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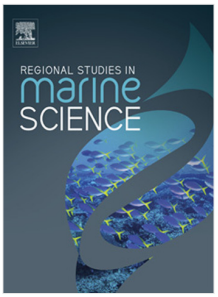

Microplastics in Ghanaian coastal lagoon sediments: Their occurrence and spatial distribution

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Microplastics in Ghanaian coastal lagoon sediment: their occurrence and spatial distribution.

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Abstract:	Each year, millions of tonnes of plastic are produced worldwide and around 8 million tons are deposited into our marine environment. Rivers comprise the major conduit for plastic transport with their deltas, estuaries and coastal lagoons representing a key interface between such systems and the oceanic environment. We have very little knowledge, however, of their role in the plastic pollution pathways. Herein we present the spatial and temporal distribution and abundance of microplastics in sediments from two coastal lagoons in Ghana, West Africa. Sediment cores were taken from Mukwei Lagoon, Kpeshie Lagoon and from the mangroves at Kpeshie Lagoon; areas approximately 5-15km East of the centre of Accra. Microplastics were detected in all samples with a decreasing trend recorded from West to East. All three sites recorded a similar depth profile for plastics: after an initial increase from the surface samples, there was a significant decrease in microplastic concentrations with depth.
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Response to Reviewers:	Dr. Gunnar Lauenstein Editor- in-Chief Regional Studies in Marine Science Cut Bank Montana, United States 3 July 2020 Revision and resubmission of manuscript RSMA-D-20-00194 Dear Dr. Lauenstein Thank you for your letter and for giving us the opportunity to revise our manuscript. The manuscript has been carefully revised by a native English speaker to improve the grammar and readability. Changes have been made all over the document. However, most of the changes have been made in the introduction and discussion sections. Also, the last paragraph of the results was deleted as we think it was too repetitive.

Microplastics in Ghanaian coastal lagoon sediments: their occurrence and spatial distribution

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Abstract

Each year millions of tonnes of plastic are produced worldwide and around 8 million tons are deposited into our marine environment. Rivers comprise the major conduit for plastic transport with their deltas, estuaries and coastal lagoons being the key interface between lotic aquatic and the oceanic environment. However, we have very little knowledge of the role of coastal lagoons in the plastic pollution pathways. We present the spatial and temporal distribution and abundance of microplastics in sediments from two coastal lagoons in Ghana, West Africa. Sediment cores were taken from Mukwei Lagoon, Kpeshie Lagoon and from the mangroves at Kpeshie Lagoon; areas approximately 5-15km East from the centre of Accra. Microplastics were detected in all samples with a decreasing trend recorded from West to East. All three sites recorded a similar depth profile for plastics: after an initial increase from the surface samples, there was a significant decrease in microplastic concentrations with depth.

Keywords: Plastic pollution; coastal lagoons; mangrove; Ghana; Accra; sediment; management

1. Introduction

Plastic contamination is now so widespread across the world that the associated physical and chemical perturbations are ranked alongside Climate Change and water scarcity as a key planetary boundary threat (Villarrubua-Gómez et al., 2018; Rockström et al., 2009).

Approximately 80% of all plastic emissions are derived from land-based sources, whilst 20% are from ocean-based sources (Boucher and Friot, 2017; Pawar et al., 2016; Pokua, 2015). As plastics degrade, they form microplastics (particles <5mm) (Löder and Gerdts 2015; Claessens et al. 2011) that are globally ubiquitous and can be found in the most remote locations such as the Earth's poles and at the bottom of mid oceanic trenches (Karlsson et al. 2017; Willis et al. 2017; Fischer et al., 2016; Thompson 2015; Woodall et al., 2014; Hidalgo-Ruz et al. 2012; Cole et al., 2011; Thompson et al., 2004). Several studies have reported the presence of microplastics in lagoonal environments where they can have an impact on the health of wildlife and humans (Lenaker et al., 2019; Loruenco et al., 2017; Vianello et al., 2013; Fabbri et al., 2000). According to Nakki et al. (2017), bioturbation plays an important role in shaping the vertical distribution of microplastics in such sediments as organisms, directly or indirectly, enable such particle transport *via* a host of mechanisms (Kristensen et al., 2012 as in Nakki et al., 2017). Biofouling, agglomeration with sediment particles and uptake into biological organisms can also result in the vertical movement of microplastics within water columns and even deep into the benthic sediment, due to associated changes in density and/or hydrophobicity, which can also facilitate their horizontal movement to new environments (Kooi et al., 2017).

Plastic contamination is a relatively recent phenomenon in the Gulf of Guinea (Ackah et al., 2012). In the late 20th Century, the most problematic contaminants typically comprised those from the petroleum (namely tarballs) and agricultural (namely nutrient runoff) industries, in addition to coastal sediment fouling from a host of land-based industries (Gordon, 1998). As with many other developing countries, Ghana is currently experiencing major challenges associated with pollution control, with plastic emissions being amongst the major issues. More than 3000 tons of plastic waste are generated every day; with approximately 23% of this waste being discharged into the coastal environment (Effah, 2019; Ackah et al., 2012). Water sachets (500ml), used for potable water, constitute as much as 85% of the plastic waste generated throughout the country. Plastic contains a wide range of ecotoxic chemicals (e.g. dioxins, persistent organic pollutants, polychlorinated biphenyls) which can leach into the environment and they can also trap contaminants (e.g. bacteria from faeces, hydrophobic contaminants *via* sorption, hydrophilic contaminants *via* sorption onto co-sorbed organic matter). Plastic

can also cause direct harm to organisms *via* a host of mechanisms due to their ingestion, inhalation and by trapping their movement. The sheer scale and complexity of such problems clearly demonstrates that plastic pollution is a major environmental issue (Owusu-Sekyere 2013; Stoler et al., 2012).

Rivers are the major conduit for plastic emissions into the marine environment with estuaries and coastal lagoons being key interfaces between such terrestrial and marine systems (Thompson, 2015). Ghana comprises approximately 550 km of coastline which includes 90-100 coastal lagoons. Whilst being a major host for plastics, these transitional zones also constitute a crucial locus of ecosystem services (Apau et al., 2012; Gordon, 1987). The lagoons, with their associated mangroves, support fisheries, absorb floodwaters, protect biodiversity and serve as roosting, nesting and feeding areas for a variety of local and migratory birds; for example Keta Lagoon and Sakumo II Lagoon are designated RAMSAR sites (Tettey, 2015; Apau et al., 2012; Diop, et al., 2001; Ntiamoa-Baidu et al., 1997). One of the key challenges of microplastics within marine sediments is the potential to enter into marine pelagic fish: the fishing industry in Ghana directly supports 10% of Ghanaian's livelihoods (FAO, 2016). Moreover, fish is considered the most important source of animal protein as it contributes 60% of Ghana's animal protein intake (ATLAFCO, 2012). Despite the economic and social importance of lagoons, these are threatened by human impacts such as overexploitation of resources, pollution, and environmental degradation (Delegation of German Industry and Commerce in Ghana, 2018). Little is known about the presence or distribution of microplastics in Ghana and there is a lack of community awareness and education on this issue. Such preliminary reports so far have only explored the surface distribution of microplastics (Lourenço et al., 2017; Naidoo et al., 2015; Nel and Froneman, 2015; Hosoda et al., 2014; Ryan and Moloney, 1990) and there is no available information on the depth profile of these contaminants in Ghanaian coastal lagoons. We record the spatial distribution and abundance of microplastics through the sediment column from a number of sites adjacent to Accra.

2. Methods

2.1. Sediment core collection and dissection

Sediment samples were collected between Accra and Tema from Mukwei (5° 36'31' N, 0° 03'16' W) and Kpeshie (5° 33'52' N, 0° 08'05' W) lagoons (Figure 1). Mukwei Lagoon is a small lagoon located within the Ledzokuku Krowor Municipality in the Greater Accra Region, connected to the sea by a canal which reverses flow at high tide and thereby enables transport of seawater back into the lagoon (Tettey, 2015). Mukwei Lagoon has two main sources of fresh water; from the Sakumono Estate to the east and Nungua township on the west (Tettey, 2015). The beach adjacent to Mukwei Lagoon, known as Mighty Beach, is a recreational area and fishing activities are restricted to cast nets and long-line fishing (Tettey, 2015). Kpeshie Lagoon is located in the La Dade-Kotopong Municipal District of the Greater Accra Region. The lagoon opens directly into the ocean, though it is periodically blocked by sand bars (Ansah et al., 2011). Previously, this lagoon was an important fishing ground for the surrounding community (Ansah, 2006 as in Korbla et al., 2019).

Three sediment cores were collected: one from Mukwei Lagoon (MLC) and two from Kpeshie Lagoon; one near the coastline (KLC1) and the second near the mangrove forest remnant (KLC2) (Figure 3). The cores were 30 cm deep and 8 cm in diameter. Immediately following sampling, they were sealed with sodium polyacrylate and stored at room temperature for 10 days before being frozen at -18°C. Dissection was then performed using a handsaw wherein each core was sliced vertically at 1cm intervals, care was taken not to contaminate the sample in the slicing process, with each individual samples then stored at 4°C.

2.2. Sediment moisture and loss on ignition analysis

The moisture content of each sample was determined by measuring the mass change of one gram of sediment (taken every five centimetres) after heating at 105°C for 16 hours, followed by cooling in a desiccator at room temperature for 30 minutes. The organic matter content was then determined by heating at 550°C for four hours (followed by cooling in a desiccator at room temperature for 60 minutes), with the loss on ignition (LOI) calculated using the following equation:

$$LOI_{550} = \left((DW_{105} - DW_{550}) \,/\, DW_{105}\right) \times 100$$

where DW_{105} represents the dry weight of the sample before combustion and DW_{550} the dry weight of the sample after heating to 550°C (Heiri et al., 2001).

2.3. Particle size analysis

To conduct particle size analysis, 1cm^3 was taken from every five centimetres and placed in a 500 ml beaker. To prepare the samples for analysis, Jackson's methodology to remove organic material was used (Hyeong and Capuano, 2000; Jackson, 1985). The organic material was removed by adding 10 ml of 30% hydrogen peroxide (H_2O_2) to the beakers in a fume cupboard and left overnight to start the digestion process. After that, another 10ml of 30% H_2O_2 were added and left for one hour before warming the samples at 50°C on a hot plate for two hours then briefly bringing to boil before cooling. To clean the samples of chemicals, and prepare them for the analysis, they were placed in centrifuge tubes, topped up with deionized water and centrifuged at 3500 rpm for 8 minutes to remove any remaining chemical. The samples were washed twice more, centrifuged at 3500 rpm for 8 minutes and then oven dried at 105°C for 12 hours. Particle size analysis was carried out using the laser granulometer Malvern Mastersizer 2000® (pump speed=1500). Results were recorded as the particle volume percent in 100 size ranges between 0.02 and 2000 µm.

2.4. Microplastics analysis

To prevent airborne plastic particulate contamination and cross-contamination of plastic, glass laboratory products were used throughout and rinsed with deionized water before each use. The only use of plastics were the tubes used to collect the sediment. To assess potential contamination from airborne particles, a glass beaker was left open with deionized water during laboratory work. The deionized water was then examined under the microscope, wherein no contamination from airborne plastic particles was recorded. To determine the presence of microplastics, 10 cm^3 of sediment, measured by volume displacement, was taken from each interval with two duplicates per depth. To recover microplastics from the sediment, the samples were treated with a mixture of 150 ml of

deionised water with 22.5 ml of 30% H_2O_2 (Burt, 2014; Klein et al., 2015). This solution was subsequently heated at 90°C for one hour to remove all the organic matter before the samples were cleaned using deionized water and passed through a sieve with a mesh size of 10 µm.

To isolate microplastics, density separation was conducted following the method of Klein et al., (2015) by mixing 200 ml of a 350 gl^{-1} NaCl solution with the digested sediment, which was then stirred for two minutes. The sediment particles were allowed to settle for 16 hours before the supernatant was transferred to beakers and washed with deionised water to remove the NaCl (Klein et al., 2015). The remaining concentrated sample was filtered using a micropore filter and black microporous membranes (Whatman Cyclopore Track Etched Membrane 47 mm – 0.2 µm). The membranes were allowed to dry and then the samples were dyed with Nile Red; for this purpose, a Nile Red stock solution was prepared at 1mg mL^{-1} in acetone (Maes et al., 2017). Microplastics were identified using a fluorescent microscope (Zeiss LSM 710) under red light at 12X magnification. Image J was used to quantify the particle size distribution of the microplastics in each photograph.

2.5. Analysis

ANOVA/Kruskal-Wallis and Tukey tests were used to determine whether there was any statistical difference in either the number or size of microplastics as a function of location, depth, organic material and sediment size composition, with a significance level of 95%. Pearson/Spearman correlation was also implemented to determine correlations between the size/number of microplastics with depth, organic material and sediment size composition. All statistical analyses were conducted using RStudio 3.5.1.

3. Results

Core KLC2 contained the most organic matter overall (2.16 wt.% gr^{-1}), followed by MLC (0.96 wt.% gr^{-1}) and KLC1 (0.75 wt.% gr^{-1}). Cores KLC2 and MLC recorded the greatest concentration of organic matter between 21 and 25 cm (4.17 wt.% gr^{-1} and 2.17 wt.% gr^{-}

^{1} respectively), while KLC1 exhibited a highest measurement in the first interval, between 0cm and 5 cm, with 2.25 wt.% gr^{-1}. Particle size analysis determined that for all locations the sediment was primarily composed of sand (63 µm-2000 µm) (Figure 2). More specifically, KLC1 sediment composition comprised 99.98 % sand and 0.02 % silt (4 µm-62.9 µm); KLC2 comprised 78.47 % of sand, 17.11 % of silt and 4.42 % of clay (≤ 3.9 µm); and MLC sediment was 100 % sand (Figure 2, Appendix 1). Results also show that in KLC2 particle size decreased with depth, while particle size remained relatively constant at sites KLC1 and MLC.

A total of 964 microplastic particles were found in the three core samples across the three sampling locations; 467 particles were recorded in core KLC2, 295 particles in KLC1 and 202 in MLC. The mean abundance of microplastics per 10 cm^{3} of sediment was 16.39 ±3.26 for KLC1, 25.94 ±3.13 for KLC2 and 11.22 ±2.69 for MLC (Figure 3). The ANOVA showed a significant difference between the abundance of microplastics and locations (p= 0.001). According to the Tukey Post-hoc test, this difference is most acute between KLC2-KLC1 and KLC2-MLC with p-values of p=0.04 and p= 0.0007 respectively. Results determined that the mean size of microplastic particles for each location was 26.63 ±5.88 µm in KLC1, 38.35 ±7.71 µm in KLC2 and 17.98 ±5.25 µm in MLC. However, the ANOVA analysis between particles size and location did not display a significant difference (p=0.09).

There was a gradual increase in the number of microplastic in KLC1 up to 15 cm, reaching a maximum at the 11-15 cm before the number of microplastics decline until the 29 cm (Figure 4-A). Moreover, there was a gradual increase in the number of microplastics in KLC2 up to 10 cm before the number of microplastics declined moderately until 15 cm, followed by a slight increase up to 20 cm, after which the number of microplastics showed a gradual drop from 21 cm to 29 cm (Figure 4-B). Finally, there was a slight rise in the number of microplastics, reaching a peak at the 6-10 cm depth interval before the amount of microplastics decreased dramatically until 29 cm (Figure 4-C).

Analysis carried out in each location determined that microplastics distribution in KLC1 varied significantly according to abundance and depth (p=2.19e-07) (Figure 5-A). The

Tukey Post-hoc test had revealed that the abundance of microplastics was significantly higher between the first three depth intervals as they showed p-values <0.05. In addition, the Tukey Post-hoc test showed that the abundance of microplastics was significantly lower after the interval 11-15 cm, with the exception between the last two intervals (p=0.88). In addition, Pearson analysis displayed a moderate negative correlation between depth and abundance of microplastics, r=-0.49. For KLC2 (Figure 5-B), the ANOVA test determined that there was a significant difference between the abundance of microplastics and depth (p=0.007). According to the Tukey Post-hoc test, there was a significant increase in the abundance of microplastics between 1-5 cm and 6-10 cm depth intervals (p= 0.02). In addition, the abundance of microplastics was significantly lower between the 6-10 cm and 26-29 cm depth intervals (p=0.008), as well as between the 16-20 cm and 26-29 cm (p=0.04). After the Pearson correlation analysis between the abundance of microplastics and depth, a weak negative correlation of r=-0.29 was obtained. For core MLC (Figure 5-C) the ANOVA test showed that microplastics distribution varied significantly in abundance with depth (p=2.74e-05). The Tukey Post-hoc test showed there was a significant decrease in abundance of microplastics between the first two intervals and four last depth intervals; all presented p-values <0.05. Moreover, the Pearson analysis showed a strong negative correlation, r=-0.69, between abundance and depth.

The ANOVA showed that there was no significant difference between size and depth (p= 0.50) of microplastic particles size in KLC1 (Figure 6-A), displaying a weak negative correlation (r=-0.30). For core KLC2 (Figure 6-B), the ANOVA test showed that there was a significant difference between microplastics size and depth (p=0.04). This difference corresponded to the depth intervals 1-5 cm and 26-29 cm (p=0.02); the Pearson analysis between microplastics size and depth resulted in a strong negative correlation (r=-0.66). For core MLC (Figure 6-C) the ANOVA test showed that there was no significant difference between microplastics size and depth (p=0.49) down the core with the Pearson correlation coefficient between these two variables displaying a weak negative correlation (r=-0.31).

4. Discussion

Microplastics were detected in all three sampling sites, KLC2 being the most contaminated area accounting for approximately 80% of the microplastics. These results support a previous study (Tettey, 2015) that documented a decreasing amount of plastic waste in coastal lagoons from West to East. This spatial variability could be explained by the proximity to Accra, and the ensuing eastward prevailing flow of the Guinea Current (Lebreton et al., 2017). There is also potential that quantities of these particles are being ingested by humans who eat locally caught seafood (Fauziah et al., 2015). Our results also show a significant decrease in microplastics abundance between locations KLC1 and KLC2 which support previous studies that have showed mangrove areas to have a greater concentration of microplastics (Nel et al., 2017; Nor and Obbard; 2014; Yona et al., 2019). Mangroves and estuaries collect and retain microplastics from runoff (Nel et al., 2017) with the extensive root system of mangroves trapping a variety of debris, including plastics (Yona et al., 2019). Tides that inundate mangroves carry plastic wastes that, due to the presence of sand barriers, is ponded with the plastic debris stuck within the lagoon until there is either a high spring tide or a high river flow to flush the waste through the lagoon into the ocean (Yona et al., 2019).

A significant difference in vertical microplastic distribution was recorded across the coast: all locations exhibited a low amount of microplastics in the upper sediment layers. The sediment-water interface is highly dynamic and are frequently removed and deposited by oceanographic events, preventing the sedimentation and accumulation of microplastics in the superficial sediments (Frère et al., 2017; Turra et al., 2014). The deeper layers contain greater amounts of microplastics as they might accumulate these particles for longer time periods. Additionally, the variability in abundance of microplastics in KLC2 along the core might be due to the presence of organic materials; organic materials not properly digested, especially remaining solids such as wood and leaves, may cause a false positive result as these materials could be dyed by Nile Red dye (Valine, 2019, Wang et al., 2018). According to LOI analysis, the intervals 16-20cm and 21-25cm for KLC2 record the highest amounts of organic material. Additionally, the

significant difference between microplastics size and depth in KLC2 could be the result of the variability in sediment composition along the sediment column compared to KLC1 and MLC that remain almost constant.

Marine microscopic plastic litter is a contemporary societal problem and illustrates the challenge of balancing the use of plastic in daily life with its negative effect on the environment (Galloway et al., 2018). There are potential impacts from the plastics retained with the sediments, particularly if these are mobilized and enter into the biota and ensuing food chain. Therefore, in Ghana, like many countries, it is essential to improve waste management strategies such as recycling and reuse of plastic waste. There should be a promotion of litter-separation initiatives as the waste stream in Ghana contains high proportions of compostable materials and plastics (Ackah et al., 2012). However, before this could be implemented, the general public needs education on the correct use and disposal of plastics and its effects on the environment and their own health (Teye, 2012). Moreover, industries, especially those that produce plastics, should be required to contribute to the recycling of plastic wastes (Teye, 2012). The authorities should look for alternatives to improve the supply of drinking water to avoid the use of single use water sachets and water bottles. The challenge posed by microplastic requires society to actively engage and consider its role in consumption patterns and careless disposal (Galloway et al., 2018).

5. Conclusions

We have documented the concentration and particle size distribution of microplastics in two coastal lagoons within 20km of Accra, Ghana. Microplastics were recorded in all samples; such widespread presence suggests that these may be exhibiting a major impact on the security and purity of seafood stock in the region. Each site exhibited a peak of microplastic concentration at approximately 10cm depth. This suggests that plastics are broken down into microplastics, which are then deposited in the shallow sediments (i.e. just beneath areas which can erode away). Further research is required in order to determine the mechanics behind this phenomenon. Whilst the entrainment of microplastics into the sediment will likely create additional complexities for remediation

(i.e. microplastic recovery), it could potentially act as a sink to isolate them from the near surface biosphere and the wider marine environment, which is a vitally important resource for the Ghanaian economy.

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Figure 1. Map showing the sampling sites between Accra and Tema: Kpeshie Lagoon (A), two sampling sites: Kpeshie Lagoon coastline (KLC1) and Kpeshie Lagoon Mangrove (KLC2); and Mukwei Lagoon (B), one sampling site (MLC). Photos by Robert Marchant.

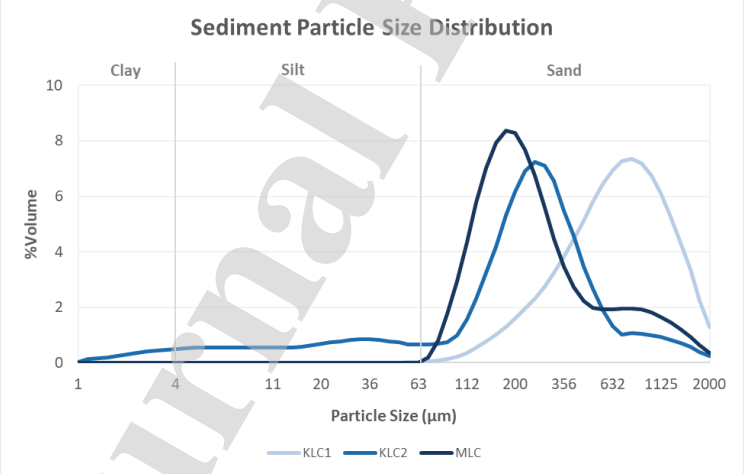

Figure 2. Particle size distribution of sediment samples collected at Kpeshie Lagoon (KLC1), Kpeshie Lagoon Mangrove (KLC2) and Mukwei Lagoon (MLC), classified according the Udden-Wentworth grain-size scale (Wentworth, 1992)

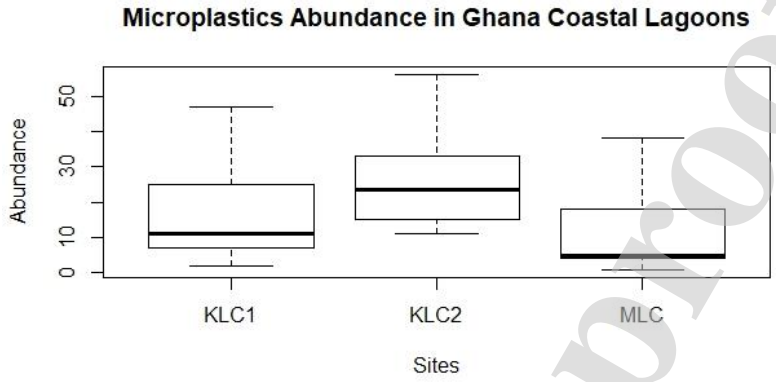

Figure 3. Boxplots of the microplastics abundance in the three sampling locations using normalized data.

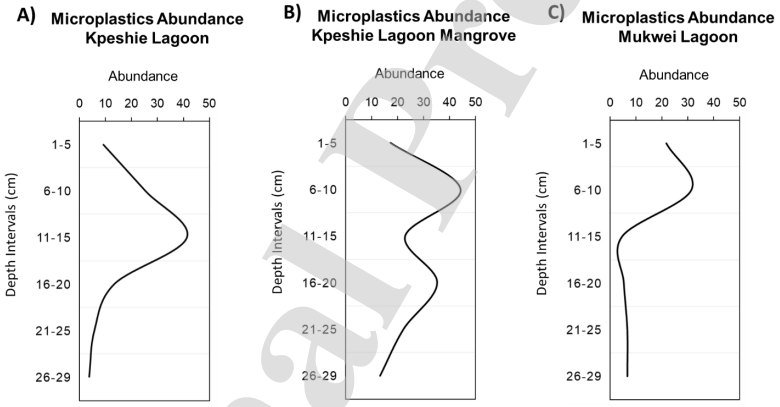

Figure 4. Changes in the vertical distribution of microplastics taking into account depth intervals in A) Kpeshie Lagoon, B) Kpeshie Lagoon Mangrove and C) Mukwei Lagoon

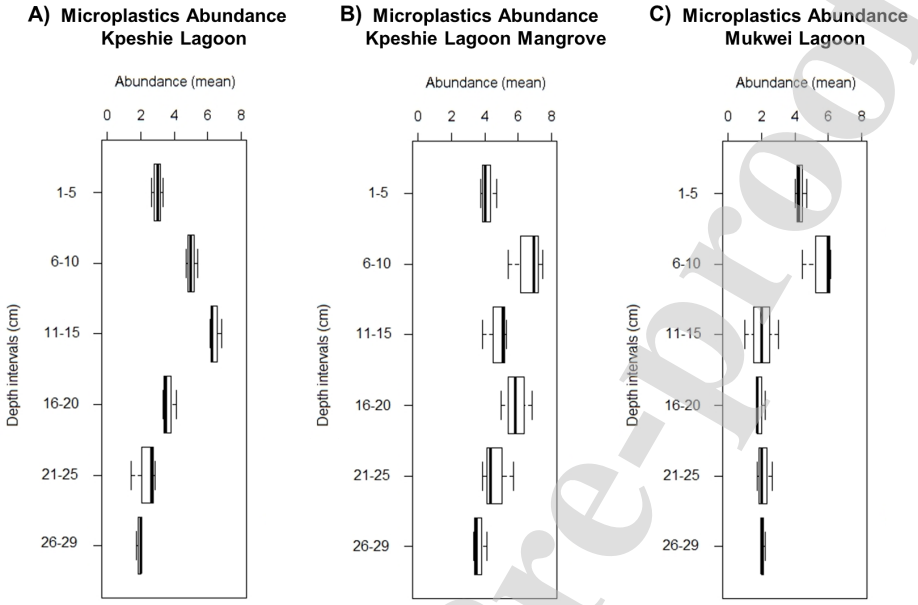

Figure 5. Boxplots of the vertical distribution of microplastics in (A) Kpeshie Lagoon, (B) Kpeshie Lagoon Mangrove and (C) Mukwei Lagoon, according to depth intervals.

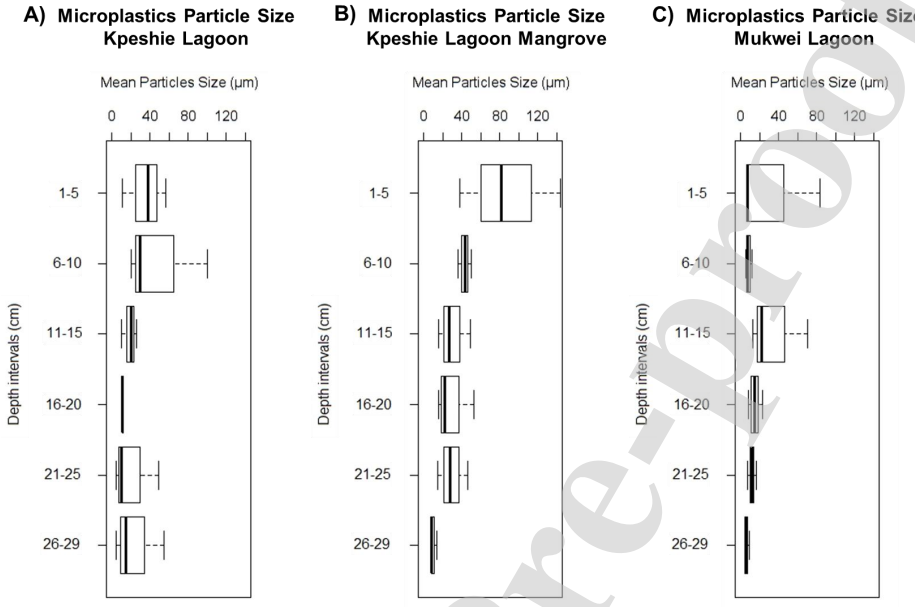

Figure 6. Boxplots of microplastic particles sizes in (A) Kpeshie Lagoon, (B) Kpeshie Lagoon Mangrove and (C) Mukwei Lagoon, according to depth intervals.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Author Statement

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Author contributions:

Nicole Chico-Ortiz: Methodology, Formal Analysis, Investigation, Writing. **Edem Mahu:** Fieldwork, Resources, Review & Editing. **Rich Crane:** Review & Editing, Visualization of Results. **Chris Gordon:** Conceptualization, Resources, Review and Editing. **Robert Marchant:** Conceptualization, Writing, Review & Editing, Visualization, Supervision.

Highlights

- The abundance and distribution of microplastics (MP) in two coastal lagoons within 20km of Accra were documented.
- Plastic waste is being broken down into MPs which are then deposited in the shallow sediments.
- The widespread presence of MPs in the sediment column rise sharply before decreasing with depth.
- MPs in the lagoon environment are likely exhibiting a major adverse impact on the health and functioning of the biosphere.
- Mechanics behind microplastics' entrainment into the sediment still need to be elucidated.