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Microplastics in beach sediments and cockles (*Anadara antiquata*) along the Tanzanian coastline

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Abstract

Little is known about the prevalence of microplastics (MPs) in East Africa. In the present study, sediments were sampled at 18 sites along the Tanzanian coast that exhibit different levels of anthropogenic activity and were extracted using floatation methodology. Cockles (*Anadara antiquata*) were collected only from eight sites and MPs were extracted following NaOH digestion. MPs were most abundant at Mtoni Kijichi Creek (MKC, 2972±238 particles kg^{-1} dry sediment), an industrial port in Dar es Salaam, and significantly higher than all other sites where the abundance range was 15-214 particles kg^{-1} dry sediment ($p<0.05$, one-way ANOVA). Fragments and fibers were found at all sites. Polypropylene and polyethylene were identified polymers. MPs were found in cockles from all sampled sites with both frequencies of occurrence and MPs per individual subject to site-specific variation. This study provides a baseline of MP data in a previously uninvestigated area.

Keywords: Microplastics; East Africa; Western Indian Ocean (WIO) region; coastal sediments; shellfish; filter feeders

Microplastics (MPs, <5mm in size) are a ubiquitous marine pollutant and, owing to their durability and persistence, present a significant threat to aquatic ecosystems and organisms (Derraik, 2002). Whilst a concerted effort has been made to document MPs in the different environmental compartments (water, sediments and biota) across the world there remain gaps in our collective knowledge of MP prevalence and abundance from different geographic regions (Ivar do Sul., 2014; Blettler et al., 2018). The African continent is one such region where, with the exception of South Africa where MPs have been extensively reported for over 30 years (e.g. Ryan, 1988; Ryan and Moloney, 1990; Naidoo, 2015; Nel and Froneman, 2015; Sparks, 2020), only a handful of recent studies document MPs in the environment and biota; e.g. Abidli et al. (2017) and Abidli et al. (2019) from Tunisia; Shabaka et al. (2019) and Khan et al. (2020) from Egypt; Kosore et al. (2018) from Kenya; Akindele et al. (2019) from Nigeria; and Adika et al. (2020) from Ghana. In Tanzania the only study to investigate the presence of MPs within freshwater fish was conducted in Lake Victoria (Biginagwa et al., 2016). Thus, MP research in the African continent, aside from South Africa, is still in its infancy and more data is required (Khan et al., 2018; Jambeck et al., 2018). This lack of knowledge needs to be urgently addressed as Africa, particularly sub-Saharan Africa, experiences rapid population growth, urban expansion and consequently challenges in appropriate measures for waste disposal (Khan et al., 2018).

The present study was conducted along the Tanzanian coastline with the prevalence, abundance and characterization of MPs investigated from 18 and 8 sites for beach sediments and cockles (*Anadara antiquata*), respectively. Sediments have been described as a sink for MPs and have thus been extensively sampled worldwide (e.g. Ivar do Sul., 2009; Vianello et al., 2013; Nor and Obbard, 2014; Naji et al., 2017). The cockle species, *A. antiquata*, is a molluscan filter feeder that is native to the Tanzanian coast and consumed as a protein source (Mzighani et al., 2005). Based on their filter feeding behavior and close association with sediments, bivalves have been widely used as bioindicators of MP pollution (e.g. Van Cauwenberghe and Janssen, 2014; Van Cauwenberghe et al., 2015; Sparks, 2020). Edible bivalves have also been considered as an entry point for MPs into the human diet. *Anadara anticuata* is ingested as a source of protein and is a source of income for coastal communities along the Tanzanian coast (Mzighani et al., 2005). The presence of MPs in this commercially important species could have both potential human health and economic implications. The present study reports, for the first time, MPs in both sediment and biota from the Tanzanian coastline.

Materials and Methods

The Tanzanian coastline forms part of the Western Indian Ocean (WIO) region and is over 1400 km long. It is bordered by Kenya to the north and Mozambique to the south. In the present study 18 sites were sampled from seven coastal regions as follows: Mtwara (4 sites), Pwani (4 sites), Dar es salaam (3 sites), Tanga (3 sites), Lindi (2 sites), Mjini Magharibi, and Pemba Kasikazini (1 site each) (Fig. 1). The sample sites reflect a gradient of differing levels of anthropogenic activities from marine protected areas and park reserves (Ruvula and Juani Island East) to industrialized ports (Mtoni Kijichi Creek). The majority of the 18 sites are beaches which are open to fisheries, petty trade and/or recreational activities.

Table 1 provides a full list of the sites, their locations and descriptions, and the samples collected. Sediments were sampled from all 18 sites while cockles were collected from the 8 sites in which they were available. Sampling was conducted from September to December 2018 which coincides with the Southern monsoon (April-October) and Northern monsoon (November-March) seasons, respectively (Mahongo et al., 2012).

Sediment sampling and MP extraction using floatation in salt solution were conducted according to established methods (Nuelle et al., 2014; Quinn et al., 2017; Naji et al., 2017). At each site a beach section measuring 100 m and parallel to the shoreline was established. Samples were taken from the intertidal zone at low tide and three replicate sediment samples taken at each site. A 90cm x90cm square frame was placed randomly within the established area and the sediment taken from within the top 1 cm of the surface with a metal spoon (Naji et al., 2017). Sediment samples were folded in aluminum foil which was in turn placed in clean plastic bags, sealed tight, and stored in a cooler box. In the laboratory sediments were dried (60ºC overnight). One kg dry weight sediment (dw) from each sampling site was used for analysis. An initial visual inspection was made of the sediments to remove larger natural debris as well as plastic debris (>5 mm) which are excluded from the accepted definition of MPs (Arthur et al., 2009). MPs were separated from the sediments using density separation protocols with salt solution (NaCl (1.2 g/cm^3)) according to Quinn et al. (2017). Although not as effective as other brine solutions (NaI or $ZnBr_2$), NaCl has been proven to be a cost effective and sufficient method of separating MPs from sediment matrices (Quinn et al., 2017). Briefly, the sediment sample was added to the NaCl solution in a 3:1 ratio. The mixture was vigorously stirred in the beaker for several minutes with a spatula after which the solution was left to settle for 10 minutes allowing plastics with a density of $\leq$1.2 g/cm^3 to float or stay in suspension as the heavier sediment particles sank. All floating solids were collected on 0.5 mm mesh sieve. Each sediment sample underwent 3 repeat steps of density separation using the same NaCl solution. Between steps the salt solution was filtered (Whatman Grade 1 filter paper, 185mm, 11 µm pore size). MPs recovered from the 3 repetitions of density separation per sample were pooled and viewed under light dissection microscopes. MPs were enumerated and grouped according to MP type (fibers, fragments, films, pellets, foams or beads) (Tanaka and Takada, 2016) and color (white, black, blue, green, brown, red, pink, transparent and others).

Twenty individual cockles were collected from each of the 8 cockle sampling sites (Table 1). Cockles were hand-picked from the intertidal zone and transported to the laboratory where cockles were weighed and measured prior to dissection. The weight (46.7-66.8g) and length (30-60mm) ranges were consistent with previous reports of *A. antiquata* along Tanzanian coastline and indicated that the cockles were adults (Mzighani et al., 2005). Cockle tissue was dissected following the opening of the shells. Each soft tissue was placed into a glass test tube to which 10M NaOH was added. Test tubes were covered in foil and placed at 60ºC for 24 h. The digestion of organic tissue with 10 M NaOH has been proven to have an efficiency of >90% (Cole et al., 2014; Biginagwa et al., 2016) whilst having little impact on the MPs, especially when compared to strong acid digestion which can discolor or degrade plastics. Post-digestion, samples were cooled and then neutralized with an equal volume of 10M H_2SO_4 to avoid damaging the paper filters. The solution was then passed through Whatman Grade 1 filter paper (90mm diameter, 11µm pore size) using a vacuum pump attached to a glass vacuum filtration unit. Each filter was examined under a light dissection microscope (x40). MPs were visually identified as possessing unnatural coloration (such as bright blue) and/or unnatural shape (such as fragments with sharp edges) (Nor and Obbard, 2014). MPs found per individual were enumerated and categorized as fibers, fragments, films, pellets, foams or beads (Tanaka and Takada, 2016).

To ensure accurate determination of MP concentration in sediment and cockles, recognized quality assurance measures were taken (Torre et al., 2016; Hermabessiere et al., 2019). Briefly, all apparatus were made of glass or aluminum. All solutions were prepared under fume hood and covered by aluminum foil (Torre et al., 2016). White laboratory coats made of cotton were worn throughout. All glassware, tools, and bench surface were rinsed with filtered distilled water. Atmospheric blanks were performed at every step of sample processing as described by Wesch et al. (2017). The NaCl solution used to separate MPs from sediments was filtered through Whatman Grade 1 filter paper prior to use. Filter papers from both atmospheric blank samples and filtered salt solution were checked under light dissection microscope alongside field samples. No MPs were found on the blank samples.

The chemical composition of representative MPs was identified non-destructively using Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR) spectroscopy. ATR-FTIR has become a standard analytical technique to identify the chemical structure of the polymer component of plastic litter and microplastics larger than 0.5mm. To comply with this size constraint, only plastic particles that were at least 0.5mm in one dimension were analysed, limiting the sample size to 15 MPs collected from sediments. Samples were selected from the most abundant categories, determined after sorting and counting all the MPs. All spectra were run over 20 scans between 4000 and 650 cm^{-1} at a resolution of 4 cm^{-1} on a Bruker Alpha-p FTIR spectrometer (Bruker, Billirica, MA, USA) fitted with a solid diamond single-bounce internal reflectance element. Spectra were compared with reference standards run on the same instrument and processed using Opus software supplied by Bruker. To make a positive polymer identification we used the approach advocated by Frias et al. (2014) to only accept matches of >70%.

MPs in sediment are expressed as particles kg^{-1} (dry sediment) and thereafter type and color categories are expressed as percentages. The number of individual cockles containing MPs from each site is expressed as the frequency of occurrence of MPs (FO%,) as follows: FO%= (Ni/N)x100, where Ni is the number of individuals containing MPs and N is the total number of cockles from that site examined (Pegado et al. 2018). All statistical tests were performed in R (version 3.6.2), using RStudio (version 1.2.5033). Differences in MP abundance in sediments between sampled sites was analyzed by fitting a linear model to the data with sediment MP abundance as log-transformed dependent variable and site as independent variable. Checks were done to confirm that model assumptions (linearity, homoscedasticity, normally distributed and uncorrelated errors) were reasonably met. Multiple (Tukey all-pair) comparisons of means were performed using the glht function from the multcomp package. The relationship between FO and the number of MPs per cockle for different sites was investigated by fitting a linear model with cockle FO as dependent variable and sediment MP abundance as independent variable. One observation was found to be overly influential (MKC, Cook's distance = 469), and was removed before refitting the model with the remaining observations. The number of MPs per cockle was compared between the sites by fitting a negative binomial generalized linear model to the data using number of MPs per cockle as dependent and site as independent variables. Goodness of fit was evaluated with a chi-square test based on the residual deviance and degrees of freedom ($p = 0.43$).

Results and Discussion

MPs were found in the sediments of all 18 sampling sites along the Tanzanian coast (14681 individual MPs in total), but there was considerable spatial variation. The site of Mtoni Kijichi Creek (MKC) had the highest MP abundance with an average concentration of 2972±238 particles kg^{-1} dry sediment. This was significantly higher than the second highest MP abundance at Mission Cross Beach (MCB, 589±99 particles kg^{-1} dry sediment), which in turn was higher than all other sites (Linear model followed by Tukey all-pair comparisons of means, Fig. 2A). The remaining sites had MP abundances in the range of 15-214 particles kg^{-1} dry sediment, and there were pairwise differences between several of the other sites, see Fig. 2A and accompanying figure legend for complete between-group differences of means. The lowest MP abundance was found in the sediment of Ruvula (15±4 particles kg^{-1} dry sediment) which is situated within a marine park reserve and has limited anthropogenic activities (Table 1). The abundance of MPs at MKC is comparable to those reported from the beaches of Venice, Italy (2175 particles kg^{-1}, Vianello et al., 2013) and Kwazul-Natal beaches, South Africa (1490 particles kg^{-1}, Naidoo et al., 2015), but lower than the more polluted areas of the Beibu Gulf and coast of China Sea (8714 particles kg^{-1}, Qui et al., 2015). The other sites of the Tanzanian coast traverse the range present in the literature from Belgium (391 particles kg^{-1}, Claessens et al., 2011), Slovenia (156 particles kg^{-1}, Laglbauer et al., 2014), Singapore (37 particles kg^{-1}, Nor and Obbard, 2014) and America (15 particles kg^{-1}, Ivar Do Sul et al., 2009).

Between sites of the Tanzanian coast there was a general trend to suggest that the abundance of MPs in sediment reflect relative levels of industrialization and urban use (i.e. beach use); from the most industrial site of MKC, through the beaches used for fisheries and recreational activities (e.g. MCB, Kilindoni beach or Coco beach) to the protected area of Ruvula. The proximity to anthropogenic inputs has been found to be a key determinant of MP concentrations in numerous locations worldwide (Castillo et al., 2016; Naji et al., 2017). MKC is a port area of intensive industrial activity that is situated within Dar es Salaam. The site also receives storm water from Kizinga and Zinga rivers which flow through the industrial suburbs of Mbagala, Kurasini and Kigamboni. The geography of the port of Dar es Salaam can be described as an elongated and semi enclosed space. This may account for the high MP abundance as particles entering the area are likely to remain trapped by the limited tidal circulation and 'low-energy hydrodynamics' (Piazzolla et al., 2020). Similarly described areas have also been shown to have a build-up in MPs (e.g. Chesapeake Bay, U.S.A., Yonkos et al., 2014; Civitavecchia harbor, Italy, Piazzolla et al., 2020).

Fragments were the most abundant MP type (39% of all MPs found) and ranged from 29-86% across all sites (Fig. 2B). Fibers were also found in the sediments of each site (2-58%) and overall constituted 17% of all MPs found. Pellets constituted 33% of all MPs found, but were only present at one site in significant numbers (MKC). Sediments collected at MKC had a pellet burden of 1590±90 particles kg^{-1} dry sediment and the pellets were identical white polyethylene (Fig. 3). These pellets are typically used to extrude plastic products. The aforementioned industrial areas of Mbagala, Kurasini and Kigamboni which drain into MKC are home to plastic industries and likely use such pellets. The localization of a specific type of industrial pellet has been documented previously on shores of Arabian Gulf beaches (Khodagui and Abu-Hilal, 1994). The presence of these pellets also explain high proportion of white MPs (44% of all MPs), but different types of white MPs (primarily fragments) were also dominant across all sites (26-54%). Blue MPs were the only other color found at all sites (9-32% and 16% overall) (Fig. 2C).

Polymer identification by ATR-FTIR was restricted to a handful of representative samples (15 MPs collected from sediments) owing to the size limitation of the instrumentation. Polyethylene (PE) and polypropylene (PP) were the only polymers found. PE was discovered to be the polymer of the white pellets that were so abundant at MKC (Fig 3). Whilst it is not possible to deduce the source of MPs based on polymer identification, particularly in the case of secondary MPs (such as fragments), PE and PP are variously used in a multitude of commercial and industrial plastic products that are likely to enter the aquatic environment.

MPs were found in cockles from all sites from which they were collected with 48% of all cockles analyzed (n=160) found to contain MPs. A total of 138 MPs were recovered from cockle tissue. Again, variability was found between sites with the FO% ranging from 20-85% (Fig. 4A).The site with the highest FO% was the site with highest MP abundance, MKC. When the linear relationship between MP abundance in the sediment and FO% was investigated, the presence of MKC in the analysis produced a significant positive relationship (R^2=0.55, p=0.04). This site represented a highly influential observation (Cook’s distance = 469), and when removed, the relationship was not significant (R^2=0.18, p=0.34, Fig. 4B) suggesting that, overall, environmental and biota concentrations were not linked. Moreover, the average number of MPs per individual was significantly higher at MKC than the other sites, with an average of 2.1±1.8 particles individual^{-1} (range 0-5 particles individual^{-1}) (Negative binomial generalized linear model, p = 0.001, Fig. 4C). For the remaining sites mean particle numbers were relatively consistent with means $\leq$ 1 particles individual^{-1}. Comparisons with the literature show that the number of MPs per individual along the Tanzanian coast to be at the lower end of the scale and although similar to mussels sampled in Norway (1.8 particles individual^{-1}, Lusher et al., 2017) are well below the MPs found across bivalve species in China (4.3-57.2 particles individual^{-1}, Li et al., 2015). In these studies, as well as those reporting MP abundances in bivalves from the coasts of Belgium (Van Cauwenberghe et al., 2015), Germany (Van Cauwenberghe and Jansen, 2014) and South Africa (Sparks, 2020) fibers and fragments were the only MPs found. Here, 75% of MPs ingested by cockles were fibers and 25% fragments, despite fragments being more abundant in the sediment. This may suggest the active selection of fibers by *A. antiquate*, but such an ascertain would require verification.

In conclusion, MPs were found at all sampling sites along the Tanzanian coast. Greatest abundances in both sediments and cockles were found at MKC, an industrial port, but overall there was no strong correlation linking environmental and biotic concentrations. The present study is only 'snapshot in time' of MP pollution in this region, but longitudinal studies are required to fully understand the prevalence of MPs. This study is particularly prescient as Tanzania, and Africa in general, engages with the issue of plastic pollution (Jambeck et al., 2018) and serves to provide a baseline for future work.

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References

Abidli S, Toumi H, Lahbib Y, El Menif NT (2017) The first evaluation of microplastics in sediments from the complex lagoon-channel of Bizerte (Northern Tunisia). Wat Air Soil Pollut 228: 262.

Abidli S, Lahbib Y. El Menif NT (2019) Microplastics in commercial molluscs from the lagoon of Bizerte (Northern Tunisia). Mar Pollut Bull 142: 243-252.

Adika SA, Mahu E, Crane R, Marchant R, Montfor J, Folorunsho R. Gordon C (2020) Microplastic ingestion by pelagic and demersal fish species from the Eastern Central Atlantic Ocean, off the Coast of Ghana. Mar Pollut Bull 153:110998.

Akindele EO, Ehlers SM, Koop JH (2019) First empirical study of freshwater microplastics in West Africa using gastropods from Nigeria as bioindicators. Limnologica 78:125708.

Arthur C, Baker J, Bamford H (2009). Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris, September 9–11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Biginagwa F J, Mayoma BS, Shashoua Y, Syberg K, Khan FR (2016) First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia. J Great Lakes Res 42: 146-149.

Blettler MCM, Abrial E, Khan FR, Sivri N, Espinola LA (2018) Freshwater plastic pollution: recognizing research biases and identifying knowledge gaps. Water Res 143: 416-424.

Castillo, AB, Al-Maslamani I, Obbard JP (2016) Prevalence of microplastics in the marine waters of Qatar. Mar Pollut Bull 111: 260–267.

Claessens M, De Meester , Van Landuyt L, De Clerck K, Janssen CR (2011) Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Mar Pollut Bull 62: 2199-2204.

Cole M, Webb H, Lindeque PK, Fileman ES, Halsband C, Galloway TS (2014) Isolation of microplastics in biota-rich seawater samples and marine organisms. Sci Rep 4: 4528.

Derraik JG, (2002) The pollution of the marine environment by plastic debris: a review. Mar Pollut Bull 44:842-852.

Frias JP, Otero V, Sobral P (2014) Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. Mar Environ Res 95: 89–95

Hermabessiere L, Paul-Pont I, Cassone AL, Himber C, Receveur J, Jezequel R, El Rakwe M, Rinnert E, Rivière G, Lambert C, Huvet A (2019) Microplastic contamination and pollutant levels in mussels and cockles collected along the channel coasts. Environ Pollut 250:807-819.

Ivar Do Sul JA, Spengler A, Costa MF (2009) Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). Mar Pollut Bull 58:1236-1238.

Ivar do Sul JA, Costa MF (2014) The present and future of microplastic pollution in the marine environment. Environ Pollut 185: 352-364.

Jambeck J, Hardesty BD, Brooks AL, Friend T, Teleki K, Fabres J, Beaudoin Y, Bamba A, Francis J, Ribbink AJ, Baleta T (2018) Challenges and emerging solutions to the land-based plastic waste issue in Africa. Mar Pol, 96: 256-263.

Khan FR, Mayoma BS, Biginagwa FJ, Syberg K. (2018) Microplastics in Inland African Waters: Presence, Sources, and Fate. In: Freshwater Microplastics. The Handbook of Environmental Chemistry: Wagner M., Lambert S. Springer, Heidelberg, Germany, 2018, Volume 58, pp. 101-124.

Khan FR, Shashoua Y, Crawford A, Drury A, Shepard K, Stewart K, Sculthorp T (2020). 'The Plastic Nile': First evidence of microplastic contamination in fish from the River Nile (Cairo, Egypt). Toxics 8: 22

Khordagui HK, Abu-Hilal AH (1994) Industrial plastic on the southern beaches of the Arabian Gulf and the western beaches of the Gulf of Oman. Environ Pollut 84: 325-327.

Kosore C, Ojwang L, Maghanga J, Kamau J, Kimeli A, Omukoto J, Ngisiag'e N, Mwaluma J, Ong'ada H, Magori C, Ndirui E (2018) Occurrence and ingestion of microplastics by zooplankton in Kenya's marine environment: first documented evidence. Afr J Mar Sci 40:225-34.

Laglbauer BJL, Franco-Santos RM, Andreu-Cazenave M, Brunelli L, Papadatou M, Palatinus A, Grego M, Deprez T (2014) Macrodebris and microplastics from beaches in Slovenia. Mar Pollut Bull 89:356-366.

Li JN, Yang DQ, Li L, Jabeen K, Shi HH (2015) Microplastics in commercial bivalves from China. Environ Pollut 207:190–195

Lusher A, Bråte ILN, Hurley R, et al (2017) Testing of methodology for measuring microplastics in blue mussels (Mytilus spp.) and sediments, and recommendations for future monitoring of microplastics (R & D-project)

Mahongo SB, Fransis J, Osime SE (2012) Wind patterns of Coastal Tanzania. Their Variability and Trends. Western Indian Ocean J Mar Sci 10: 107-120.

Mzighani S (2005) Fecundity and population structure of cockles, Anadara antiquate L. 1758 (Bivalvia: Arcidae) from a sandy/ muddy beach near Dar es Salaam, Tanzania. West Indian Ocean J Mar Sci 4:77–84

Naidoo T, Glassom D, Smit AJ (2015) Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa. Mar Pollut Bull 101:473–480

Naji A, Esmali Z, Khan FR (2017) Plastic debris and microplastics along the beaches of the Strait of Hormuz, Persian Gulf. Mar Pollut Bull 114: 1057-1062.

Nel HA, Froneman PW (2015) A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. Mar Pollut Bull 101:274–279

Nor NHM, Obbard JP (2014) Microplastics in Singapore's coastal mangrove ecosystems. Mar Pollut Bull 79: 278-283.

Nuelle M-T, Dekiff JH, Remy D, Fries E (2014) A new analytical approach for monitoring microplastics in marine sediments. Environ Pollut 184:161-169.

Pegado T de S e S, Schmid K, Winemiller KO, Chelazzi D, Cincinelli A, Dei L, Giarrizzo T (2018) First evidence of microplastic ingestion by fishes from the Amazon River estuary. Mar Pollut Bull 133: 814-821.

Piazzolla D, Cafaro V, Mancini E, Scanu S, Bonamano S, Marcelli M (2020). Preliminary investigation of microlitter pollution in low-energy hydrodynamic basins using *Sabella spallanzanii* (Polychaeta: Sabellidae) tubes. Bull Environ Contamin Toxicol, 104, 345-350.

Qiu Q, Peng J, Yu X, Chen F, Wang J, Dong F (2015) Occurrence of microplastics in the coastal marine environment: First observation on sediment of China. Mar Pollut Bull 98: 274-280

Quinn B, Murphy F, Ewins C, (2017) Validation of density separation for the rapid recovery of microplastics from sediment. Analytical Methods 9:1491-1498

Ryan PG (1988) The characteristics and distribution of plastic particles at the sea-surface off the southwestern Cape Province, South Africa. Mar Environ Res 25:249–273

Ryan PG, Moloney CL (1990) Plastic and other artefacts on South African beaches: Temporal trends in abundance and composition. S AFR J SCI/S-AFR TYDSKR WET 86:450-452.

Shabaka SH, Ghobashy M, Marey RS (2019) Identification of marine microplastics in Eastern Harbor, Mediterranean Coast of Egypt, using differential scanning calorimetry. Mar Pollut Bull 142: 494-503.

Sparks C, (2020) Microplastics in Mussels Along the Coast of Cape Town, South Africa. Bull Environ Contam Toxicol In press.

Tanaka K, Takada H (2016) Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Sci Rep 6:34351

Torre M, Digka N, Anastasopoulou A, Tsangaris C, Mytilineou C (2016) Anthropogenic microfiber pollution in marine biota. A new and simple methodology to minimize airborne contamination, Mar Pollut.Bull 113: 55-61.

Van Cauwenberghe L, Janssen CR (2014) Microplastics in mussels cultured for human consumption. Environ Pollut 193:65–70

Van Cauwenberghe L, Claessens M, Vendegehuchte MB, Janssen CR (2015) Microplastics are taken up by mussels (Mytilus edulis) and lugworms (Arenicola marina), living in natural habitats. Environ Pollut 199:10–17

Vianello A, Boldrin A, Guerriero P, Moschino V, Rella R, Sturaro A, Da Ros L (2013) Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification. Estuar Coast Shelf Sci 130:54-61.

Wesch C, Elert AM, Wörner M, Braun U, Klein R, Paulus M (2017) Assuring quality in microplastic monitoring: About the value of clean-air devices as essentials for verified data. Sci Rep 7:1-8.

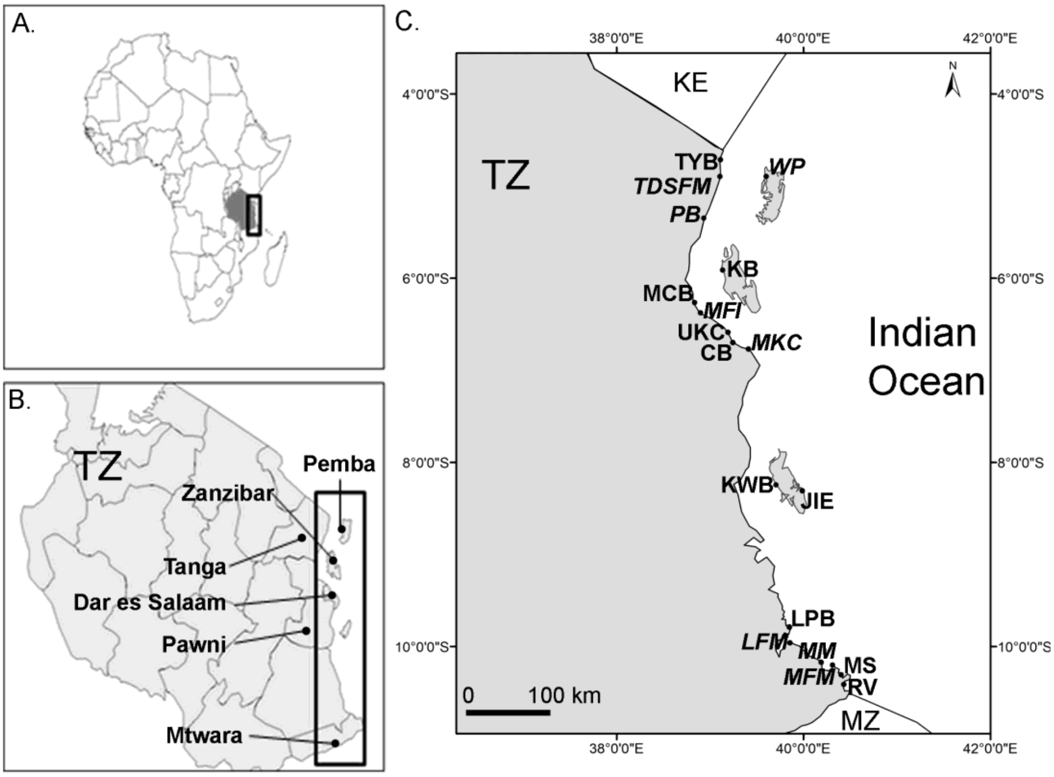
Yonkos LT, Friedel EA, Perez-Reyes AC, Ghosal S, Arthur CD (2014) Microplastics in Four Estuarine Rivers in the Chesapeake Bay , U.S.A . Eviron Sci Technol 48:14195-1402

Fig 1. MP sampling sites along the coast of Tanzania. Regions (B) and sampling sites (C) are shown. For site abbreviations refer to Table 1. Sites from which both sediment and cockles were collected are denoted by italic lettering. (TZ=Tanzania, KE=Kenya, MZ=Mozambique)

Fig 2. Abundance, type and color properties of MPs sampled from 18 sites along the Tanzanian coast. (A) MP abundance in sediment samples (particles kg^{-1} dry sediment, mean value ± standard deviation, n=3). Lettering denotes significant differences between sites (Linear model followed by Tukey all-pair comparison of means). Type (B) and color (C) percentage distributions of MPs collected at each site. For site abbreviations refer to Table 1.

Fig 3. Examples of MPs from sediment samples and associated ATR-FTIR spectra: blue polyethylene fragment (A), green polypropylene fragment (B) and white polyethylene pellet (C). Sample spectra are shown in blue and compared with known reference samples in red. Scale bars represent 5 mm.

Fig 4. Prevalence and abundance of MPs in cockles (*Anadara antiquata*). (A) FO% of the number of individual cockles containing MPs from each site (n=20 individuals per site). (B) Correlation between sediment MP abundance (particles kg^{-1} dry sediment) and FO% was shown to be significant when MKC was included (inset, linear model, $R^2=0.55$, p=0.04), but without the influence of this site with an extremely high sediment abundance the relationship was not significant (linear model, $R^2=0.18$, p=0.34). (C) Number of MPs per individual (particles $individual^{-1}$, n=20 for each site). The boxplots display minimum/first quartile (= 0 for all sites), median, third quartile and maximum (upper whisker). Observations more than 1.5 times the interquartile range above the third quartile are considered outliers and are shown with black points. Crosses signify mean values. Stars denote a significant difference from the other sites (Negative binomial generalized linear model, p = 0.001).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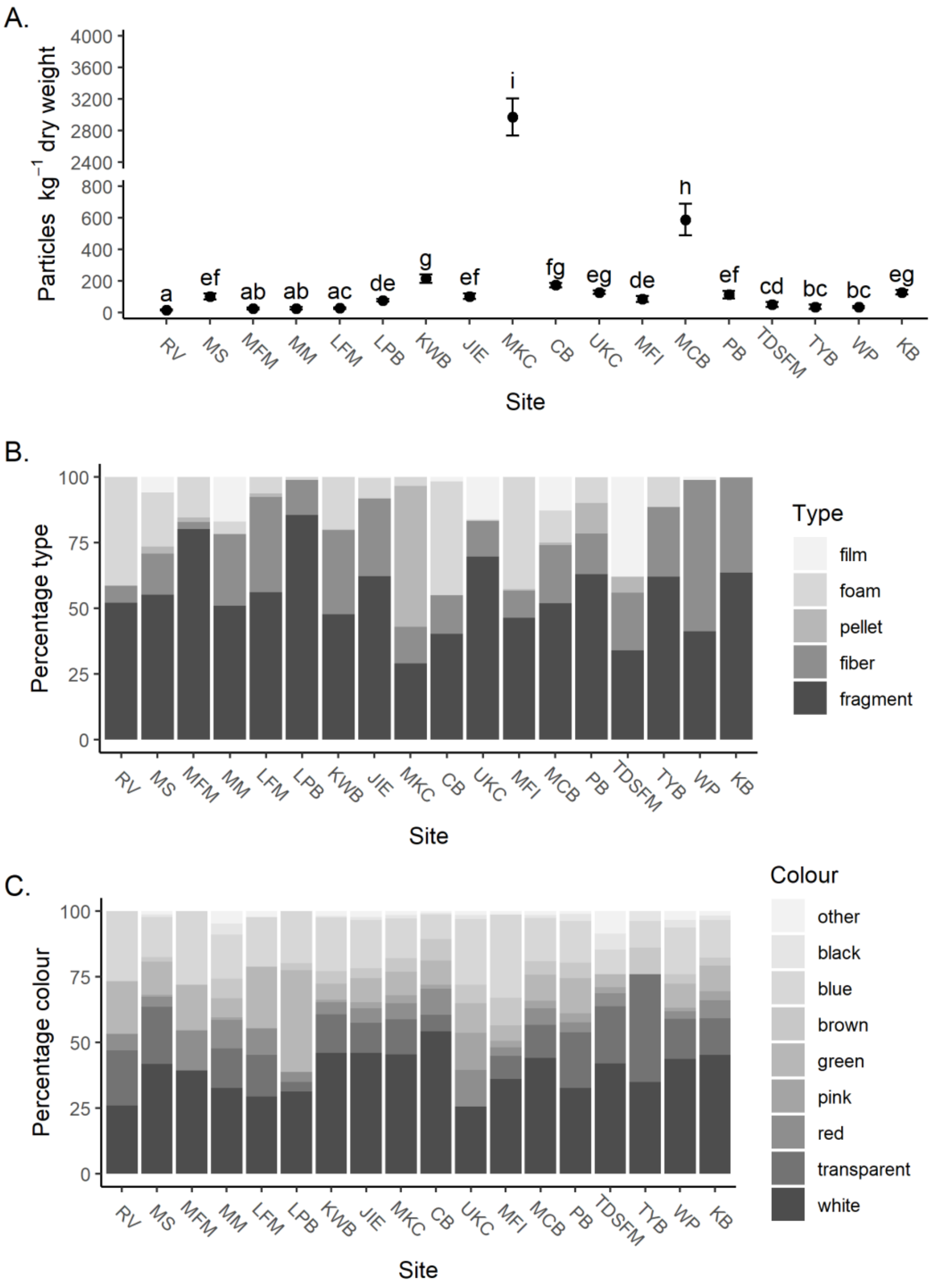
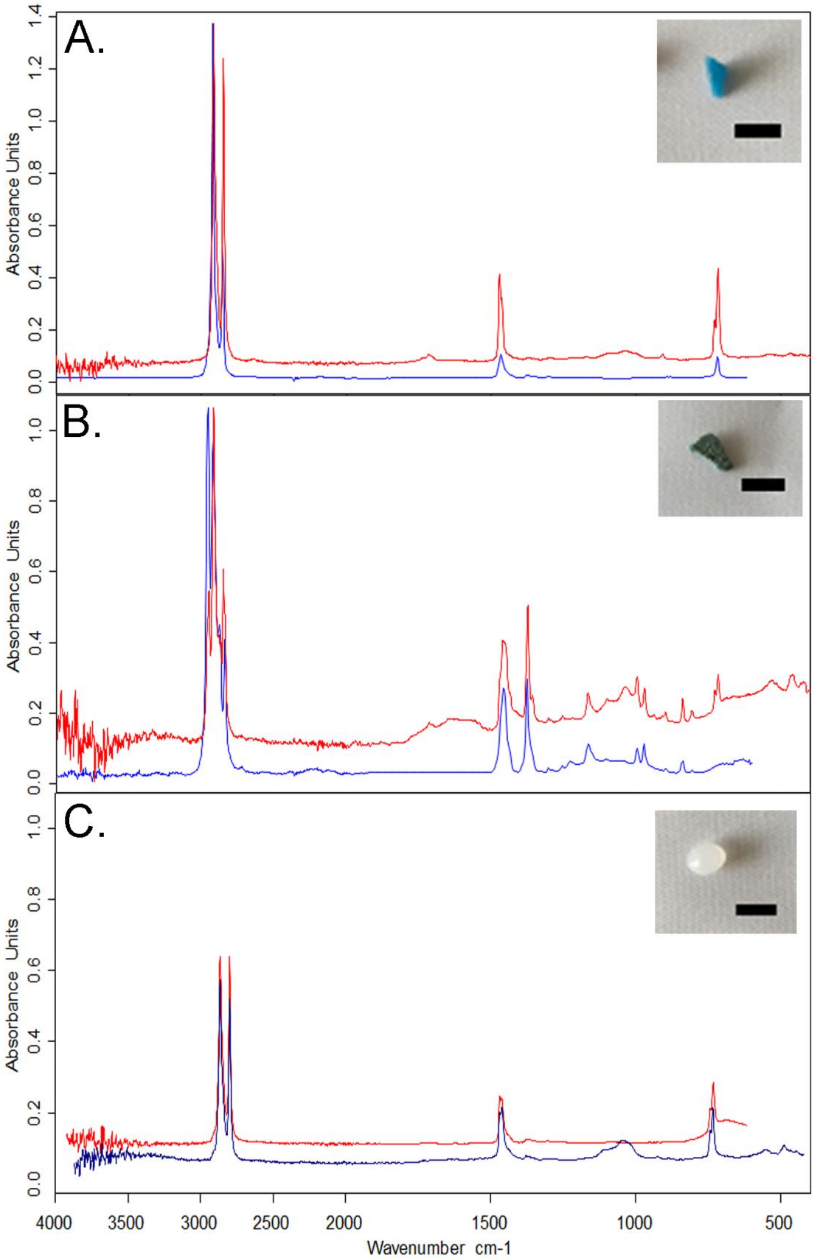
MCB
MFI
UKC
CB
MKC
Indian Ocean
KWB
JIE
LPB
LFM
MM
MFM
MS
RV
MZ
0
100 km



A.
Particles kg^{-1} dry weight
4000
3600
3200
2800
2400
800
600
400
200
0
a
ef
ab
ab
ac
de
g
ef
i
fg
eg
de
h
ef
cd
bc
bc
eg
RV
MS
MFM
MM
LFM
LPB
KWB
JIE
MKC
CB
UKC
MFI
MCB
PB
TDSFM
TYB
WP
KB
Site
B.
Percentage type
100
75
50
25
0
Type
film
foam
pellet
fiber
fragment
RV
MS
MFM
MM
LFM
LPB
KWB
JIE
MKC
CB
UKC
MFI
MCB
PB
TDSFM
TYB
WP
KB
Site
C.
Percentage colour
100
75
50
25
0
Colour
other
black
blue
brown
green
pink
red
transparent
white
RV
MS
MFM
MM
LFM
LPB
KWB
JIE
MKC
CB
UKC
MFI
MCB
PB
TDSFM
TYB
WP
KB
Site


A.
B.
C.
Absorbance Units
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
4000
3500
3000
2500
2000
1500
1000
500
Wavenumber cm-1

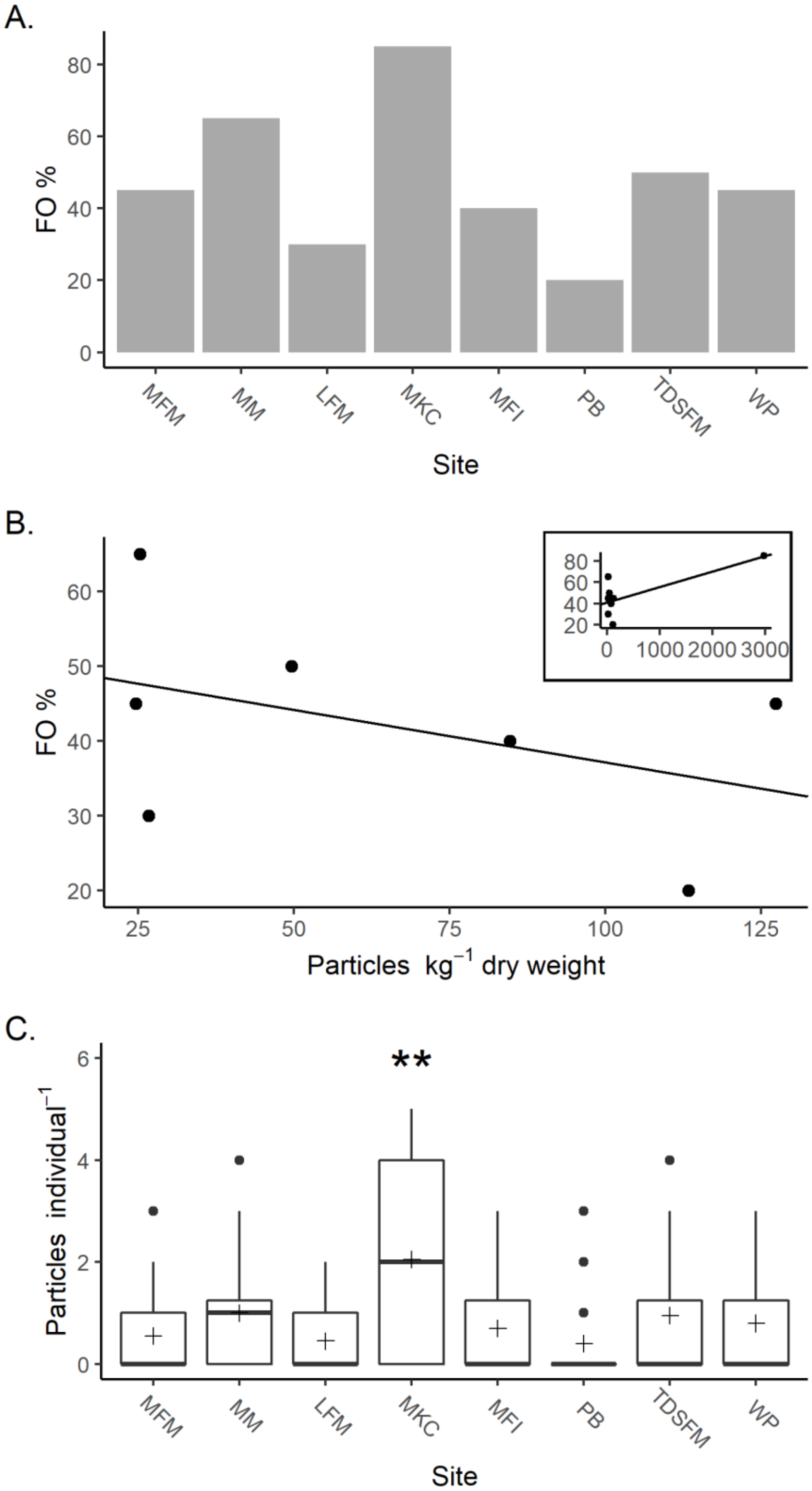

A.
FO %
80
60
40
20
0
MFM
MM
LFM
MKC
MFI
PB
TDSFM
WP
Site
B.
FO %
60
50
40
30
20
25
50
75
100
125
Particles kg^{-1} dry weight
80
60
40
20
0
1000
2000
3000
C.
Particles individual^{-1}
6
4
2
0
**
MFM
MM
LFM
MKC
MFI
PB
TDSFM
WP
Site

Table 1.Location of sampling sites along the Tanzanian coastline (Abbrev.= Abbreviation; UDSM=University of Dar es Salaam)

#	Site name	Abbrev.	Location (longitude, latitude)	Region	Description and main anthropogenic activities	Samples collected
1	Ruvula	RV	-10.313129, 40.39121	Mtwara	Sandy beach located within marine park reserve, limited fisheries and recreational activities.	Sediment
2	Msimbati	MS	-10.337339, 40.432096	Mtwara	Sandy beach, public, exposed to open sea, dominated by fisheries and recreational activities.	Sediment
3	Mtwara Fish Market	MFM	-10.26498, 40.18892	Mtwara	Sandy beach, dominated by ferry transport, landing site and fish trade.	Sediment and cockle
4	Mtwara Mikindani	MM	-10.272875, 40.109534	Mtwara	Sandy beach, dominated by ferry transport, fishing, petty trade and boat making.	Sediment and cockle
5	LindiFish Market	LFM	-9.998842, 39.719186	Lindi	Sandy beach, dominated by ferry transport, landing site and petty trade.	Sediment and cockle
6	Lindi Public Beach	LPB	-9.989072, 39.711838	Lindi	Sandy beach, dominated by recreational activities and petty trade.	Sediment
7	Kilindoni West Beach	KWB	-7.920862, 39.645884	Pwani	Sandy beach, near estuary, dominated by recreational activities, landing sites and petty trade.	Sediment
8	Juani Island East	JIE	-7.992872, 39.802617	Pwani	Sandy beach located within marine park reserve, limited human activities, exposed to open sea.	Sediment
9	Mtoni Kijichi Creek	MKC	-6.865375, 39.297382	Dar es Salaam	Muddy/sandy beach, near Mtoni estuary to the South and Dar es Salaam port to the North. Receives storm water from Kizinga and Zinga rivers, limited recreational activities.	Sediment and cockle
10	Coco Beach	CB	-6.768165, 39.282021	Dar es Salaam	Sandy beach dominated by recreational activities and petty trade.	Sediment
11	UDSM Kunduchi Campus	UKC	-6.661819, 39.217368	Dar es Salaam	Sandy beach dominated by recreational activities and petty trade.	Sediment
12	Mbegani Fisheries Institute	MFI	-6.473806, 38.972535	Pwani	Sandy beach, semi enclosed bay, limited fisheries and recreational activities.	Sediment and cockle
13	Mission Cross Beach	MCB	-6.432924, 38.905671	Pwani	Sandy beach, exposed to open sea, characterized by intensive recreational activities, fisheries and petty trade.	Sediment
14	Pangani Beach	PB	-5.430106, 38.982362	Tanga	Sandy beach, dominated by recreational activities and fisheries.	Sediment and cockle
15	Tanga Deep Sea Fish Market	TDSFM	-5.067407, 39.09773	Tanga	Sandy beach, dominated by fisheries activities including landing site, nets repair and petty trade.	Sediment and cockle
16	Tanga Yacht Beach	TYB	-5.059103, 39.119683	Tanga	Sandy/gravel beach, privately operated, dominated by recreational activities, regular beach clean ups and petty trade.	Sediment
17	Wete Pwani	WP	-5.06146, 39.71816	Pemba Kaskazini	Sandy beach, located within a bay, limited recreational activities, receives land based inputs from nearby Wete town.	Sediment and cockle
18	KizingoBeach	KB	-6.178122, 39.199053	Mjini Magharibi	Sandy beach, located in urban area, characterized by land based inputs from nearby settlements, fishing and recreational activities.	Sediment

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