplastics, were relatively low (Table 1). For example, Moore et al. (2001) found eight times more plastic in the North Pacific Central Gyre on average, and maximum plastic concentrations were eleven times more in the Arabian gulf, found by Abayomi et al. (2017). Lower plastic concentrations were also found on the KwaZulu–Natal coastline compared to the urbanised Stockholm coastal shelf (Gewert et al., 2017), while concentrations were similar to those offshore in the Baltic Sea (Gewert et al., 2017) and at the Laurentian Great Lakes (Eriksen et al., 2013). The plastic morphotypes in these studies were also similar and included fragments, fibres, polystyrene and films. Plastics were mainly white, clear, opaque, blue and black. The colours of these particles are of importance as it could affect the likelihood of marine organisms ingesting them (Ryan, 1987; Ory et al., 2017). Ory et al. (2017) for instance, found that some fish will consume more blue particles because these resemble the blue copepods they usually feed on. The size of particles also determines the likelihood of ingestion at different scales. For example, the particles found in this study were relatively large and therefore may not be available to small filter feeding organisms but may be consumed by larger fish and other vertebrates (Choy and Drazen, 2013).

Some studies (e.g. Bergmann et al., 2017; Mintenig et al., 2017; Haave et al., 2019) have found the majority of particles from deep sea sediments and water or from waste water treatment works (WWTW) in the smallest size classes that were recorded. In contrast, the largest proportion of particles in several of the samples in this study were in the size class 1–5 mm. However small particles are likely to sink from surface waters more quickly than larger particles, due to the greater surface: volume ratio and associated effects of biofouling (Fazey and Ryan, 2016) and smaller particles are thus expected to be proportionately more abundant at depth than at the surface. Additionally, some WWTW are known to filter up to 90% of microplastic particles (Raju et al., 2018), raising the possibility that the remainder will be in the smaller class sizes. Thus the difference in the size distribution of particles between this and other studies is likely an effect of habitat and depth.

Unexpectedly, plastic concentrations in winter were higher than in summer. Possible reasons for this could be that the samples were taken on different days at different sites and, therefore, showed a patchy distribution. Additionally, historical rainfall accounts did not show any trend with the abundance of plastics found in samples (www.dbnrain.co.za). It is also likely that prevailing wind and currents in winter accumulated particles within a particular sampling area at the time of sampling. Particle movement in this zone is also difficult to track since it is a transitional zone, with particles moving toward the beach and also being washed back offshore (Lebreton et al., 2012; Isobe et al., 2014). Interestingly, during the same sampling years as this study, de Villiers (2018), found higher beach sediment microfibre levels around Durban in the winter season rather than the summer season. These authors also noted that this was “inconsistent with increased river runoff” because the area receives more rainfall in summer and therefore the opposite trend was expected, as found in this study.

4.1. Caveats, future work and recommendations

One caveat of this study is that it fails to capture the lower end of the microplastic size spectrum and thus underestimates microplastic concentrations as found by Conkle et al. (2017). Collecting plastic particles using a finer mesh and with alternate methods should therefore be done in future. In addition, including sub–surface and sediment samples is also important since estimates are that < 10% of ocean plastics are found on the surface (Clark et al., 2016). The use of a Tucker trawl seems to be more appropriate for sub–surface samples (Brunner et al., 2015). Although chemical identification methods, such as FTIR, was not done on particles, the particles found here were large enough to be identified as plastic with the aid of a microscope. There is also a need to better track these particles on the coast since we have an intricate eddy current system and modelling can help us with this (see Collins and Hermes, 2019). This is important since clean–up operations would also be more effective (Sherman and Van Sebille, 2016). We also recommend that samples be collected at closer intervals and dates within the same year, if logistically possible, to better investigate if there are any seasonal differences in plastic counts caused by the increased rainfall and run-off during summer months.

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