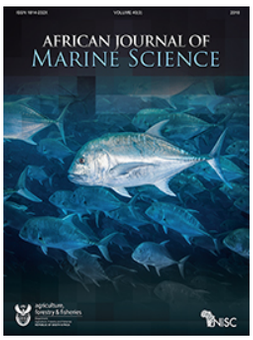

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Occurrence and ingestion of microplastics by zooplankton in Kenya's marine environment: first documented evidence

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Microplastics can be ingested by marine organisms and may lead to negative impacts at the base of marine food chains. This study investigated the occurrence and composition of microplastics in the sea-surface water and sought evidence of ingestion by zooplankton. Surface seawater was collected using a stainless-steel bucket and sieved directly through a stainless-steel sieve (250-µm mesh), while a 500-µm mesh net was towed horizontally to collect zooplankton, at 11 georeferenced stations off the Kenyan coast in February 2017, on board the national research vessel RV *Mtafiti*. Microplastic particles were sorted and characterised using an Optika dissecting microscope. Polymer types were identified using an ALPHA Platinum attenuated total reflection—Fourier-transform infrared (ATR-FTIR) spectrometer. A total of 149 microplastic particles, with an average abundance of 110 particles m^{-3}, were found in the surface seawater. A total of 129 particles were found ingested by zooplankton groups, where Chaetognatha, Copepoda, Amphipoda and fish larvae ingested 0.46, 0.33, 0.22 and 0.16 particles $ind.^{-1}$, respectively. Filaments dominated both the surface-water microplastics and the ingested microplastics, contributing 76% and 97% to those compositions, respectively. White particles were prevalent in the water (51%), whereas black was the colour found most commonly (42%) across the zooplankton groups. The sizes of particles that were in the water were in the range of 0.25–2.4 mm, and those ingested ranged between 0.01 and 1.6 mm. Polypropylene was predominant in the surface water, whereas low-density polyethylene was the most-ingested polymer type. The results provide the first documented evidence of the occurrence, composition and ingestion of microplastics by zooplankton in Kenya's marine environment, indicating that microplastics have the potential to enter pelagic food webs and cause pollution in the study area.

Keywords: georeferencing, infrared spectroscopy, Kenyan EEZ, low-density polyethylene, ocean pollution, polymer, polypropylene, sea surface

Introduction

Pollution of oceans by plastics represents an increasing concern for both science and society. Global production of plastics has shown a steady increase since 1950, reaching 311 million tons in 2014 (Frere et al. 2017; Law 2017). Plastics accumulate in marine environments and become the primary constituents (60–80%) of all marine debris and constitute about 90% of floating debris worldwide (Retama et al. 2016; Frere et al. 2017). Plastic is a general term that refers to a family of organic polymers derived from petroleum sources, including polyvinylchloride (PVC), nylon, polyethylene (PE), polystyrene (PS) and polypropylene (PP), with common plastic polymers being PP, PE, low-density polyethylene (LDPE) and polyacrylates (Law 2017). Plastic polymers that are positively buoyant in seawater are retained at the sea surface, where they are dispersed before becoming entrapped in areas of low circulation, and finally sink after entanglement and biofouling (Castillo et al. 2016; Zobkov et al. 2017).

Usage patterns suggest that plastic production and quantities of plastics in aquatic environments will likely continue to increase over time (Anderson et al. 2016), with their source regions being largely centred around areas of anthropogenic activity and more-densely populated regions (Clark et al. 2016), and with plastics entering the sea via beaches, rivers, stormwater runoff, agricultural and industrial sewage, wastewater discharge or transport by wind. Maritime activities contribute through the materials lost by commercial and recreational fishing, and the debris dumped by freight and cruise ships (Castillo et al. 2016; Avio et al. 2017).

The combination of multiple inputs and diffuse sources could result in spatiotemporal variability in the distribution of floating plastic in surface waters (Kang et al. 2015). The exact quantity of plastic in the ocean and of volumes entering the ocean from waste generated on land is unknown. Recent studies estimate that 275 million tonnes of plastic waste was generated in 192 coastal countries in 2010, of which 4.8–12.7 million metric tons might have entered the ocean (Maes et al. 2017). The majority of marine plastics are considered to originate from land-based sources (Wang et al. 2017).

When plastic waste is exposed to UV radiation and mechanical forces, the plastic slowly breaks down into smaller and smaller fragments, known as secondary

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microplastics, of irregular shapes and sizes, which are the main form of plastic debris found in the environment (Avio et al. 2017; Maes et al. 2017). Raw plastic pellets and granules, plastics from products such as facial cleansers or the synthetic fibres released from textiles as a result of washing clothes, and other plastics that come into the environment in intact form are called primary microplastics (Zhao et al. 2014; Alomar et al. 2016; Avio et al. 2017; Maes et al. 2017; Rodríguez-Seijo and Pereira 2017; Zobkov et al. 2017).

Various studies have shown that microplastics are now distributed in all oceans, occurring on shorelines, in sediments and in surface waters, even in remote locations (e.g. Arctic) and at all depths (Cincinelli et al. 2017). At present there is no universally agreed nomenclature for the various sizes of plastic. Although the term microplastics is often used generically to refer to any small pieces of plastic, it is becoming more common to restrict this term to those particles smaller than 5 mm in diameter. Various researchers have proposed dividing microplastics into small microplastics (0.1–1 mm) and large microplastics (1–5 mm), creating practical categories that more accurately reflect the ability to collect and sort such material. The term macroplastics generally refers to larger plastic objects (2.5 cm–1 m) that are still recognisable products, such as bottles, containers, toys and buoys. Particles that are larger than 5 mm but smaller than 2.5 cm may reasonably be termed mesoplastics (Young and Elliott 2016).

Microplastics can be ingested by a wide range of marine organisms, such as filter-feeders or higher-level predators, and thus negative impacts of microplastics at the base of the marine food chain are likely to occur (Kang et al. 2015; Clark et al. 2016). For instance, ingested plastic debris negatively affects seabirds and other marine wildlife in a number of ways, including direct effects such as nutritional deprivation and physical damage to the digestive tract (Atoll et al. 2016). Microplastics are found in high abundance in surface waters, which marine zooplankton predominantly inhabit when feeding, increasing the potential for them to be ingested. Zooplankton are a vital source of food for secondary consumers (e.g. fish, cetaceans), and, as such, might represent a route via which microplastics enter the food web, posing a risk to secondary producers and apex predators and, potentially, to human health (Steer et al. 2017). Furthermore, the small dimensions of microplastics and their occurrence in a wide variety of colours and shapes, including possible similarity to food sources, render them available for ingestion by organisms commonly unaffected by larger marine debris (Collignon et al. 2014). Therefore, there is a need to obtain information on the ingestion and transfer of microplastics by different groups of zooplankton in order to lay a foundation for the ecological risk assessment of microplastics in the marine environment (Sun et al. 2017).

To effectively address the issue of microplastics in the marine environment, information on their abundance, distribution and composition in the world's oceans is required. Data collected from the natural environment are particularly important as they (i) provide an indication of the extent of the problem and (ii) inform laboratory studies by providing information on the environmentally relevant concentrations of microplastics that biota are exposed to in the natural environment. For example, information about microplastics at coastal upwelling sites in the Atlantic Ocean is important as it could provide (i) an indication of the probability of encounter between organisms and microplastics at such sites and (ii) insight into the potential effect of oceanographic phenomena such as upwelling on microplastics in the world's oceans (Kanhai et. al. 2017). The occurrence and ingestion of microplastics by zooplankton in Kenya's marine environment is basically unknown, particularly in the exclusive economic zone (EEZ), located offshore of the country's territorial waters, which is the largest oceanic region in Kenya. The aim of this study was to conduct the first investigation on the occurrence, abundance and composition of waterborne microplastics and to provide evidence of ingestion of microplastics by zooplankton in Kenya's marine environment.

Materials and methods

Study area

The Kenyan coastline extends from the Kenya–Somalia border in the north (1.7° S, 41.5° E) to the Kenya–Tanzania border in the south (4.7° S, 39.2° E) (Figure 1). The country's territorial waters extend 12 nautical miles from the coast and offshore is a 200-nautical mile EEZ, with a combined total area of 142 400 km^2. The marine climate is influenced by two seasonal wind regimes, or monsoons. The southeast monsoon lasts from April to October and is associated with high rainfall (55–272 mm) and a temperature range of 20–31 °C. The shorter northeast monsoon lasts from November to March and is characteristically drier (8–84 mm of rainfall) and hotter (23–32 °C). The coastal waters are influenced by the northward-flowing East Africa Coastal Current and the southward-flowing North Equatorial Current.

Sampling

Surface-water microplastics

Bulk surface seawater samples were collected from 11 georeferenced stations in the central part of Kenya's EEZ (Figure 1). The sampling exercise was conducted during the northeast monsoon, between 6 and 21 February 2017, on board the RV *Mtafiti* national research vessel. One sample was collected at each site using a 15-l stainless steel bucket to collect a total volume of 120 l or 0.12 m^3 of water, which was sieved directly through a 250-µm stainless steel mesh. The samples were transferred into glass jars containing 70% ethanol for preservation and to help discolour the organisms, hence facilitating the identification of microplastics (Kovač Viršek et al. 2016).

Zooplankton

One zooplankton sample was collected from each station by horizontally towing a zooplankton net with a 500-µm mesh and a General Oceanics flowmeter attached to the mouth. Towing was conducted at a speed of 0.5–1.8 knots for a period of 20–30 minutes. The net was retrieved and rinsed with seawater in order to collect all zooplankton, which were then transferred into glass jars containing 70%

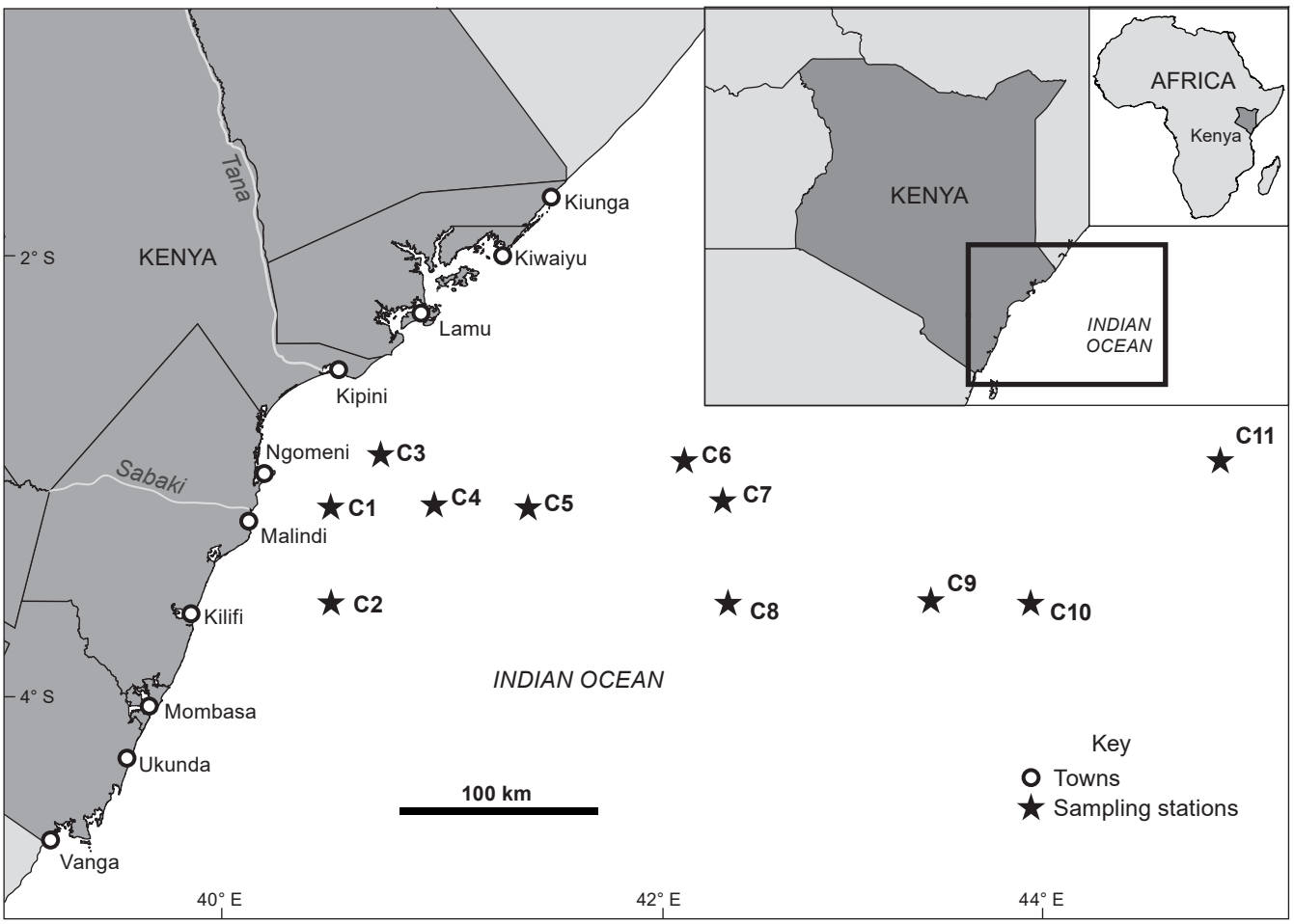

Figure 1: Map showing the study area and locations of the 11 sampling stations (C1–C11)

ethanol. The samples were transported to the laboratory for further processing and analysis.

Oceanographic and environmental factors

Sampling locations were recorded in degree decimals using an onboard differential global positioning system (DGPS) instrument. Wind direction and speed were measured using a Furuno Nasta wind vane, and salinity, sea surface temperature (SST) and pH were recorded *in situ* using a HANNA multiparameter pH/EC/TDS/salinity/temperature meter.

Laboratory analyses

Microplastics extraction from sea-surface water

Surface-water microplastics were extracted by filtering samples through 0.7-µm GF/F Whatman Filter Paper using a Pall Filtration Unit connected to a Rocker 400 Vacuum Pump. The filters were dried in a stainless steel vertical laminar flow hood (Crichton et al. 2017) and then placed in glass petri dishes and stored at –20 °C until analysed (Cincinelli et al. 2017). The individual dried filters were visually inspected under a dissecting microscope (Optika, Italy), at ×20 magnification, to count the microplastic particles and then categorise them based on morphological characteristics, such as shape (filament/fibre, fragment, pellet, granule, film or foam), colour (black, blue, green, brown, orange, pink, red, transparent, white or yellow) and size (see Castillo et al. 2016; Kanhai et al. 2017; Maes et al. 2017). The microscope was equipped with an Optikam B2 digital camera to photograph and measure the sizes of particles, using Optika Vision Lite 2.1 and MIPro Standard 1.2 software, respectively. The total number of particles identified were recorded for each shape, colour and size category (Kovač Viršek et al. 2016). Microplastics abundance in surface water was calculated according to Duis and Coors (2016) as the number of microplastic particles per unit volume (m^{-3}). A subsample was selected and analysed for polymer type, using ALPHA Platinum attenuated total reflection–Fourier-transform infrared (ATR-FTIR) spectroscopy. During the sorting exercise, natural materials remaining at the picking stage, such as diatom tests and salt crystals, might be mistaken for microplastics. This problem was solved by dragging forceps across the particles: if they powdered or fell apart, they were not plastic materials. If the particles retained their shape, then they were properly identified as microplastics (Masura et al. 2015; Peng et al. 2017). Mesoplastics (particles >5 mm) were not included in our results.

Zooplankton samples

Zooplankton samples per station were counted under the dissecting microscope, during which process 10 individuals were selected from each of the four groups (Chaetognatha, Copepoda, Amphipoda and fish larvae) on the basis of the important roles of these organisms in marine food webs (Clark et al. 2016; Steer et al. 2017; Sun et al. 2017). The individuals in each group were further examined under the microscope to determine whether there were any microplastic particles adhering to them, and if so the particles were removed with tweezers (Desforges et al. 2015). Digestion of the zooplankton groups to determine the ingested microplastics was performed following the technique of Castillo et al. (2016). The 10 individuals from each group were placed in glass scintillation vials containing 20 ml 1M NaOH and digested on a horizontal water-bath shaker at room temperature for 24 h, followed by heating at 60 °C for 2 h, and then further heating at 100 °C for 30 min. After digestion the samples were cooled to room temperature and vacuum-filtered through 0.7-µm GF/F Whatman Filter Paper. The dried filtrides were dried further in a vertical stainless steel laminar flow hood, and then microscopically inspected for the presence of microplastic particles, which were then counted, characterised and photographed, and subsamples were analysed for polymer type using ATR-FTIR. Ingested microplastics were quantified as particles per individual zooplankton group.

ATR-FTIR identification of polymers

Subsamples of microplastic particles, consisting of nine particles (seven in the size range 1.1–1.7 mm, and two in the range 2.3–2.4 mm) from the surface water and four (range 0.6–1.6 mm) from the ingested particles, were analysed to determine the types of polymers, using ATR-FTIR spectroscopy (Bruker, Germany), according to the methods of Massos and Turner (2017) and Kanhai et al. (2017). Since our equipment was not designed for a micro-FTIR, bigger sizes were selected due to difficulties encountered in handling small particles. The particles were clamped onto the ATR diamond crystal before measurement which consisted of 24 scans in the spectral wavenumber range of 4 000–400 cm^{-1} at a spectral resolution of 4 cm^{-1}. Bruker's OPUS 7.5 spectroscopy software was used for processing and evaluating all spectra. Identification involved the comparison of the absorbance spectra of the samples with libraries of reference spectra, in which each sample spectrum was compared with those of known standard polymers in the Bruker Optics ATR-Polymer Library. Prior to analysing each sample, background scans were performed and sample spectra were automatically corrected. The spectra-matching threshold value was set at 80%. Therefore, in the overall analysis, matches with >80% similarity were accepted, and samples that produced spectra with a match of <80% were automatically rejected.

Quality control

Quality control was conducted following the methods of Masura et al. (2015), Duis and Coors (2016), Cincinelli et al. (2017), Crichton et al. (2017), Kanhai et al. (2017) and Peng et al. (2017). The filters were dried in a laminar flow hood and covered with aluminum foil. Glassware, tools and workspaces were thoroughly cleaned with filtered water and paper towels prior to use. Cotton lab coats were worn at all times, avoiding wearing polyester-type clothing (fleece jackets, polyester lab coats, etc.) to prevent samples from being contaminated by textile fibres. Glass materials and stainless steel were used for sample processing, unless stated otherwise. All apparatus made of plastic (sieves, squirt bottles, etc.) were microscopically inspected before use to ensure that there was no contamination from any of these materials to the environmental samples. Sieves were also washed and dried in a laminar flow hood before and after use. Latex gloves were worn for sorting and counting to prevent hands from coming into close contact with the microscopic samples. Glass materials were used at all times; in particular, all filters were stored in glass petri dishes and sealed with aluminium foil. Plasticware was rinsed several times with analytical-grade ethanol before use. Procedural blanks were run in parallel with the samples to account for potential contamination during the extraction procedure. Precautions were taken regarding contamination, including (i) air-contamination controls set up during sampling and visual identification, and (ii) blanks set up during vacuum filtration. Background blanks in the laminar flow hood were run regularly to identify typical fibres expected from airborne contamination. No contamination was detected throughout the quality-control process.

Statistical analyses

Correlation analyses were performed using STATISTICA 7 to determine whether there were any correlations between microplastics abundance and environmental variables, as well as between abundance and distance from the shore/major towns. A generalised additive model (GAM) was also developed, using R 3.2.3, to determine which location and oceanic and environmental variables may have contributed to microplastics abundance (Kanhai et al. 2017; Maes et al. 2017). The model was used to test the null hypothesis that environmental variables had no significant effect on microplastics abundance ($\alpha = 0.05$).

Results

Environmental variables

Wind direction was predominantly northeasterly, at an average speed of 2.68 m s^{-1}, throughout the cruise, with salinity ranging from 32.2 to 33.6, and SSTs of 26.3–28.7 °C. Pearson correlation tests ($\alpha < 0.05$) between microplastics abundance and each location (latitude and longitude), wind speed, wind direction, SST, salinity and pH showed a significant (negative) correlation ($r = -0.67$) only between microplastics abundance and SST. Additionally, a GAM was developed according to Kanhai et al. (2017), where the total microplastics counted per sampling station was the response variable and the environmental parameters were explanatory variables. A Poisson family distribution of error terms was specified with a log-link function due to the fact that the microplastics abundance data were counts. The output of the initial model was examined and consequently a nonparametric smoother (s) was applied to Longitude and Wind Speed since their p-values were not significant, whereas those of Latitude, Wind Direction, Salinity and SST were significant and hence required no smoother. Longitude was

significant after the application of a smoother, whereas Wind Speed was not significant and was thus eliminated. This led to the lowest Akaike information criterion score (67.746) and the fewest explanatory variables. The final GAM (R^2 = 0.281) and deviance explained (72.4%) is as shown below:

MP abundance ~ Latitude + *s*(Longitude) + Wind Direction + SST + Salinity

where MP = microplastics.

The five explanatory variables (Longitude, Latitude, SST, Salinity and Wind Direction) present in the final model were found to have significant correlations with the abundance of microplastics in Kenya's EEZ, in the following descending order: Longitude > Wind Direction > SST > Latitude > Salinity (Table 1).

Table 1: Explanatory variables included in the final best-fit generalised additive model

Explanatory variables	*p*-value
Longitude	6.09e-08
Wind direction	0.000234
Sea surface temperature	0.006335
Latitude	0.014007
Salinity	0.043724

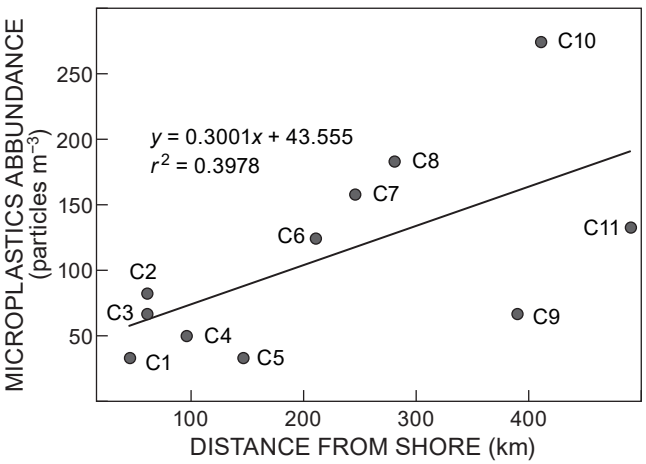

Figure 2: Linear regression showing the association between microplastics abundance and distance from shore

Distribution of the surface-water and ingested microplastics

Microplastics were detected at all the sampling stations, with a total of 149 microplastic particles confirmed. Microplastics abundance varied across the sampling stations, with a range of 33.3–275 particles m^{-3} and an overall abundance of 110 particles m^{-3}. The highest abundance was recorded at station C10 (275 particles m^{-3}), followed by station C8 (183 particles m^{-3}), with the lowest abundance recorded at stations C1 and C5 (33 particles m^{-3}). The findings show a general increase in the microplastics abundance in an offshore direction (Figure 2). A total of 129 microplastics particles were found ingested by the zooplankton groups (Table 2), with the majority of the particles ingested at station C8 (24 particles), followed by stations C2 (20 particles) and C3 (19 particles). No ingested microplastics were found in samples from station C1. Of the total ingested particles, Chaetognatha ingested the highest number of particles (0.46 particles $ind.^{-1}$), followed by Copepoda (0.33 particles $ind.^{-1}$), Amphipoda (0.22 particles $ind.^{-1}$) and fish larvae (0.16 particles $ind.^{-1}$).

Characterisation of the microplastics

In surface water

Surface-water microplastics were identified and categorised into four common shapes (fibres/filaments, fragments, granules and foams). Filaments contributed 76%, followed by fragments (12%), and granules and foams (collectively 12%) (Figure 3). Given that the dominant shapes in the water samples were filamentous, which were mostly coiled (and elastic when stretched), only 29 of the 149 particles were measured. The dominant size category was in the range 0.25–1.0 mm (*n* = 18), followed by 1.1–1.7 mm (*n* = 7) and 2.3–2.4 mm (*n* = 4). Given that they were all <5 mm in length confirms them as microplastics according to the definition of GESAMP (2015). Across the 11 sampling stations, 51% of the particles (*n* = 75) were white and 26% (*n* = 39) were black; the remaining 23% (*n* = 34) collectively comprised blue, brown, green, yellow, red and pink (Figure 4).

Ingested by zooplankton

A total of 129 particles were found ingested by the zooplankton groups and they comprised only filaments and fragments. Filaments were the dominant shape at 1.1 particles $ind.^{-1}$ (97%, *n* = 125), with fragments at just 0.04 particles $ind.^{-1}$ (3%, *n* = 4) (Figure 5). The sizes consumed by the different zooplankton groups were not measured; however, 36 of the 129 ingested particles were measured and categorised as 0.01–0.1 mm (*n* = 16), 0.1–0.4 mm (*n* = 16) and 0.5–1.6 mm (*n* = 4). For the filaments and fragments, black was the colour found most commonly (42%, *n* = 53), followed by red and brown (each 17%, *n* = 21), blue (13%, *n* = 19), green (9%, *n* = 13) and orange (2%, *n* = 2) (Figure 6). White particles were not found ingested by any of the zooplankton groups throughout the study area.

ATR-FTIR analysis

Polypropylene (PP) and low-density polyethylene (LDPE) were the only polymers identified among particles from the water subsamples, where PP was more common. Among the ingested microplastics, only LDPE was identified. Figures 7 and 8, respectively, show the polymers' identification by the results obtained from the comparison between PP and LDPE particles and the Bruker Optics ATR standard polymers spectra library.

Discussion

The abundance of microplastics increased with distance from land, contrary to the expectation that microplastics would be more abundant closer to shore (Kang et al. 2015).

Table 2: Microplastic particles ingested by zooplankton groups. ND = not detected

Station	Ingested microplastic particles per group (10 ind. per group were digested in bulk)				Ingested microplastics per sampling station
	Chaetognatha	Copepoda	Amphipoda	Fish larvae	
C1	ND	ND	ND	ND	ND
C2	4	6	5	5	20
C3	7	4	5	3	19
C4	8	6	ND	1	15
C5	8	3	ND		11
C6	ND		5	2	7
C7	3	1	3	1	7
C8	11	7	1	4	24
C9	3	6	ND		9
C10	5	ND	ND	2	11
C11	2	3	5		6
Total ingested microplastic particles	51	36	24	18	129
Total ingested particles per ind. (ingested particles/110)	0.46	0.33	0.22	0.16	1.17

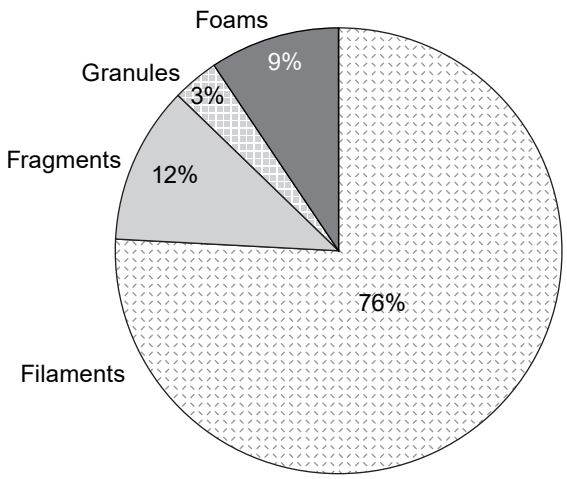

Figure 3: Percentage composition of microplastic particle shapes found in the sea-surface water

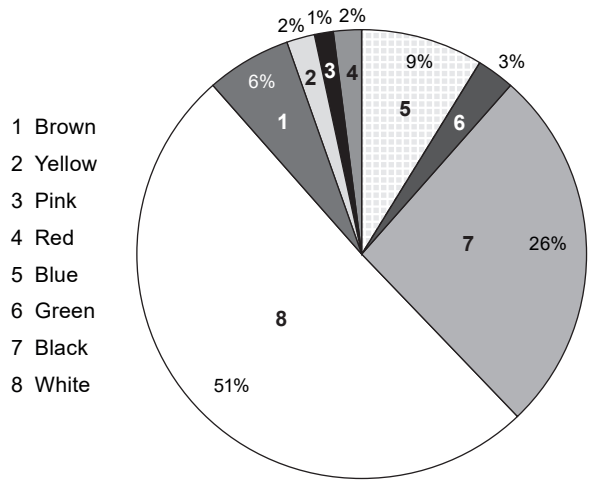

Figure 4: Percentage composition of various microplastic particle colours found in the sea-surface water

Given that the area defined as Kenya's EEZ is situated offshore of the territorial waters, it was likely that the high microplastics abundance found came from land-based sources adjacent to the study area, such as major towns (Kilifi, Malindi, Ngomeni and Kipini) and rivers (Sabaki and Tana) which discharge into the ocean (Wang et al. 2017). As noted by Nel and Froneman (2015), once microplastics enter the marine environment they are distributed over both short and long distances, as determined by water circulation and ocean currents.

The current lack of data on microplastics elsewhere in the western Indian Ocean precludes a regional comparison. However, microplastics abundance in this study appears to be higher than the abundance reported in Qatar's EEZ (Castillo et al. 2016), though we report microplastics abundance here as particles m^{-3}. Furthermore, the comparison considered only the sampling environment and did not take into consideration surface-water sampling depth and sieve mesh sizes. Inconsistencies in the sampling methods could influence measures of microplastics abundance since (i) there might be vertical stratification of microplastics in the water column, (ii) smaller mesh sizes would increase the quantity of microplastics collected during sampling (Kanhai et al. 2017), and (iii) different volumes of water sampled could hinder comparisons of microplastics in different areas of various oceans (Sun et al. 2017).

The significant correlation of environmental factors with microplastics abundance, found by means of the generalised additive model (GAM), is in agreement with Kanhai et al. (2017), who investigated microplastics abundance,

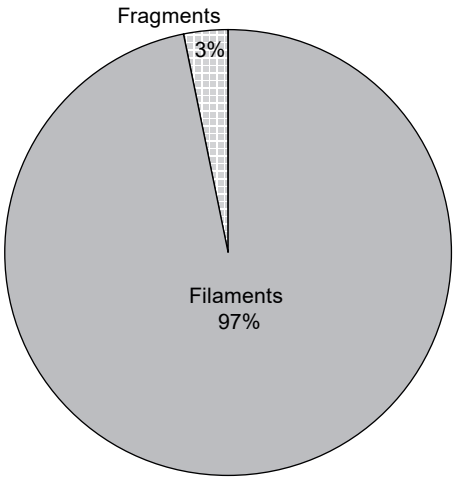

Figure 5: Percentage composition of microplastic particle shapes ingested by the zooplankton groups combined

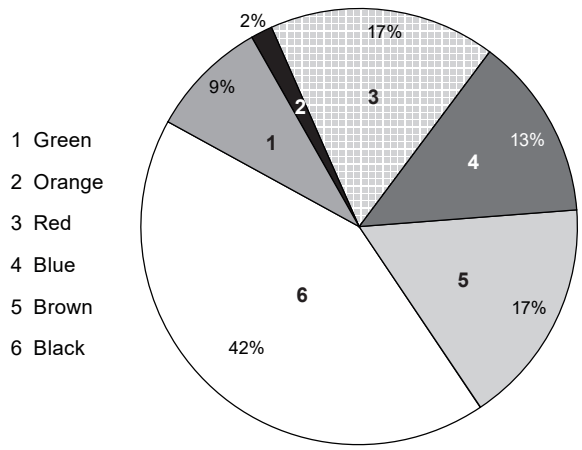

Figure 6: Percentage composition of various microplastic particle colours ingested by the zooplankton groups combined

distribution and composition in the Atlantic Ocean along a transect from the Bay of Biscay to Cape Town, South Africa.

Wind might affect the distribution of microplastics through vertical mixing (Frere et al. 2017; Maes et al. 2017). Wind speed during this study was fairly weak (mean 2.68 m s^{-1}), which might have favoured surface stratification and accumulation of microplastics near the surface. The increase in the abundance of microplastics with distance from shore might have been due to wind-driven transport of microplastics from nearshore (territorial) waters into the EEZ.

Consideration of environmental factors is known to play a significant role in the interpretation of the abundance and distribution of microplastics (Qiu et al. 2016); therefore, a GAM was applied to understand their potential influence on the abundance of microplastics in the study area (Kanhai et al. 2017). The model indicated that location (longitude and latitude), SST, salinity and wind direction contributed significantly to microplastics abundance, based on data from 11 samples. The final model showed that wind speed had no influence on microplastics abundance, probably because wind speed was weak throughout the study, and hence did not reach the threshold that could cause vertical mixing. A similar observation was made by Collignon et al. (2014) in the Bay of Calvi (Corsica, Mediterranean Sea).

The observed predominance of filamentous particles is consistent with previous findings in both surface and subsurface waters (Aytan et al. 2016; Kanhai et al. 2017), with the caveat that filaments as a category of microplastics are generally more discernible than other categories. Fragments, for example, have a higher chance of being overlooked due to their similarity in appearance to natural materials, suggesting the presence of an 'operator selection bias' towards filaments (Kanhai et al. 2017). In aquatic environments, filaments, fragments, granules and films are the most commonly found particles (Duis and Coors et al. 2016). The higher percentage of filaments could originate from abrasion and/or weathering of larger plastic items transported over large distances by prevailing currents, or derived from local fishing gear (nets, lines, etc.), ropes and clothing (Cincinelli et al. 2017; Kanhai et al. 2017). Filaments generally vary greatly in colour due to their parent materials (Cincinelli et al. 2017); however, white (51%) was the predominant colour, an indication that the source polymer type could have been PE, as suggested in characterisations by Rodríguez-Seijo and Pereira (2017).

The differences observed in the number of particles ingested per individual zooplankton group might have been a result of different feeding habits—given that copepods mainly feed on phytoplankton, protists and marine snow/aggregates, whereas chaetognaths and fish larvae feed largely on zooplankton (Sun et al. 2017). Furthermore, copepods might also be more susceptible to ingesting polypropylene, polyethylene or polystyrene, which have densities below that of seawater (~1.02 g cm^{-3}), because they feed near the surface (Clark et al. 2016). The prevalence of ingestion of filaments by the zooplankton groups might not only reflect their apparent predominance in the environment but also might have been enhanced by the fact that plastic filaments are capable of self-folding and twisting, which reduces their overall size and thus potentially increases their bioavailability (Desforges et al. 2015). Microplastic particles of various colours were ingested by the zooplankton groups, with black being the colour found most commonly in all the groups combined.

In aquatic environments, PE, PP and PS are the most frequently found polymers (Duis and Coors et al. 2016), and PP was identified at all the sampling stations. Its resistance to high temperatures (55–70 °C: Qiu et al. 2016), extensive application and relatively low cost lead to its prolific use in a wide range of consumer products; thus, PP was often the predominant polymer found in the environment (Castillo et al. 2016). Density might also be a factor that influences the presence of PP and LDPE, in that PP has a density of 0.89–0.91 g cm^{-3} and PE 0.093–0.98 g cm^{-3} (Duis and Coors 2016; Avio et al. 2017), with both being lower than the density of seawater. Therefore, they are expected to be positively buoyant in seawater and to be retained on the sea surface, becoming concentrated in areas of low circulation (Castillo et al. 2016). Additionally, PP and LDPE particles in the study area might have arisen from plastic

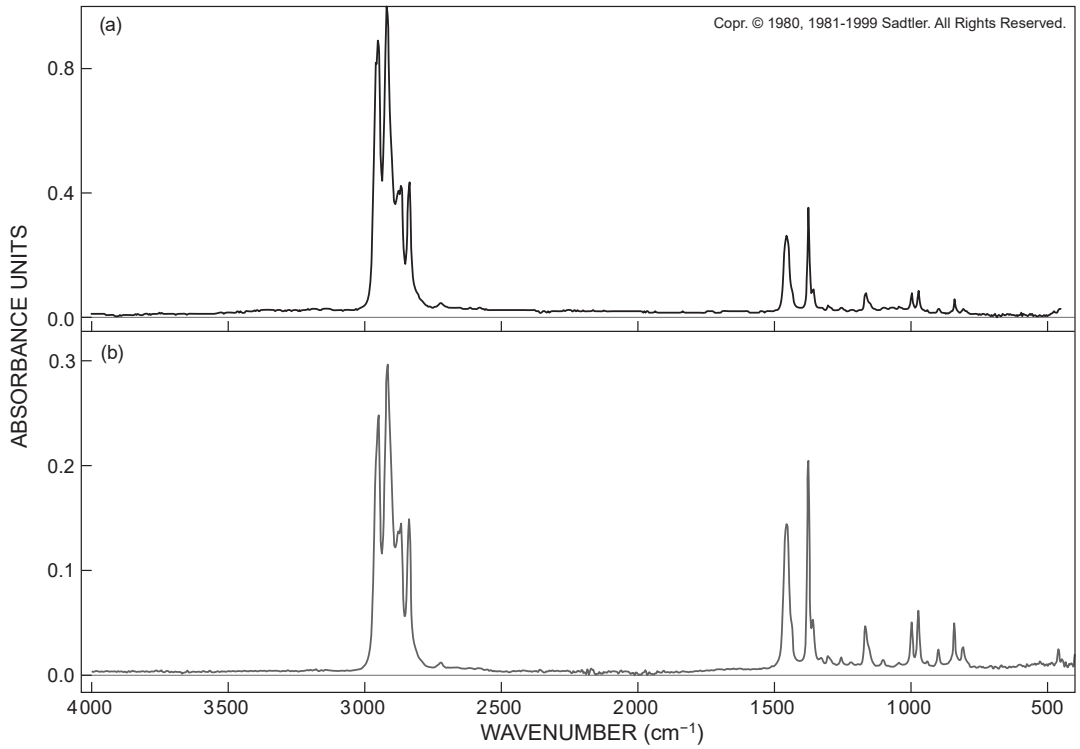

Figure 7: ATR-FTIR spectra for (a) sample C10 with (b) the reference polypropylene (PP) spectra from the Bruker Optics ATR standard polymers spectra library

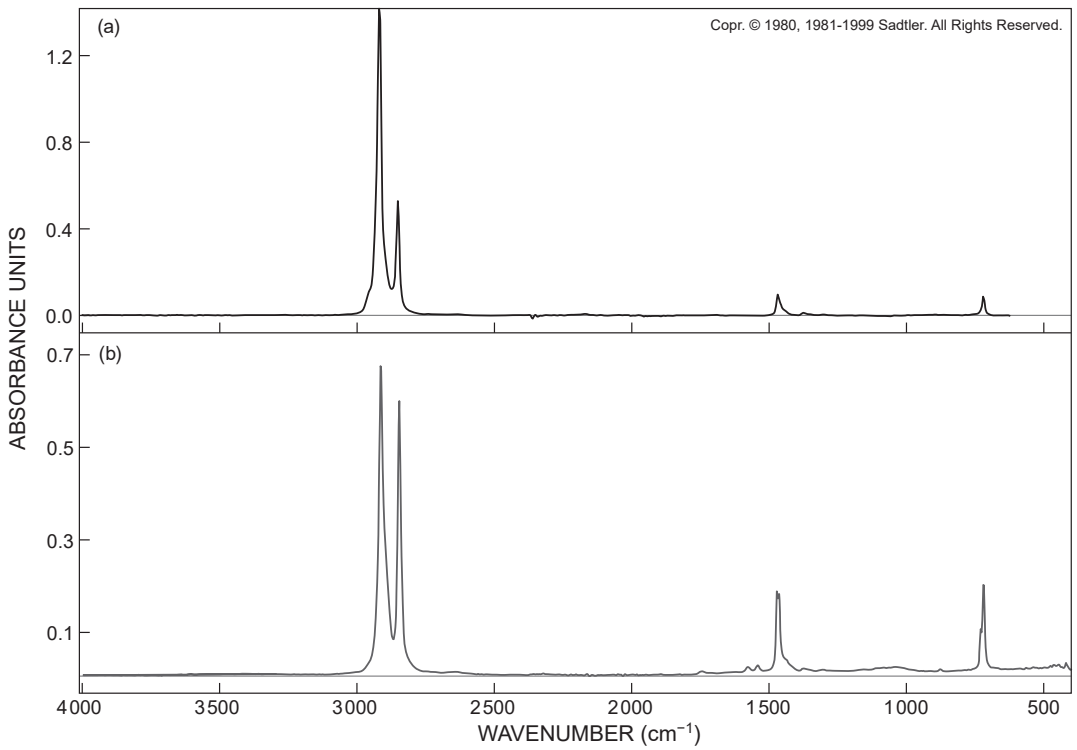

Figure 8: ATR-FTIR spectra for (a) sample C10 with (b) the reference low-density polyethylene (LDPE) spectra from the Bruker Optics ATR standard polymers spectra library

bags, ropes, food packaging and synthetic fibres from shipping and fishing activities (Hanvey et al. 2016).

Conclusions

The results of this study confirm the presence of microplastics in Kenya's marine environment and their ingestion by zooplankton, thus indicating that microplastics enter pelagic food webs. A GAM analysis showed that oceanographic and environmental factors were significantly correlated with the abundance of water-column microplastics. Microplastic filaments and white particles were predominant in the surface water, whereas black particles had the highest occurrence among the ingested microplastics found. Notably, the most abundant colour (white) was not found among the ingested particles. The dominant polymer in the water was PP, whereas LDPE was the only ingested polymer identified. The study provides information on microplastics abundance and the compositions that zooplankton might be exposed to, and hence offers baseline data from which the monitoring of microplastics in Kenya's marine environment might develop. The findings also provide a basis for similar research inshore of Kenya's EEZ, into nearshore territorial waters, which could lead to identification of the anthropogenic sources of these microplastics; such research would improve our understanding of the potential association of microplastics with toxic chemicals, especially as these may be transferred to the food chain, and could ultimately assist with the identification of mitigation measures to control microplastics pollution.

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