UNIVERSITY OF CAPE COAST

PLASTIC POLLUTION IN SEDIMENTS AND MARINE FISH SPECIES FROM TWO ARTISANAL FISHING HOTSPOTS ALONG THE COAST OF GHANA

PEARL SAKYI – DJAN

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BY

PEARL SAKYI- DJAN

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ABSTRACT

Plastic pollution is a global environmental challenge that threatens marine biodiversity and ecosystem health. The focus of this thesis was to evaluate the level of plastic pollution along the coast of Ghana and also, to examine microplastic contamination in some marine fish species. The study was conducted at two of the largest artisanal fishing harbours– Elmina and Tema – in Ghana, West Africa. Macroplastic (> 2.5 cm or 25 mm) and mesoplastic (5 mm to 25mm) litter on and within the beach sediments of the harbour was analysed based on international guidelines for monitoring marine litter. Followed by microplastic (≤ 5 mm) contamination analyses of two commercial fish species, Angola dentex (*Dentex angolensis*) and Barracuda (*Sphyraena sphyraena*) landed in the harbours, using the Fourier transform infrared (FTIR) spectroscopy analysis. The marine litter analyses (macroplastic) indicated a diversity of plastic materials mostly dominated by single-use plastics (water sachet and takeaway bags). The results from the mesoplastics analyses specify the dominance of styrofoam and hard plastic fragments as the dominant materials. The FTIR results showed a higher occurrence of microplastics in *Dentex angolensis* at Elmina, with microfibers accounting for 60-100% of the ingested microplastics. Five different polymer groups were identified, with polyethylene, polystyrene, and polyurethane being the most commonly consumed polymers. Although plastic ingestion was low, it could be traced to the plastics evaluated along the coast. All stakeholders must pay attention to addressing pollution, especially plastics, to prevent further contamination of marine life.

KEYWORDS

Artisanal

Fish species

Hotspots

Marine

Plastic pollution

Sediments

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DEDICATION

To myself and God Almighty

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LIST OF ACRONYMS

ADB: Asian Development Bank

AUC: African Union Commission

FAO: Food and Agriculture Organization

FTIR: Fourier Transformed Infrared

IUCN: International Union for Conservation of Nature

MESTI: Ministry of Environment Science Technology and Innovation

OSPAR: Oslo and Paris Convention

PA: Polyamide

PE: Polyethylene

PS: Polystyrene

PU: Polyurethane

PV: Polyvinyl

UNEA: United Nations Environment Assembly

UNEP: United Nations Environment Programme

CHAPTER ONE

GENERAL INTRODUCTION

Background to the Study

Plastic Contamination of Marine Environment

Plastic pollution is a global environmental challenge threatening marine biodiversity and ecosystem health (Gallo, Fossi, Weber, Santillo, Sousa, Ingram & Syberg, 2018). Plastic waste is a pressing issue worldwide, with an estimated annual global production of approximately 359 million metric tonnes. Of this, 14.5 million metric tonnes find their way into the oceans, contributing to marine pollution (Wayman & Niemann, 2021). These plastics enter the ocean each year, causing damage to aquatic life and coastal communities. In the process of entering the sea, certain factors such as natural (sunlight, wind, rainfall) and human (burning) influences cause the debris to degrade. It is worth noting that, primary plastics or degraded plastics come in varying sizes, ranging from macroplastics measuring 2.5 cm and above, mesoplastics ranging from 5 mm (0.5 cm) to 2.5 cm, and microplastics smaller than 5mm. These size ranges are acceptable global standards for measuring plastic in the environment (Cheshire et al., 2009; MSFD Technical Subgroup on Marine Litter, 2013).

Abundance of plastics in aquatic systems

Plastics (macro-, meso- and micro-) are available in marine habitats, ranging from surface waters to the deep sea (Courtene-Jones et al., 2017; Jamieson et al., 2019; Lusher et al., 2014; Thompson, 2015), as well as in sediments on beaches and coastal regions (Barnes et al., 2009; Browne et al., 2011; Van Cauwenberghe et al., 2015). Also, they are found in marine organisms (the digestive systems, respiratory structures, and tissues) (Adika et al., 2020; Andrady, 2011; Courtene-Jones et al., 2019; Depledge et al., 2013; Pappoe et al., 2022).

Microplastics (MP), as observed, tend to increase near cities or regions of relatively high human interaction (Browne et al., 2011; Depledge et al., 2013; de Sa et al., 2015; Eriksen et al., 2013; Yonkos et al., 2014). Equally, there are also exceptional levels seen in other remote areas (Gilman, 2013), in Arctic Sea ice (Kanhai et al., 2020; Obbard et al., 2014), and in deep-sea fauna (Courtene-Jones et al.,2017; 2019; Jamieson et al., 2019; Van Cauwenberghe et al., 2013). The distribution of microplastics is influenced by wind and degraded by salinity, temperature, precipitation, impermeable surfaces onshore, and vertical migration. These factors demonstrate the interconnectedness of marine and terrestrial environments. However, when predicting an increase in microplastics within a region, it is important not to attribute it to highly populated areas solely. (Browne et al., 2010; Gilman, 2013; Lusher et al., 2014; Yonkos et al., 2014).

In sediments, plastics of varying sizes in nearshore or offshore marine sediments have been studied along many coastlines worldwide. Dekiff et al. (2014) observed a homogenous distribution of macro- and mesoplastics across a 500-m stretch of North Sea shoreline. They discovered that the abundance of microplastics did not relate to visible plastic debris (macroplastics) and beach sediments (mesoplastics). Dekiff et al. (2014) suggested that the presence or absence of visible plastic should not be a determining factor for selecting a sampling site. Hence, monitoring microplastic and other sizes of plastics (macroplastics, mesoplastics) must be done separately (Dekiff et al., 2014).

Microplastic samples were collected from shoreline sediments from the Tamar Estuary southwest of the UK. Browne et al. (2010) found that polymers such as *polyvinyl chloride (*PVC), polyester (PES), and polyamide (PA)/nylon dominated the samples. Further, Woodall et al. (2014) detected microplastics in the samples and found between 1.4 to 40 particles per 50 ml of sediment from the North Atlantic Ocean, Mediterranean Sea, and SW Indian Ocean. Whilst it is difficult to compare, Courtene-Jones et al. (2019) looked at deep-sea sediment from the Rockall Trough in the NE Atlantic. Their results indicated that most plastic particles were found in the top 0.5 cm of sediment with a mean of 0.197 ±0.129 MP/gram of dry weight (g d.w) (Courtene-Jones et al., 2019). These results are similar to those found in coastal sediments (Claessens et al., 2011; Clunies-Ross et al., 2016; Frias et al., 2016). The abundance of microplastics was between 20 and 80 pieces/10 g of sediment (Mathalon & Hill, 2014). By far, Zbyszewski and Corcoran, (2011) have observed that polyethylene (PE) is the most common plastic in industrial areas,

The reported abundances of microplastics in global surface waters differ dramatically. They range from less than one piece/m^3 to thousands of pieces/m^3 (Anderson et al., 2016). In water samples from the Northeast Atlantic collected by Lusher et al. (2014), more than 90% of their samples contained microplastics with a density of 2.46 pieces/m^3, which were mainly black or blue fibres (Lusher et al., 2014). Lake Ontario's surface waters contain between 90,000 and 6,700,000 particles/km^2 (Helm et al., 2016).

Notably, some five African countries such as Egypt, Nigeria, South Africa, Algeria, and Morocco—are among the top 20 plastic waste producers globally (Jambeck et al., 2018). The scarcity of clean drinking water exacerbates the plastic waste problem in most African regions. In many of the continent's megacities, drinking water is packaged in single-use sachets and plastic bags (Angmor, Frimpong, Mensah & Okyere, 2024). Ghana, Nigeria, and Liberia collectively consume 8.2 billion, 7.3 billion, and 277.4 million plastic water sachets annually (Wardrop et al., 2017). These three countries generate a total of 28,000 tons of plastic waste annually from high-density polyethylene (HDPE) and low-density polyethylene (LDPE) packaging alone (Wardrop et al., 2017).

In furtherance of the above, with regards to comparative consumption patterns, per capita sachet water consumption in Ghana and Liberia is comparable to the 2013 per capita bottled water consumption in the United States and the United Kingdom, respectively (Ersek, Sharples, & Thomas, 2022). Specifically, Ghana's annual per capita sachet water consumption is 149.1, while Nigeria's is 20.0, and Liberia's is 30.9 (UNDESA, 2015). These figures underscore the high levels of packaged water consumption in West Africa, particularly in Ghana. Hence, plastic waste poses an environmental challenge and a major socio-economic development issue in African countries. It impacts biodiversity, infrastructure, tourism, and the livelihoods of fisheries (Doughty & Eriksen, 2014; Jambeck et al., 2018; UNEP, 2014).

Plastic Pollution Situation in Ghana

The transformation of the political economy of plastics in Ghana is undergoing significant changes, with a rise in domestic plastic consumption and participation in the global plastic waste trade. The country generates around one million tonnes of plastic waste annually, managed through both formal and informal channels (Ministry of Environment, Science, Technology and

Innovation (MESTI), 2020). However, the treatment and disposal aspects of waste management remain inadequately prioritized, leading to significant inequality (Mudu et al., 2021). Mensah (2021), in tracing the historical trajectory of plastics in Ghana, highlighted the pervasive nature of plastics in Ghanaian daily life since the 1990s. This period saw the widespread adoption of plastic bags in place of traditional baskets for market visits and the replacement of plantain leaves with plastic food containers ‘takeaway’ -by street food vendors. Additionally, refillable water glasses were exchanged for sachet water, popularly referred to as ‘purewater’. These changes were framed as convenient and hygienic, contributing to the normalization of plastic packaging in Ghanaian households.

The National Plastics Management Policy 2020 (MESTI, 2022) indicates that there are currently 120 plastic-producing companies in Ghana, collectively manufacturing approximately 52000 plastic products annually. Despite the well-documented adverse health effects and the absence of effective waste management infrastructure, toxic and wasteful plastic packaging continues to proliferate in the country. Ghana's colonial history plays a critical role in shaping the current plastic waste issues (Sibeko & Korokoro, 2019), with enduring power dynamics reflecting entrenched colonial legacies (Little, 2019). The nation's involvement in the global plastic waste trade has been criticized as a form of waste colonialism. Additionally, the proliferation of unsustainable plastics in domestic production further exacerbates environmental injustice (Lerner, 2020). The resolution titled "End Plastic Pollution" passed by the UN Environment Assembly in 2022 mandates the development of a legally binding agreement to address plastic pollution by 2024 (UNEP, 2022). These issues have prompted the establishment of international conventions, such as the Bamako Convention and the Basel Convention, aimed at protecting African countries from illegal dumping and incineration of hazardous waste (Chandrasekhar, 2022; UNEP, 1989, 2018, 2022).

Generally, policies have been implemented to control plastic waste management systems (Awo, 2019). For instance, efforts have been made by the government and non-governmental agencies to address plastic pollution in Elmina, Tema and other coastal communities in Ghana. These efforts have been translated into initiatives to ban single-use plastics. Additionally, frequent clean-up efforts and awareness about plastic pollution have been engaged in such communities (Plastic Punch, 2021),

Significantly, as the Ellen MacArthur Foundation (World Economic Forum, 2016) reported, 'without significant action' by the year 2050, the number of plastics will outweigh the number of fishes in the marine ecosystem. This may result in food fish scarcity, leading to malnutrition, especially in children.

Impact of plastic pollution on marine ecosystems and human health

Ecosystem health, according to Rapport, Böhm, and Oldenborger (2021), is the condition of an ecosystem in which its dynamic attributes, such as biodiversity, productivity, and the capacity to adapt to change, are sustained over time, ensuring the continued provision of ecosystem services that support human well-being. Human health, as defined by the World Health Organization (WHO, 1948), is ‘the state of complete physical, mental and social well-being and not merely the absence of disease or infirmity’. Additionally, literature has expanded on this concept to incorporate elements of environmental and social determinants of health, highlighting the interconnectedness of human health with broader ecological and societal factors (Marmot & Wilkinson, 2005).

The health of marine ecosystems and human health are intricately linked. The deterioration of marine ecosystems can have profound impacts on human well-being, primarily through the provision of ecosystem services such as food, water quality, and climate regulation.

The question that arises then is, 'How is the health of marine ecosystems deteriorating? Marine ecosystems are facing significant stress due to pollution, overfishing, habitat destruction, and climate change. The degradation of coral reefs, mangroves, and seagrass beds reduces biodiversity and the resilience of these ecosystems (Hughes et al., 2017). These habitats are crucial as they provide spawning grounds for fish, protect coastlines from erosion, and support tourism and recreation. Pollution, particularly plastic pollution and chemical contaminants, has a devastating impact on marine life.

Furthermore, marine organisms, ranging from zooplankton to large mammals, often ingest plastic debris especially microplastic (MP), mistaking it for food (Adika et al., 2020; Browne et al., 2008; Cole et al., 2011; Courtene-Jones et al., 2017; Hall et al., 2015; Hoarau et al., 2014; Imhof et al., 2013; Nelm et al., 2018; Setala et al., 2014; Thompson et al., 2004; Wright et al., 2013b). Ingestion of plastics occurs in varying modes of feeding, which include filter-feeding, inhalation at the air-water surface, suspension-feeding, devouring prey exposed to microplastics, or through direct ingestion (Baulch & Perry, 2014; Depledge et al., 2013). This ingestion can cause physical harm, such as blockages in the digestive system, reduced feeding, subsequent malnutrition, or starvation (Wright et al., 2013a). Once microplastics are ingested, they are transferred to the higher trophic levels in the food web (Andersen et al., 2016; Farrell &

Nelson, 2013; Murray & Cowie, 2011; Setala et al., 2014). According to Botterell et al. (2019), plankton, due to their similar sizes to the microplastics, are the gateway of microplastic entry to the food web, because they are often mistaken as food by predators (consumers) (Browne et al., 2007).In the food chain and web, zooplankton are a crucial food source but they ingest MP (Nelms et al., 2018). Reports on some marine plankton ingestion observed are: Marine algae (*Scenedesmus* sp.), grazing microzooplankton (marine ciliate: *Strombidium sulcatum*), polychaete, (*Arenicola marina),* sea cucumber, (*Holothuria floridana)* adsorps nano/microplastics, (Wright et al., 2013b). More species have been studied on their ingestion of microplastic: some species can excrete immediately after ingestion, for example, copepods, amphipods, and mud snails (Imhof et al., 2013; Setala et al., 2014). Others such as *Gammarus pulex* (amphipod), *Potamopyrgus antipodarum* (mud snail), and *Eurytemora affinis* (copepods) absorb and accumulate microplastics (Imhof et al., 2013; Setala et al., 2014). From the various feeding methods, Arthur et al. (2008b) noted that filter feeders may consume MP particles directly from the water column whilst, Leslie et al. (2014) concluded that filter feeders may have more exposure to microplastics than other feeding methods. Also, there is evidence of microplastic ingestion in both pelagic and demersal fish species reported globally (Adika, 2020; Lusher et al., 2013; Munno et al., 2016; Pappoe et al., 2022; Phillips, 2014; Rasta et al., 2020; 2021). On the other hand, few other studies have quantified macro and microplastics in aquatic mammals, turtles, and seabirds. Such studies include Eriksson and Burton (2003): which explored scat of Macquarie Island Fur Seals; Nelms et al. (2018), who examined the scat of Cornish grey seals *(Halichoerus grypus)* in Gweek. Ryan et al. (2016), examined about 32 species of seal, and 12 sp. were detected to ingest marine debris. Hoarau et al. (2014) deduced small pieces of mesoplastics within marine turtles as evidence of broken-down larger plastics within the gastrointestinal tract (GIT), A study on sea turtles by Schuyler et al. (2014) reported plastic bags mistaken for jellyfish, ingested and causing harm to sea turtles. The ingested plastic may cause harmful destruction to intestinal functionality (Nelms et al., 2018; Wright et al., 2013a) or instant mortality.

Effects of exposure to ingested plastics

Plastics are made of harmful chemicals, and these harmful chemicals (e.g., phthalates, bisphenol A) are released when they come in contact with water bodies, affecting marine organisms and ecosystem balance. Plastics can also adsorb and concentrate harmful chemicals, such as persistent organic pollutants (POPs). These chemicals can then be ingested by marine organisms along with the plastic, leading to bioaccumulation and biomagnification through the food web (Rochman et al., 2013b). These toxic substances can cause various health problems in marine life, including endocrine disruption, reproductive issues, and increased mortality rates (Rochman, 2016; Teuten et al., 2009).

Anderson et al. (2016), Andrady (2011), Cole et al.(2011) and Ross & Morales-Caselles (2015) have classified the mode of toxins transmission into three pathways: 1) the stress of ingestion and energy used for egestion during physical blockage, 2) leached additives from plastic, for example, plasticisers, and 3) exposure to microplastics contaminants (e.g., persistent organic pollutants or 'POPs). The consequences of exposure to microplastics vary according to the accumulation volume, the organism's ability to excrete particles, and possible trophic transfer (Wright et al., 2013a).

Further, toxins from plastics accumulate in the food chain, affecting higher trophic levels (e.g., fish consumed by humans) (Andrady, 2011). The ingested plastics by marine species may also result in long-term changes to genes (DNAs) and the reproductive makeup of organisms– a phenomenon which has been comprehensively explained by these authors (Brow et al., 2022; de Las Hazaset al., 2022; Hodkovicovaet al., 2022 and Maranaet al., 2022).

Plastics can also entangle and damage fragile habitats; for example, critical marine habitats, such as coral reefs, mangroves, and seagrass beds can be damaged by plastic pollution. Also, plastic debris can smother coral reefs, blocking sunlight and hindering photosynthesis, which is essential for the health of these ecosystems (Lamb et al., 2018), ultimately leading to a loss of biodiversity and ecosystem function (Gregory, 2009). Animals like sea turtles, seabirds, and marine mammals can become entangled in plastic debris, affecting their mobility, feeding, and reproductive abilities. Furthermore, the longevity and persistence of plastic last for centuries causing a continual damaging impact on marine ecosystems. The loss of marine biodiversity and habitat degradation, due to plastic pollution can impair the ability of ecosystems to provide essential services such as carbon sequestration and coastal protection. This can increase human vulnerability to climate change impacts, such as more frequent and severe storms and sea-level rise (Barbier, 2017).

Impact of plastics on human health

The health of marine ecosystems directly affects human health through the consumption of seafood. Plastic pollution contaminates food and water sources, leading to the ingestion of microplastics by humans (Thompson et al., 2009). Microplastics have been found in seafood, drinking water, and even table salt

(Smith et al., 2018). Concerns raised about plastic ingestion among people living in East and West Africa are worrying. It is alleged, that, residents in these areas tend to consume fish which may contain microplastics in their gastrointestinal tract as well as other parts, which may be detrimental to the health of the residents who consume this fish (Adika et al., 2020; Browne et al., 2013; GESAMP, 2015; Rochman et al., 2013a & b; and Wright & Kelly, 2017). Also, adsorb toxins (POPs, heavy metals, and other hazardous substances) by plastics from the environment can be transferred to humans (Teuten et al., 2009). Contaminants such as heavy metals, persistent organic pollutants (POPs), and microplastics in marine organisms can accumulate in human tissues over time (Rochman et al., 2013c), leading to various health issues. Such health issues include cancer, neurological disorders, and reproductive problems (Rios-Mendoza et al., 2018; Schecter et al., 2010). For instance, POPs are known to cause endocrine disruption, reproductive and developmental problems, and increased cancer risk (UNEP, 2009). The incineration of plastic waste releases toxic fumes, including dioxins, furans, and polychlorinated biphenyls (PCBs), which can cause respiratory problems and other health issues when inhaled (Auta et al., 2017; Wang et al., 2016). Additionally, the presence of microplastics in the air can contribute to respiratory issues when inhaled, posing a risk to lung health (Gasperi et al., 2018). Certain chemicals used in the production of plastics, such as bisphenol A (BPA) and phthalates, are known endocrine disruptors. These substances can interfere with hormone function, leading to a range of health problems, including reproductive disorders, obesity, diabetes, and thyroid dysfunction (Talsness et al., 2009).

In conclusion, plastic pollution poses significant risks to human health through the contamination of food and water, exposure to toxic chemicals, and respiratory issues. Addressing this issue requires comprehensive strategies that include reducing plastic use, improving waste management, and conducting further research to understand and mitigate the health impacts.

Statement of the Problem

The issue of plastic pollution is a significant global concern that threatens the environment, human health, and sustainable development (Awuchi & Awuchi, 2019). African countries, including Ghana, are particularly affected by factors such as rapid urbanisation and population growth, increased consumption, and inadequate waste management infrastructure (Baeumler et al., 2021). Ghana faces challenges in establishing effective waste management systems, leading to waste accumulation and improper disposal, blocked drainage systems, and air pollution (Mudu et al., 2022; Williams et al., 2023). The extensive use of single-use plastics and synthetic hair extensions, both made of plastic, only worsens the problem, as these items end up in landfills and waterways, damaging our ecosystems and public health (Adam et al., 2021; Franklin-Wallis, 2023).

Plastic pollution has several adverse effects on the marine ecosystem. Wildlife entanglement and ingestion are common consequences of plastic debris in the oceans (Oguz et al., 2018). Plastic waste accumulation in coastal and marine habitats, including coral reefs, mangroves (Goncalves, 2023; Musah et al., 2021), and seagrass beds, leads to habitat destruction, reduced biodiversity, and loss of nurseries and feeding grounds for marine species (Gallo et al., 2018; Tekman et al., 2022; Thompson et al., 2009). Plastics contain toxic chemicals that can disrupt the physiological processes of marine organisms, impair reproduction, and weaken the immune systems of marine organisms, leading to chemical pollution (Rochman et al., 2015). As plastics break down into smaller particles, microplastics thus, less than 5 millimetres in size, are formed and can be ingested by marine organisms, leading to potential health risks for organisms at higher trophic levels, including humans (Zarfl & Matthies, 2019). Plastic pollution can disrupt the natural balance of marine ecosystems, leading to population declines and imbalances in the food web, which can have cascading effects on the entire ecosystem (Horton et al., 2017). Also, plastic pollution has significant implications for human health, as toxic chemicals from plastics can leach into water and soil (Barboza, Vethaak, Lavorante, Lundebye & Guilhermino, 2018; Smith et al., 2018; Usman et al., 2020). Air pollution from burning plastic exacerbates respiratory problems (WHO, 2024) and can contribute to the release of greenhouse gases, resulting in climate change. Lastly, plastic pollution can negatively impact the fishing, aquaculture, and tourism industries, which rely heavily on healthy marine environments (Cózar et al., 2014).

The rise in attention in the study of microplastics has been driven by health and environmental concerns (UNEP, 2016). Waste disposal and mismanagement have been widely discussed in various publications. Yet, there is limited information on the impact of plastic pollution on the food habits of commercially exploited species in Ghana. The Ghana Population and Housing Census in 2021 report suggests tons of plastic waste is generated daily in Tema and Elmina; with about 250, 000 tons dumped into the Atlantic Ocean annually (Alimi et al. 2020; Gbogbo et al. 2023). The level of plastic in the Atlantic

Ocean is forcing fishers to resort to other waterbodies and livelihood options in Ghana (Chasant, 2020). However, studies on plastics in Ghana have focused mainly on macroplastic debris in marine water, sediment, and riverine ecosystems, (Blankson et al. 2022; Chico-Ortiz et al 2020; Gbogbo et al. 2020). Despite the potential harm caused by plastics in fish species, research on this topic has not received much attention in Ghana (Adika et al., 2020; Pappoe et al., 2022). Also, a few sediment-related studies have overlooked the mesoplastics analysis in the literature (e.g., Chico-Ortiz et al., 2020), and with no seasonality considered in the study. Available literature (Adika et al., 2020) on microplastic is generally limited in microplastic polymer analysis. Therefore, to fill this literature gap, this study shifts attention to a seasonal examination of microplastic contamination in two commercial fish species – *Sphyraena sphyraena* (Barracuda), a pelagic fish, and *Dentex angolensis* (Angola dentex), a demersal fish – commonly landed in Ghana using the FTIR spectroscopy for polymer identification.

Purpose of the Study

It is well-established that plastic pollution can disrupt the natural ecosystem, leading to population declines, imbalances in the food web, and overall deterioration of the marine environment's health (Horton et al., 2017). Therefore, it is imperative to continuously investigate the potential effects of microplastics on commercially exploited species in Ghana. By doing so, policymakers and stakeholders can acquire the necessary information to make informed decisions, enabling them to manage and mitigate the impact of plastic pollution on Ghana's fisheries and marine environment, ultimately leading to more sustainable and healthier marine ecosystems.

Research Aims and Objectives

This study estimated the spatial distribution, types, and characteristics of macro- and mesoplastic debris on beaches and shoreline sediments in two fishing hotspots in Ghana. The fish under examination serve as a valuable protein source, yet they face considerable pollution risks due to the prevailing plastic waste menace. The primary aim of this study is to analyse the distinctive features of microplastic found in the examined samples. These features may impact the ingestion rate of micro-particles originating from plastic and provide insights into the types of plastics to which Ghanaian fish are exposed in their natural habitat. Based on the aims, the present study had two main objectives:

1. To evaluate the level of plastic pollution along the coast of Ghana, with specific focus on macroplastic and mesoplastic litter on beaches around artisanal fishing hotspots

2. To examine microplastic contamination in two commercial fish species –*Sphyraena sphyraena* (Barracuda), a pelagic fish, and *Dentex angolensis* (Angola dentex), a demersal fish – commonly landed in Ghana.

Significance of the Study

Over the past few decades, the production and the consumption of plastics has increased dramatically, leading to a global production estimate of 368 million metric tons in 2019 alone (PlasticsEurope, 2020). Unfortunately, the mismanagement of plastic waste has caused it to accumulate in a variety of ecosystems, from deep oceans to remote landscapes, resulting in a range of negative consequences for biodiversity, ecosystem functioning, and human health (Jambeck et al., 2015; Lebreton et al., 2017). The negative effects of plastic pollution go beyond just environmental degradation, with studies demonstrating that plastics can transport dangerous substances and pathogens, leading to the spread of pollutants and diseases in both aquatic and terrestrial environments (Meng et al., 2021; Rochman et al., 2013a; Teuten et al., 2009; Zhong et al., 2023). Wildlife is also affected, with entanglement and ingestion of plastics causing physical harm and mortality for marine mammals, seabirds, and fish (Laist, 1997; Wilcox et al., 2015). Tackling the complex and interdisciplinary nature of plastic pollution requires a collective effort from scientists, policymakers, and the public. This study aims to explore the current knowledge regarding plastic pollution, its spatial distribution, types, and characteristics in two fishing hotspot communities in Ghana, to inform evidence-based policies and practices to mitigate the adverse impacts of these persistent pollutants on our planet.

Delimitation

The study is about plastic pollution, which has become prevalent in the marine ecosystem and is gradually being incorporated into marine organisms' feeding habits, especially fish species. The study area focus was mainly the marine hotspots of two coastal regions of Ghana- Tema in the Greater Accra and Elmina in the Central region, specifically along the coastal beaches, within the sediments, and among the marine fish species in the water body. Within the fish species, the gastrointestinal tract (GIT) was observed where some microplastics were retrieved.

Limitations

The study of plastic pollutants in the environment is not a new area of study, but the mesoplastic and microplastic study are new areas in Ghana. However, currently, there are no developed methodologies to suit our environmental space (Tropics). Therefore, the adopted method used in temperate regions is used which may not necessarily suit the tropical regions.

Definition of Terms

Plastics: *a synthetic, organic polymer made from fossil fuels (IUCN Commissions, 2024).*

Polymer: a substance made of many repeating units *(Science History Institute, 2024).*

Macroplastics: plastics with a size greater or equal to 2.5cm (25 mm) (Cheshire et al., 2009)

Mesoplastics: plastics with a size greater than five millimetres but equal to 2.4cm (<5 mm = 24 mm) (Cheshire et al., 2009)

Microplastics: plastics with a size less than or equal to five millimetres (≤ 5 mm) (Cheshire et al., 2009).

Pollution: introduction of harmful materials into the environment, (National Geographic, 2024).

Plastic Pollution: accumulation in the environment of synthetic plastic products to the point that they create problems for wildlife and their habitats as well as for human populations *(IUCN Commissions, 2024)*.

Bioaccumulation: The gradual accumulation of substances, such as plastics and their associated chemicals, in an organism over time (Teuten et al., 2009).

Persistent Organic Pollutants (POPs): Toxic chemicals that adversely affect human health and the environment over long periods (UNEP, 2009).

Biodiversity: The variety of life in a particular habitat or ecosystem, crucial for maintaining ecosystem resilience and function (Hooper et al., 2012).

Ecosystem Services: The benefits that humans obtain from ecosystems, including provisioning (e.g., food and water), regulating (e.g., climate regulation), supporting (e.g., nutrient cycling), and cultural services (e.g., recreational and spiritual benefits) (Costanza et al., 1997).

Organisation of Study

The research is divided into six chapters. Chapters one and two follow the typical thesis format, while Chapters three, four, and five are drafted as manuscripts addressing specific issues on plastic pollution. Chapter six focuses on the summary, conclusion, and recommendations.

Chapter One primarily serves as the introduction, providing the background of the study and the history of the topical issues and their effects. Chapter Two focuses on the literature review, which includes various articles related to the study. It discusses the approaches used to address issues related to the topic and outlines international and local laws and treaties guiding and guarding against plastic pollution.

Chapter Three examines the prevalence of macroplastic pollutants, mainly along coastal beaches, observing their physical characteristics, photochemical characteristics, and polymer makeup. These pollutants were also quantified based on seasonal observations in two study areas.

Chapter Four addresses the prevalence of mesoplastic pollutants mainly within the sediment of coastal beaches, discussing their physical characteristics, photochemical characteristics, and polymer makeup. Their seasonal abundance is quantified in two study areas.

Chapter Five addresses microplastic pollutants that are being ingested or consumed by some marine fish species. The study observed two fish species, pelagic and demersal, to determine if they are contaminated with microplastics. The study identified the plastic's types, colours, and polymer makeup and quantified its presence based on seasonal observations in two study areas and among the two species. Chapter Six presents the summary of the study, its conclusions or outcomes, and outlines recommendations for future research.

Chapter Summary

This chapter introduced the topical issue of ‘plastic pollution’ of the research. This included the background history and the global and local perspectives of plastic pollution. The problem statement or the need for this study and how other studies approached solving or tackling the issue were reviewed. Finally, the challenges and supporting treaties available to guide and inform plastic users were outlined.

CHAPTER TWO

LITERATURE REVIEW

Economic Impact of Plastic Pollution

Plastic pollution can result in economic losses to industries such as fisheries, aquaculture, and tourism, which depend on a healthy marine ecosystem. The marine fishing industry, especially, is vulnerable to plastic pollution, as it can cause damage to fishing gear, decrease catch rates, and affect quality and seafood safety. Indonesia, for instance, losesUS$270 million annually due to plastic debris in their fishery (COSTI, 2015). Tourism is another industry heavily impacted by plastic pollution, as visitors are attracted to coastal destinations for their recreational activities. Plastic waste on beaches can deter tourists and reduce spending, leading to loss in revenue for the government and local businesses. A study in the Philippines estimated that plastic waste reduced annual tourism revenue by approximately $US 233 million (ADB, 2018). Even though Ghana has reported no losses in the tourism industry due to plastic pollution, the need to address the situation is now.

International Treaties for Addressing Marine Plastic Pollution

Marine plastic pollution has become a global environmental challenge that requires a concerted effort from the international community to address. In tackling this issue, various international treaties have been established. One of the most prominent treaties is the United Nations Convention on the Law of the Sea (UNCLOS), which recognises the importance of protecting the marine environment and encourages states to take measures to prevent pollution (United Nations, 1982).

Another important treaty is the International Convention for the Prevention of Pollution from Ships (MARPOL), which sets out regulations for preventing pollution by ships, including the discharge of plastics into the sea (International Maritime Organization, 1973). The Convention on Biological Diversity (CBD) also recognises the impact of marine plastic pollution on biodiversity and ecosystems and encourages states to take measures to prevent it (Kim, Tanaka, & Perrings, 2019).

In addition, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal addresses the issue of plastic waste trade and encourages states to prevent the export of hazardous waste, including plastic waste, to developing countries (Goyal, 2018). The Stockholm Convention on Persistent Organic Pollutants also addresses the issue of plastic pollution by regulating persistent organic pollutants (POPs), which can accumulate in the marine environment and harm marine life (Mohapatra, Nøklebye, Arora, & Basu, 2023). Furthermore, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, adopted by the United Nations Environment Programme, encourages states to take measures to prevent land-based sources of marine pollution, including plastic waste (Cham, 2017). These international treaties are crucial in addressing marine plastic pollution and promoting sustainable development. However, their effectiveness depends on the willingness of states to implement and enforce them, as well as the collaboration and cooperation of the international community.

African Treaties for Addressing Marine Plastic Pollution

Plastic pollution has emerged as a significant threat to marine ecosystems, wildlife, and human health, particularly in the African continent. A work shop titled "A Global Treaty on Plastic Pollution: Perspectives from Africa" (Stöfen-O'Brien, 2022) has emphasised the need for effective solutions to address plastic pollution in Africa and the significance of a coordinated global response. The workshop participants highlighted the increasing global momentum to address plastic pollution and cited initiatives such as the Ocean Day Plastic Pollution Declaration at the UN High-Level Debate on the Ocean (Stöfen-O'Brien, 2022). African nations have committed to advancing discussions on plastic pollution mitigation at international forums, including the United Nations Environment Assembly (UNEA) (Stöfen-O'Brien, 2022).

According to the report by UNEA, there are gaps in national policies concerning plastic pollution management, including inadequate regulatory frameworks, weak enforcement mechanisms, and limited capacity for waste management across African countries (Stöfen-O'Brien, 2022). The workshop emphasised the necessity of a global treaty to effectively combat plastic pollution, with African perspectives playing a crucial role in shaping this collective vision. The workshop participants emphasised the importance of coordinated international efforts to address the root causes of plastic pollution and implement sustainable solutions.

The workshop discussed various potential elements of a global treaty, including extended producer responsibility (EPR), circular economy approaches, and enhanced collaboration among governments and organisations (Stöfen-O'Brien, 2022). These perspectives underscored the importance of adopting holistic and innovative strategies to address plastic pollution at its source.

The report highlights the need for continued collaboration, knowledge sharing, and policy development to address marine plastic pollution in Africa effectively. It calls upon African nations to actively engage in global initiatives to mitigate plastic pollution and safeguard marine ecosystems for future generations (Stöfen-O'Brien, 2022).

Policy recommendations

Based on insights from the workshop, some policy recommendations were proposed to address this issue.

Firstly, there is a need to reinforce global commitments to end plastic pollution by advocating for stronger international agreements and cooperation. The United Nations Environment Programme (UNEP) notes that only 9% of plastic waste is recycled, and the global production of plastics has increased from 1.5 million tons in 1950 to 359 million tons in 2018. Therefore, stronger global commitments are essential.

Secondly, national policies and action plans for plastic pollution management must be enhanced; attention should be focused on effective waste management, recycling, and reduction strategies. The World Bank estimates that the cost of inaction on plastic pollution management in Africa could reach $13 billion annually by 2030. Therefore, investing in national action plans and policies is crucial for mitigating plastic pollution's economic and environmental impacts.

Lastly, global policies must be harmonised with regional instruments to prevent marine litter. Collaboration with organisations such as the African Union Commission (AUC) and the United Nations Environment Assembly (UNEA) is crucial. The AUC's Agenda 2063 and the UNEA's Global Plan of Action for Marine Litter are regional instruments that can be aligned with global policies to prevent marine litter and promote sustainable environmental stewardship.

In conclusion, addressing marine plastic pollution in Africa requires national, regional, and global efforts. Implementing the proposed policy recommendations and fostering international cooperation can help African nations mitigate the impacts of plastic pollution and promote sustainable environmental stewardship.

Implemented 'plastic 'pollution' policies in Africa

Several African countries have implemented policies and initiatives to address plastic pollution. For instance, Kenya implemented one of the strictest bans on plastic bags in 2017, prohibiting their manufacture, sale, and use, with penalties for violators, including fines and imprisonment (Gakuo, 2019). Similarly, Rwanda has implemented a ban on single-use plastics, enforced through stringent regulations, including fines and confiscation of prohibited items (Kagabo, 2020). South Africa also adopted an Extended Producer Responsibility (EPR) framework to promote a circular economy approach to plastic pollution mitigation, requiring producers to finance and participate in recycling and waste management initiatives (EPR South Africa, n.d.). Also, Tanzania has implemented regulations restricting the use of plastic bags to reduce environmental pollution (Njau & Lyimo, 2020), while Nigeria, emphasising waste reduction, recycling, and public education initiatives, has developed a National Policy on Plastic Waste Management to address the challenges associated with plastic pollution, (FOS & UNIDO, 2013).

These policies and initiatives demonstrate African countries' diverse approaches to tackling plastic pollution. Although progress has been made in some regions, there is a continued need for robust enforcement mechanisms, public awareness campaigns, and collaboration with stakeholders to achieve long-term solutions to this pressing environmental issue.

Ghana's National Plastic Management Policy

Like many other countries, Ghana has recognised the pressing need to address plastic pollution and its adverse effects on the environment, human health, and sustainable development. The National Plastic Management Policy was developed to manage plastics comprehensively, promote recycling, and establish a dynamic domestic recycling industry (Ministry of Environment, Science, Technology and Innovation [MESTI], 2022). The policy has several key aspects that are briefly discussed below.

Vision and Guiding Principles

The policy envisions a comprehensive plastic management system that would contribute positively to natural capital, environmental protection, and socio-economic development. The policy's guiding principles include promoting circular economy approaches, enhancing waste management, and fostering innovation in plastic recycling (MESTI, 2022).

The policy aims to enable the development of a vibrant and market-driven domestic recycling industry, contribute to economic growth, job creation, and environmental protection, and mitigate climate change by addressing plastic pollution (MESTI, 2022).

Past Efforts and Legal Framework

Ghana has made efforts to manage plastics over the years. In the 1980s, a committee was established to research the challenges posed by plastic waste in the country. Currently, the existing environmental policies and relevant legislation provide a foundation for plastic waste management (MESTI, 2022; United Nations Environment Programme [UNEP], 2019).

Ghana's plastic management efforts align with the SDGs, particularly Goal 14 (Life Below Water) and Goal 12 (Responsible Consumption and Production). The policy emphasises sustainable practices and responsible plastic use (MESTI, 2022).

Plastic Waste Management in Ghana

Plastic waste management has become a significant environmental challenge in Ghana, with implications for public health, ecological integrity, and sustainable development. Despite efforts to implement waste management strategies, the country grapples with plastic pollution's adverse impacts. This study provides an overview of the current state of plastic waste management in Ghana, examines existing challenges, and explores potential solutions to address this issue.

Current State of Plastic Waste Management

Plastic waste is pervasive in urban and rural areas in Ghana. According to an Environmental Protection Agency (EPA) report, Ghana generates approximately 1.7 million tonnes of plastic waste annually, polluting water bodies, clogging drainage systems, and contaminating soil. Only two percent of this waste is recycled (EPA, 2018). The remaining plastic waste is either burnt or in landfills, posing serious environmental and health risks, spreading diseases, and degrading natural habitats (Amoako et al., 2016).

Like many other developing countries, Ghana faces challenges in managing plastic waste due to rapid urbanisation, population growth, and limited infrastructure for waste collection and disposal (Amoako et al., 2016). Despite the enactment of legislation such as the Environmental Sanitation Policy and the Plastic Waste Management Policy, effective implementation and enforcement remain major obstacles (Boadi et al., 2019). Limited financial resources, inadequate institutional capacity, and a lack of public awareness contribute to the challenges facing plastic waste management in Ghana.

Challenges in Plastic Waste Management

One of Ghana's primary challenges in plastic waste management is the absence of a comprehensive recycling infrastructure. However, informal recycling activities are often inefficient and unregulated, leading to low plastic recycling rates (Amoako et al., 2016). Additionally, the reliance on using landfills as the primary method of waste disposal exacerbates environmental pollution and resource depletion.

Furthermore, inadequate public education and awareness programs contribute to a lack of understanding regarding the importance of proper waste disposal and recycling practices among the populace (Boadi et al., 2019). Behavioural change campaigns and community engagement initiatives are essential for promoting sustainable waste management practices and reducing plastic pollution.

Potential Solutions and Recommendations

Addressing Ghana's plastic waste management challenge requires a multifaceted approach involving government intervention, private sector involvement, and community participation. Strengthening regulatory frameworks, investing in recycling infrastructure, and promoting innovation in waste management technologies are critical steps toward sustainable plastic waste management (Amoako et al., 2016).

Partnerships between government agencies, non-governmental organisations, and local communities are crucial for developing and implementing effective waste management strategies. Which is, more public education campaigns are also vital in raising awareness about plastic pollution's environmental impacts and encouraging sustainable consumption patterns (Boadi et al., 2019). Ghana faces significant challenges in plastic waste management, however, by investing in recycling infrastructure and raising public awareness, it can move towards a more sustainable future.

CHAPTER THREE

THE LEVEL OF MACROPLASTIC POLLUTION ON TWO ARTISANAL FISHING HOTSPOTS IN GHANA

INTRODUCTION

Macroplastic pollution, characterized by large plastic fragments in the environment, has emerged as a formidable challenge to global ecosystems and human well-being. As a subset of plastic pollution, macroplastics, typically defined as plastic debris larger than 25 mm, have become ubiquitous in terrestrial and aquatic environments, posing many ecological and environmental threats (Thompson et al., 2009). The pervasive nature of macroplastic pollution is a testament to the durability of these materials and the inadequacies in waste management and disposal practices (Geyer et al., 2017).

In recent decades, the escalating production and consumption of plastics has exacerbated the issue, with an estimated 368 million metric tons of plastic produced globally in 2019 alone (PlasticsEurope, 2020). The mismanagement of plastic waste, coupled with the persistence of macroplastics in the environment, has led to their accumulation in diverse ecosystems; from the depths of the oceans to remote terrestrial landscapes (Jambeck et al., 2015; Lebreton et al., 2017). Consequently, the deleterious effects of macroplastic pollution on biodiversity, ecosystem functioning, and human health have become subjects of increasing concern within the scientific community.

The consequences of macroplastic pollution extend beyond visible environmental degradation. Studies have shown that macroplastics can act as vectors for transporting hazardous substances and pathogens, facilitating the spread of pollutants and diseases in aquatic and terrestrial environments (Meng, et al., 2021; Rochman et al., 2013b; Teuten et al., 2009; Zhong et al., 2023). Additionally, the entanglement and ingestion of macroplastics by wildlife, such as marine mammals, seabirds, and fish, have been documented as prime causes of physical harm, impaired mobility, and mortality (Laist, 1997; Wilcox et al., 2015).

Earlier studies on plastic waste in Ghana have, however, primarily concentrated on the characterization of littering (VanDyck et al., 2016; Agbozo et al. 2023), spatiotemporal distribution (Gbogbo et al. 2023; Nukpezah et al. 2022), and the behaviour of microplastics (Blankson et al. 2022; Chico-Ortiz et al. 2020; Gbogbo et al. 2020). However, missing in these studies (Gbogbo et al. 2023; Nukpezah et al. 2022; VanDyck et al. 2016) are the seasonal variation and abundance of macroplastic pollutants along the beaches. This study, therefore, explores the current knowledge gap in the macroplastic study, by focusing on the seasonal dynamics or nuances of this debris. Specifically, this section of the thesis examined the seasonal concentration, spatial distribution, types, and characteristics of macroplastics on beaches around fishing harbours in Ghana. The goal of this research was to provide data to inform evidence-based policies and interventions to limit the pollution of Ghanaian beaches. The specific objective was to evaluate the levels of plastic pollution along the coastal beaches of Ghana and their seasonal distribution and abundance.

Beaches around Tema and Elmina fishing harbours were sampled for this study. The selection of Elmina and Tema as the study areas was based on several key factors, including the significant presence of canoe fisheries and fishers in these regions. According to the Ghana Canoe Framework Survey of 2016, the Central region, where Elmina is located, hosts approximately 31% of fishers and 33%

of canoes, while the Greater Accra region, represented by Tema, has 24% of fishers and 23% of canoes. These findings underscore the importance of these regions in the fishing industry and highlight their substantial projected annual fish production. Therefore, focusing on Elmina and Tema is essential for gaining a comprehensive understanding of macroplastic pollution in artisanal fishing hotspots in Ghana.

MATERIALS AND METHODS

Study area

Macroplastics were collected from beaches along two fish landing sites in Ghana These sites were Beach-five, which is around the Tema Fishing Harbour (5°38'36.17"N, 0°1'10.28"E) and Elmina Beach, which is close to Elmina fish landing quay (5°4'56.51 "N, 1°20'50.11"W)(Fig. 1). Sampling was undertaken during the rainy and dry seasons (October 2022 and January 2023 respectively). Factors essential for study area selection include canoe fisheries' and fishers' presence in their regions.

It is worth noting that Tema, situated in the Greater Accra region, has the largest fishing harbour, while Elmina, in the Central region, has the third largest fishing harbour. Both regions are projected to produce a substantial number of fish annually, thus further exploring this topic is imperative.

Sample collection

Sampling was undertaken along a $500m^2$ area established after the high tide mark (Fig. 2). The transect length, 100m by 5 m width, followed OSPAR guidelines and was consistent with previous reports (Lippiatt et al., 2013; Noik and Tuah, 2015; OSPAR, 2010). Macroplastics were handpicked within the transect area (500 m^2), this procedure required no replicates. According to OSPAR (2010),' *if more than one sampling unit occurs on a beach, the minimum separation distance shall be at least 50 m*'. However, the 50 m gap was impossible in this case due to the smaller nature of the selected beaches, so there was no multiple sampling unit.

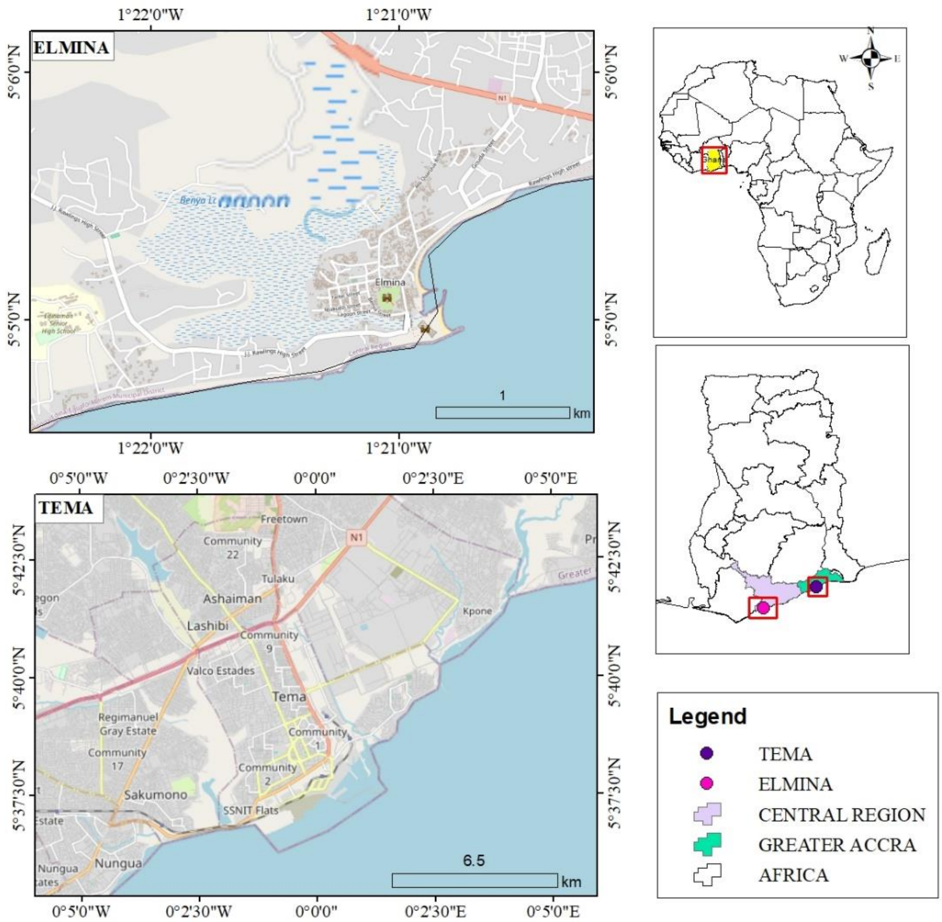

Figure 1: Map of the study area indicating the two sampling sites, Elmina in the Central and Tema in the Greater Accra region.

Sample processing

The debris (plastics/ non-plastic) was rinsed in filtered distilled seawater in the laboratory (Blettler et al., 2017) and dried for 48 hours. The total weight of the dried debris was measured to the nearest 0.1 gram. In accordance with the

NOAA Technical Memorandum (Lippiatt et al., 2013) and OSPAR (2010), all macro-particles were counted and sorted into different categories based on their functional origin. Various physical characteristics (fibre, film, foam, fragment, and styrofoam) of macroplastics were weighed, sizes measured, and their photochemical characteristics (colours) were recorded. The quantities of macroplastic items were estimated per 500 m^2 area. The observed macroplastic item polymers were then identified.

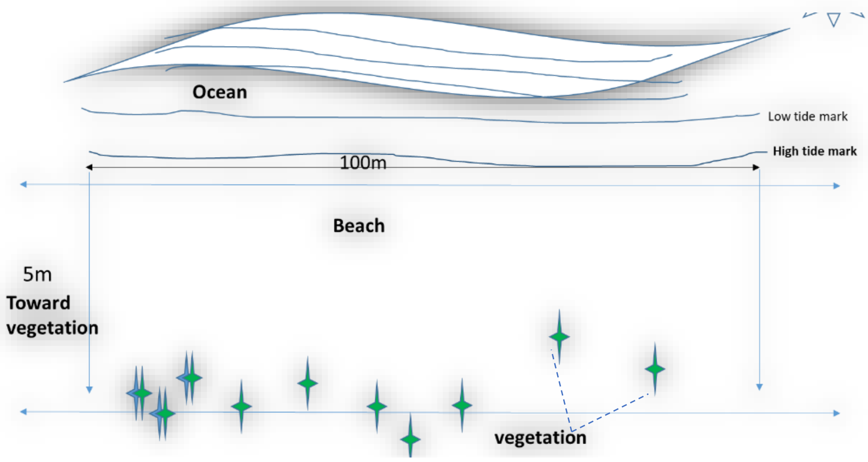

Figure 2: Experimental design of the study of macroplastics from Tema and Elmina fishing hotspots (OSPAR (2010) modified)

Data Analysis

The concentration of macroplastics was estimated by dividing the count and area sampled. The equation for macro debris item concentration (per transect) is given as:

$$c = \frac{n}{(wl)};\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1) \text{ (Lippiatt et al., 2013)}$$

Where *c* denotes the concentration of debris items (no. of debris items m^{-2}); *n*- no. of macro-debris items observed; *w*- transect width (m);*l*-transect length (m).

Clean Coast Index

The Clean Coast Index (CCI) is an index for determining a beach's cleanliness. This index estimates the level of clean beaches based on plastic litter data base (Alkalay et al., 2007). The CCI index is given as:

$$\mathrm{CCI} = \frac{\text{Total litter on sampling unit}}{\text{Total area of sampling unit}} \mathrm{X\ K} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where K= 20. K is a meaningless constant that makes the numerical value of the CCI intuitive. The K = 20 was adopted from the Mediterranean context (Portman and Brennan, 2017). The CCI scale defines values from 0 to 2 as very clean beaches, 2–5 clean, 5–10 moderately clean, 10–20 dirty and > 20 extremely dirty.

Statistical analyses were performed with Statistical Package for Social Sciences (SPSS) software version 26 and Microsoft Excel. Before the analyses, Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check the normality of the data. Also, Mann-Whitney U Test was used to test for differences between two independent groups.

Kruskal-Wallis H Test was used to analyze variance between groups. It compared the scores on continuous variables for three or more groups. Kruskal Wallis was used because it is less sensitive to outliers. A posthoc test using the Bonferroni test was used to determine a pairwise comparison between each independent group (location, season, physical and photochemical characteristics) to assess the statistically significantly different group.

RESULTS

A total of 418 macroplastic litter items were collected from the beaches of Tema Fishing Harbour and 563 items from the beach of Elmina Fishing Quay.

Debris collected comprised 496 during the rainy season (199 from Tema and 297 from Elmina) and 485 collected debris in the dry season (219 from Tema and 266 from Elmina).

1. Concentration of Macroplastic debris

From equation (1), the *Concentration of macroplastics* was calculated for both beaches (study sites) during the two major seasons (rainy and dry) in Ghana.

Concentration of macroplastics - rainy season:

a. Tema Fishing Harbour: $C = \frac{n}{(wl)}$;
   n=199;w=5m;l=100m:

   $C = \frac{199}{(5x100)}$;

   C= 0.398 particles (or items) m^{-2}

b. Elmina fishing quay: $C = \frac{n}{(wl)}$;
   n=297;w=5m;l=100m:

   $C = \frac{297}{(5x100)}$;

   C= 0.594 particles or items m^{-2}

Concentration of macroplastics - dry season:

a. Tema Fishing Harbour: $C = \frac{n}{(wl)}$;

   n=219;w=5m;l=100m:

   $C = \frac{219}{(5x100)}$;

   C= 0.438 particles (or items) m^{-2}

b. Elmina fishing quay: $C = \frac{n}{(wl)}$;

   n = 266;w=5m; l=100m:

$$C = \frac{266}{(5x100)};$$

C= 0.532 particles (or items) m^{-2}

During the rainy season, the concentration of Macroplastics was slightly higher in the Elmina fishing quay 0.594 particles (or items) per m^{-2} rather than Tema fishing Harbour which recorded 0.398 particles (or items) m^{-2}. This observation was not different during the dry season, with Elmina having more particles per m^{-2} than Tema. However, from the two results, Elmina decreased from 0.594 m^2 to 0.532 m^{-2}, whereas, at the Tema Fishing Harbour, macroplastic concentration increased from 0.398 m^{-2} to 0.438 m^{-2} during the rainy and dry seasons, respectively. However, Chi-Square test analyses indicated a statistically significant difference (χ^2 df = 1; $\alpha = 0.05$ $p < 3.84$) (Table 1).

Table 1: **Chi-Square seasonal analyses of macroplastic debris collected from Tema and Elmina**

Locations and Seasons	Observation 1	Observation 2	Expected value	Chi-Square (χ^2) DF=1; $\alpha = 0.05$
T_{DRY} Vrs T_{RAINY}	0.438	0.398	0.418	*0.001*
EL_{DRY} Vrs EL_{RAINY}	0.532	0.594	0.563	*0.003*
T_{RAINY} Vrs EL_{RAINY}	0.398	0.594	0.496	*0.038*
T_{DRY} Vrs EL_{DRY}	0.438	0.532	0.485	*0.008*
T_{DRY} Vrs EL_{RAINY}	0.438	0.594	0.516	*0.023*
T_{RAINY} Vrs EL_{DRY}	0.398	0.532	0.465	*0.018*

Note: T_{DRY}- Tema dry season; T_{RAINY}- Tema rainy season; EL_{DRY}-Elmina dry season; EL_{RAINY}- Elmina rainy season.

2. The Clean Coast Index (CCI)

Result patterns from Equations (1) and (2) have similar reflections. The score of the clean coast index at Tema for each season was 7.96 for the rainy and 8.76 for the dry season, showing a slight rise in the litter. However, the scores indicate a '*moderately clean* beach'. Also, Elmina recorded a decrease in the CCI index (equation 2) from 11.88 in the rainy season to 10.64 in the dry season, showing a decrease in the number of litter items observed. These values fell within the '*dirty beach'* category.

a. *Rainy season*

i. Tema Fishing Harbour

$CCI = \frac{199}{500} X\ 20;$

$CCI = 7.96;$

ii. Elmina

$CCI = \frac{297}{500} X\ 20;$

$CCI = 11.88$

b. Dry season

i. Tema Fishing Harbour

$CCI = \frac{219}{500} X\ 20;$

$CCI = 8.76;$

ii. Elmina

$CCI = \frac{266}{500} X\ 20;$

$CCI = 10.64$

3. Composition of macroplastic debris/litter

The results gathered showed the composition of similar and repetitive occurrences of certain litter items (Table 2 shows the type of plastics collected; see Appendix A for images). Therefore, these litter items were of two main categories- the physical characteristics and the unknown group. The physical characteristics were grouped into five categories fibre, fragment, foam, Styrofoam and film, and the unknown (n.a).

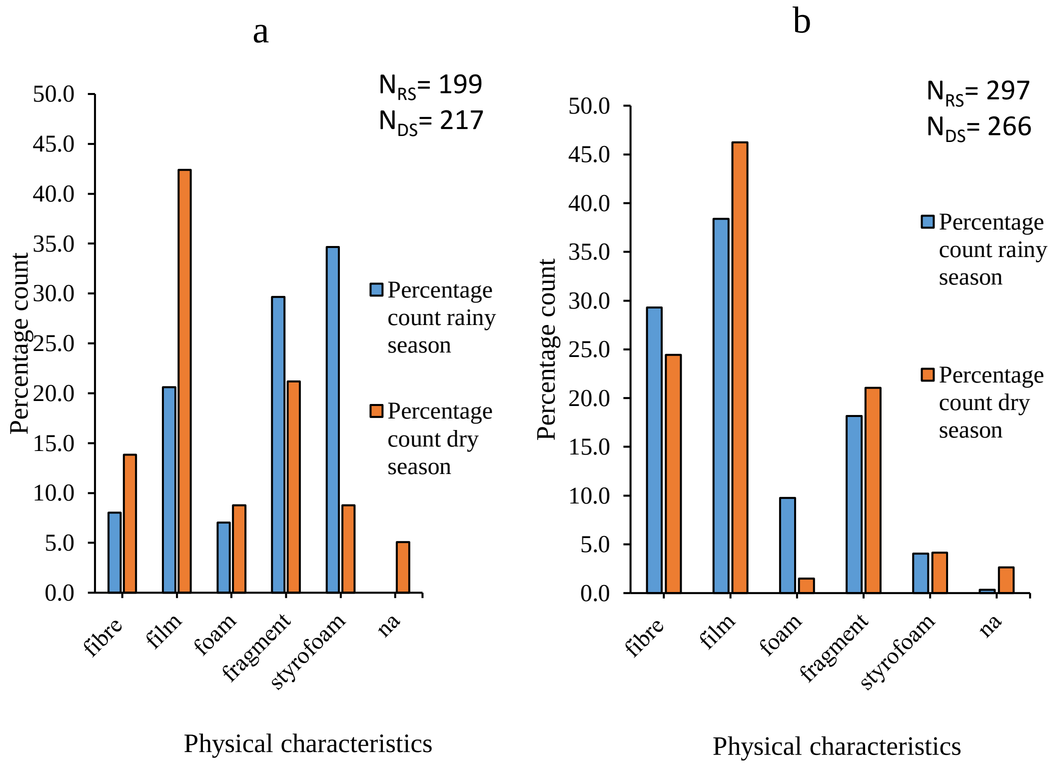

Figure 3: Seasonal macroplastic percentage count at the study sites a) Tema b) Elmina

In the seasonal occurrence, five physical characteristics of macroplastic from the coast of Tema were observed. Particles that did not fit under the five descriptions were classified as *'not applicable'* (na). Seasonal variations were observed in the characteristics in the rainy season 199 macroplastics were sampled, of which the dominant physical characteristic was Styrofoam and foam was the least. The percentage count of debris ranged from 7.0 % to 34.7 %. During the dry season, 217 macroplastics were collected, with the film being the dominant and the ‘not applicable’ (na) group the least. The percentage count ranged from 5.1 % to 42.4 %.

From the Elmina coast, five physical characteristics and the 'na' group, were observed, where 297 and 266 plastics and other litter were collected during the rainy and dry seasons, respectively. Both seasons showed slight variations in the occurrence of physical characteristics. The dominant characteristic was the film for each season, with a slight difference in percentage count- 38.4 % in the rainy season and 46.2 % in the dry season. The least dominant in the rainy season was the na group (0.3 %), and foam (1.5 %) was in the dry season.

Seasonal macroplastic weights (g) of physical characteristics

The seasonal weights of the physical characteristics of macroplastics obtained for the Tema rainy season ranged from 6.8 ± 0.8 to 806 ± 86.2 grams. The heaviest physical characteristic was styrofoam, and the lightest was fibre. Observations in the dry season differed from the rainy season; fragments were the heaviest, while Styrofoam was the lightest. The total (debris) weight ranged from 10.4 ± 0.5 to 206.2 ± 19.7 grams. Elmina's seasonal weights of the physical characteristics were as follows: in the rainy season, the heaviest characteristic was the film and the lightest was the fibre.

The weights ranged from 0.66 ± 2.06 to 7.15 ± 0.25 grams. The dry season weights ranged from 0.49±0.01 to 9.78 ± 0.70 grams.

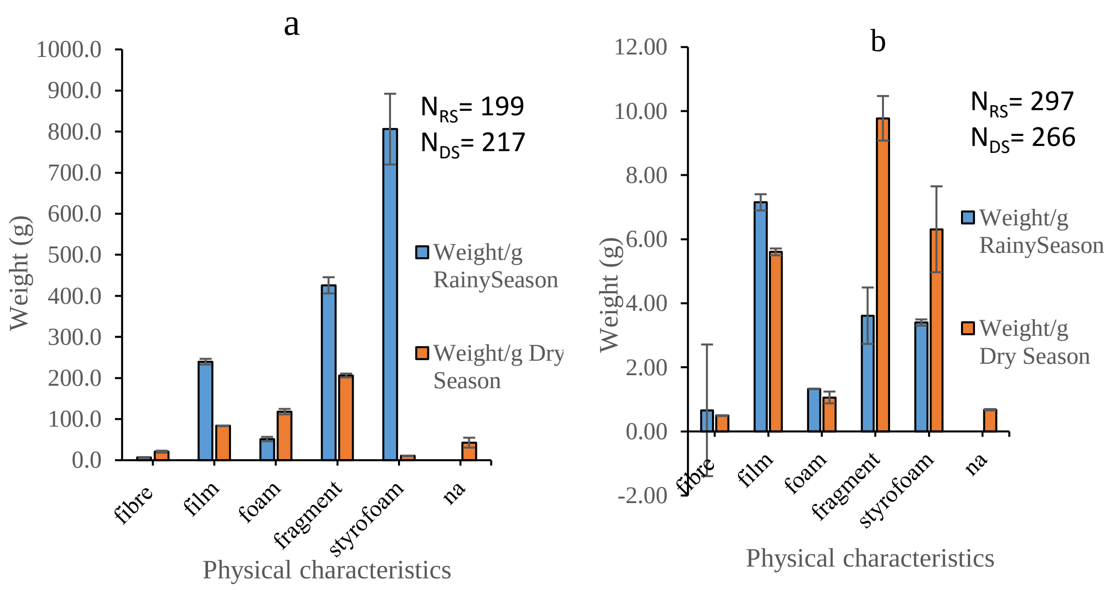

Figure 4: Seasonal macroplastic weights in grams from the study sites a). Tema b). Elmina

Table 2: Macroplastic debris composition obtained in this study

Physical characteristics	Particle Source	Polymer Group
Fibre	mesh, rope, straw (mat/bed/sack) hair (wig)	*Polyamide* (PA/Nylon) *Polyester* (PES)
Film	Plastic bags, phone protectors, single-use, plastic (pure-water sachets) wrappers,	Low-density*polyethylene* (LDPE)
Foam	Refrigerator insulator, bed mattress, floats buoys.	*Polyurethane* (PU) Expanded *polystyrene* (EPS)
Fragment	Hard plastics (bucket, cutlery, cups) bottles, drinking straw Caps and lids (bottle)	High-density *Polyethylene* (HDPE) *Polyethylene terephthalate* (PET) *Polypropylene* (PP)
Styrofoam	Food package/electronics package	*Polystyrene* (PS)

Seasonal photochemical output

The outcome of the seasonal photochemical analysis was as follows: Tema (a) accounted for a total of 22 and 23 colours for the rainy and dry seasons, respectively. White (35.2 %) was the most dominant colour in the rainy season, whereas black (27 %) was dominant during the dry season. The least dominant colours were a range of colours for both seasons, representing 0.5 %. Therefore, for both seasons, 14 colours, of which some were multiple colours (black, blue,

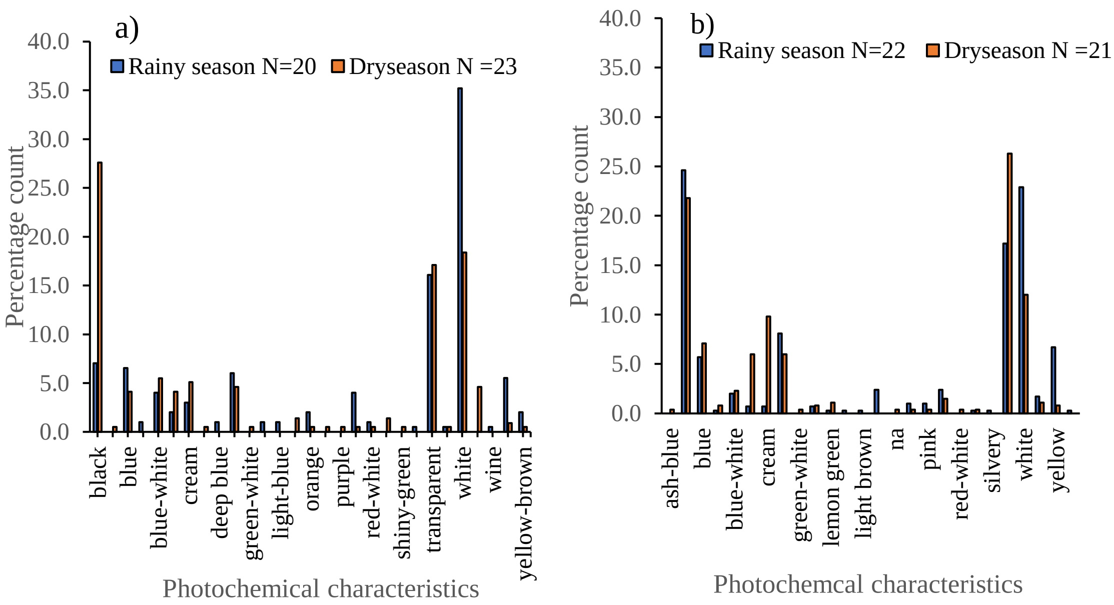

Figure 5: Seasonal photochemical characteristics of macroplastic observed a) Tema, b) Elmina.

blue-black, blue-white, brown, cream, red, red-white, transparent, violet, white, yellow and yellow-brown) were common, whereas 15 differed (black-white,cream-green, deep blue, green, green-white, lemon, light blue, na, orange, pink, purple, sea blue, shiny green, silvery, white-yellow and wine).

The photochemical characteristics observed from Elmina Fig 5(b) totalled 22 in the rainy season and 21 in the dry season. The dominant colour was black (24.6

%) for the rainy season and transparent (26.3 %) for the dry season. There were 13 other colours found, and sea blue was the most common in both seasons. Comparing both seasons, 17 colours, including some multi-colours (black, blue, blue-black, blue-white, brown, cream, green, grey, lemon, orange, pink, red, sea blue, transparent, white, wine and yellow), were common, while nine colours differed (ash-blue, green-white, light blue, light brown, light pink, na, red-white, silvery and white-yellow).

In all, 19 colours (Black, blue, blue-white, brown, cream, green, green-white, lemon green, light blue, orange, pink, red, red-white, sea blue, transparent, white, white-yellow, wine, yellow) were similar to the two sampling areas (Tema and Elmina) and 13 colours differed (ash-blue, black-white, blue-black, blue-green, cream-green, deep blue, grey, light brown, light pink, purple, shiny-green, silvery, violet).

DISCUSSIONS

The number of macroplastics differed slightly per location and season. The concentration of macroplastics was higher in the rainy than in the dry season, which was statistically significant (Table 1). This may be explained by the proximity (originating a depositional area slightly downstream). Tema Beach had a lower concentration of litter than the restricted Elmina Beach. Upon further interaction with community members at Tema, they mentioned a cleaning agency that occasionally cleans the beach. The cleaning could explain why the busy Tema beach had little plastic debris/litter. Elmina Beach is restricted to public usage but available to some construction workers. These workers may have contributed to the litter present. Much of the debris at Elmina was buried, which may be due to water runoff from the hinterland or through the tide bringing litter in and then sand burying it. Further investigation indicated no cleaning agency was responsible for cleaning the Elmina beach. Information received indicated that Elmina Beach used to be open access (Pers. Comm.), which may also confirm the higher litter rate and the buried debris.

At each location, on average, 490.5 particles/500 m^2 were recorded. To compare this research outcome with other works, a simple ratio (dividing 490.5 by five) was calculated to meet the comparison. An average of 98.1 macroplastics were estimated within a 100 m^2 area for Tema and Elmina. Sciacca and van Arkel (2015) reported that the average macrolitter items on beaches were 51 per 100 m^2 for Bermuda, 33 per 100 m^2 for the Azores, and 26 per 100 m^2 for Easter Island, which are all far smaller figures compared to this research. However, Jeyasante et al. (2020) reported higher quantities of macroplastic litter ranging from 138 -616 items/100 m^2 in their research in India. This is perhaps not unexpected since India is one of the world's top five countries that mismanages its waste (Meijer et al., 2021). Early studies conducted in Ghana also reported an average of 129 items/100 m^2 (Bocquentin et al., 2019) and an average of 105.8 items/100 m^2 in the Western Region (Amankwaah et al., 2019). Bocquentin et al. and Amankwaah et al. (2019) recorded higher quantities of items per 100m^2 compared to this study. However, the Clean Coast index result indicated that Tema Beach was moderately clean (7.96 for the rainy season and 8.76 for the dry season), whereas Elmina Beach was considered to be dirty (11.88 for the rainy season and 10.64 for the dry season). The significant components of macroplastics per location and season included food wrappers, plastic bags, foam (refrigerator insulator), food containers, styrofoam (takeaway packs), and hard plastics (Table 2 and Appendix A). These items were grouped into physical (type) and photochemical (colour) characteristics. Physical characteristics were classified into five significant groups, which is acceptable in plastic research (Bletter et al., 2017; Brate et al., 2016; Jeyasanta et al., 2020; UNEP, 2016). These are fibre, film, foam, fragment and styrofoam, as indicated in Table 2. A few items were unidentified (n.a) and were exempted. From the observation in Figure 3(a)-Tema and 3(b)-Elmina, all physical characteristics were present but with varying percentage compositions. Film dominated in the dry season whilst styrofoam was more prevalent in the rainy season at Tema (Fig 7a). At Elmina, the film was dominant for both seasons. Films consisted mainly of plastic bags (shopping bags, single-use plastics); these bags' primary polymers were low-density polyethylene (LDPE). Furthermore, films were primarily black or transparent in colour (photochemical characters- Fig. 5). Jeyasanta et al. (2020) also made this observation in India. The degradation of LDPE samples due to photodegradation in river shorelines was investigated by

Williams and Simmons (1996). They found that the longevity of these plastics is the primary reason for their prevalence and distribution on river banks and beaches. The observation of this current study aligned with this conclusion, as numerous LDPE macro items, mostly shopping bags, especially at Elmina Beach, were in their initial and advanced stages of plastic breakdown. The research indicated that plastic pollution is more commonly associated with domestic solid wastes than industrial ones. In terms of weight contributions (Fig.4), Styrofoam and fragments had the highest contributions in the rainy season at Tema (Fig. 4a). The Styrofoam group consisted of takeaway packs and electronic packages (refer to Table 2). These items may seem light and of low density, but they are heavy, especially when 'whole'. Styrofoam belongs to the polystyrene polymer group and was mainly white in colour (photochemical characters- Fig. 5). In the dry season, fragments were the highest contributor for both locations, consisting of hardplastics, belonging to the High-density polyethylene group. These fragments appeared in various colours, indicating a variety of plastic resins. Figure 5 reveals the seasonal photochemical characteristics for both locations. In Tema, white plastics dominated in the rainy season, whilst in the dry season, black plastics were more prevalent.

Conversely, Elmina recorded black and transparent plastics as the most common in rainy and dry seasons, respectively. Transparent plastic particles were mostly single-use plastics, especially the ‘purewater sachets’ during the dry season due to the “harmattan”; hence, water demand is usually high and may be a contributing factor. The photochemical features reflected the physical characteristics (Fig 4) of the items observed. Table 1 indicates the other polymer groups identified. Polypropylene (PP) is used in food packaging and bottle labelling. PP can break down due to heat and UV radiation from sunlight on dry beach sediments but is resistant to biodegradation (Masry et al. (2021). PP can also absorb harmful organic pollutants, which can cause environmental issues. Jeyasanta et al. (2020) found higher concentrations of pollutants in PP pieces from the sea than in the other waterbodies. Although Jeyasanta et al. (2020) worked mainly in waterbodies, it may indicate that the plastic debris on water surfaces ends up on the beaches due to wave actions. According to Rochman et al. (2013c), not all monomers used in plastic bags are harmful, but they can still absorb other pollutants and thus become toxic.

Polyethylene terephthalate (PET) beverage bottles were also categorised as macroplastics (Table 2). Williams and Simmons (1996) discovered 96 plastic bottles per km in a 5-m wide transect at Merthyr Mawr Beach, an estuarine beach in South Wales. Similarly, Jeyasante et al. (2020) identified 190 bottles in India within a 100 m^2 area. However, this study recorded fewer bottles, about 30 in total. From an ecological point of view, Derraik (2002) observed that the presence of bottles may facilitate the colonisation of species that prefer hard surfaces, which could displace indigenous species. Furthermore, Karatayev et al. (2010) identified the bivalve *Limnoperna fortunei* species as an alien that firmly attaches to hard substrates like plastic bottles at Rio Tercera, Argentina. This confirmed a claim by Derraik (2002) that plastic surfaces may serve as habitat for some species. This study did not observe species attachments at both sites or during the two seasons. It may likely be due to the fewer bottles (32) encountered or the fact that species that may require hard substrate for attachment were absent in both areas.

Chapter Summary

Chapter Three discussed macroplastic pollution, referring to plastics with a size range of 2.5 cm and above. These plastic sizes are very common in the environment, especially in hotspot locations like the beaches in Ghana. The study examined the quantity of plastics within 500 m^2, where the types of plastic materials (physical characteristics), their colours (photochemical characteristics) and their polymer makeup were recorded. This study observed the seasonal occurrence of these plastic debris from two study locations. Analyses indicated that both beaches have some pollution levels, but Tema Beach was cleaner than Elmina using the Clean Coast Index. The study concludes and confirms that plastic pollution is prevalent along water bodies, including the marine.

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CHAPTER FOUR

MESOPLASTIC POLLUTION ON TWO ARTISANAL FISHING HOTSPOTS IN GHANA

INTRODUCTION

Human activity has led to the appearance of marine debris on beaches (Marine Conservation Society, 2004). Unfortunately, plastic and other non-biodegradable synthetic materials are the most common marine debris found, which are responsible for damaging marine habitats and impacting biota (Jeyasanta et al., 2020; Kumar et al., 2016). Although plastics are helpful due to their desirable properties, such as elasticity, hardness, lightness, transparency, and durability, their production has significantly increased over the past two decades (OECD, 2022), generating significant waste with adverse environmental, social, and economic consequences (Debrot et al., 1999; Geyer et al., 2017). Coastal regions are particularly vulnerable to plastic pollution due to their proximity to land-based sources (Jambeck et al., 2015) and are also densely populated. Recent studies have revealed that densely populated countries are significantly affected by plastic pollution. Countries including the Philippines, India, China, Brazil, and Nigeria (the lead in Africa) have the most mismanaged waste (including plastics) globally (Geyer et al., 2017).The African continent alone accumulates about 22 % of global mismanaged plastic.

The West African coastline is particularly at risk of plastic pollution due to its proximity to oceanic currents that carry waste from other regions (Ukwe & Ibe, 2010). The plastic debris items are said to degrade and break down into various sizes: mega, macro-, meso, micro-, and nano-plastics. According to the UNEP, macroplastic is defined as items having a size greater than 2.5 cm (Cheshire et al., 2009). Therefore, macroplastic is the most reported form of plastic pollution, especially in Ghana. Mesoplastic refers to a size ranging from 5 mm to 24 mm. This size of plastic has not yet received much attention compared to that of macroplastic debris. Mesoplastics are often buried, as described by Jeyasanta et al. (2020), and are assumed to be absent.

Chemical components from plastics can leach into sediments and are therefore accessible to sediment-dwelling organisms such as crabs, worms, and other fauna. Studies have shown that broken plastic debris can serve as surfaces for contaminants and pathogens to attach to, which can be transferred to marine organisms and ultimately to humans when consumed (Browne et al., 2013; Meng et al., 2021; Rochman et al., 2013a, 2013b; Zhong et al., 2023). Given the limited research attention, the environmental implications of mesoplastics are a cause for concern. Previous studies on plastic waste in Ghana, however, have predominantly focused on analyzing littering (VanDyck et al. 2016), spatiotemporal distribution (Gbogbo et al. 2023; Nukpezah et al. 2022), and the behaviour of microplastics (Blankson et al. 2022; Chico-Ortiz et al. 2020; Gbogbo et al. 2020). However, what is lacking in these studies (Gbogbo et al. 2023; Nukpezah et al. 2022; VanDyck et al. 2016) is biased to macroplastic debris skipping to microplastic. This study aims to address this existing gap by departing from earlier studies by examining the seasonal dynamics and nuances of mesoplastic pollution in selected Ghanaian beach sediment. This study aims to provide an in-depth analysis of mesoplastic pollution on two of Ghana's hotspot beaches. Specifically, the goal is to estimate the fragments' types, characteristics, and spatial distribution within the sediment.

MATERIALS AND METHODS

Study Area and Study Map

Sampling for this study was undertaken at two locations (Fig. 6). These were Elmina in the Central region (5°4'56.51 "N, 1°20'50.11" W) and Tema in the Greater Accra region (5°38'36.17"N, 0°1'10.28"E).

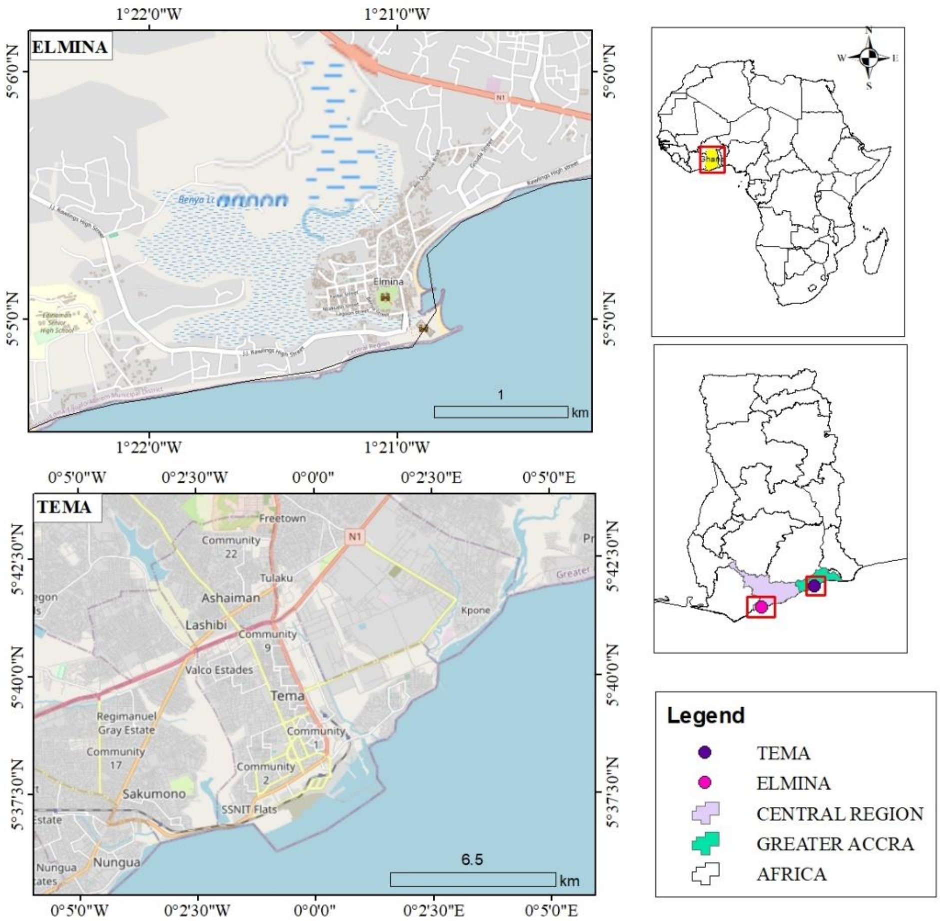

Figure 6: Map of the study area showing the two sampling locations Tema and Elmina

These two regions account for the bulk (56.3 %) of canoes operated in all the 304 beach landing sites along the coast of Ghana (Canoe Frame Survey, 2016). They are also considered to be essential landing sites for artisanal fisheries in Ghana. Based on Ghana's canoe frame survey (2016), ~31% of all fishers and >33 % of all canoes were recorded in the Central region, whereas 24.0 % of fishers and 23.0 % of canoes were recorded in the Greater Accra region. Sampling took place in the rainy season (October 2022) and dry season (January 2023).

Sample collection

Sampling was undertaken along three transects established after the hightide mark (Fig. 7). The length of each transect was 100m long, consistent with previous reports (Lippiatt et al.,2013; Noik & Tuah, 2015; OSPAR,2010). Mesoplastics were sampled from quadrats (50 x 50 cm) established on each transect. Ten quadrats were used on each transect at intervals of 10 m (see Fig 7). Based on previous studies, only the top 5 cm of sediment in each quadrat was collected for the mesoplastic analysis (Gallitelli et al., 2020).

Figure 7: Sampling design of the study of mesoplastics from Tema and Elmina fishing hotspots (modified from OSPAR, 2010)

Sample processing

Each sediment sample was processed in the field using a Retsch stainless steel sieve with a mesh size of 4 mm. All meso-debris collected were returned to the laboratory for further analysis. In consonance with Bletter et al.'s (2017) procedure for analysis of debris, debris was washed in distilled saline water and air-dried for 48 hours. Dried litter items were sorted into five categories based on the physical characteristics universally used for mesoplastic analyses (Bletter et al., 2017; Brate et al., 2016; Jeyasanta et al., 2020; UNEP, 2016). These categories were fibre, fragment, foam, Styrofoam and film. Each category per site was quantified, and the lengths and weights were measured to the nearest 0.1 cm and 0.1 mg respectively.

Data Analysis

The concentration of mesoplastic was estimated by dividing the count by the area sampled. The area concentration (i.e., the number of debris items m^{-2}) was calculated as follows (modified from Lippiatt et al. 2013): $C=\frac{n}{a}$; c – concentration of debris items (no. of debris items m^{-2}); n – no. of debris items observed; a – area sampled.

Statistical analyses

All statistical analyses were performed using Statistical Package for Social Sciences (SPSS) software version 26 and Microsoft Excel. Before the analyses were conducted, Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check the normality of the data. Mann-Whitney U Test was used to test for differences between two independent groups. The analyses were used to compare the concentration of mesoplastics from beach sediments among locations and seasons. The Kruskal-Wallis H Test was used for between-group analysis of variance, comparing the scores of continuous variables for three or more groups. Kruskal Wallis was used because it is less sensitive to outliers. A posthoc test using the Bonferroni test was used to determine a pairwise comparison between each independent group (location, season, physical and photochemical characteristics) to assess the statistical significance between different groups.

RESULTS

Quantitative and Qualitative Description of Plastics

A quantity of1171 and 347 mesoplastic particles were collected from the Tema and Elmina coasts, respectively, during the two seasons in Ghana. Particles comprised 415 in the rainy season and 1103 in the dry season from both sites.

Table 3: Mesoplastics debris composition obtained in this study

Physical characteristics	Particle source	Polymer Group
Fibre	mesh, rope, straw (mat/bed/sack)	*Polyamide* *Polyester*
Film	Plastic bags, phone protectors, single-use plastics (pure-water sachets)	Low-density *polyethylene*
Foam	Refrigerator insulator, bed mattress, floats	*Polyurethane*
Fragment	Hard plastics (buckets, bowls, cutlery, cups, bottles, drinking straw)	High-density *polyethylene*
Styrofoam	Food package (takeaway) electronics insulator	*Polystyrene*

A. *The concentration of mesoplastic litter*

The concentration of mesoplastic for the rainy season was estimated as 0.522 items m^{-2} and 0.308 items m^{-2} for Tema and Elmina, respectively. In contrast, the results for the dry season were 1.82 items m^{-2} and 0.390 items m^{-2} for Tema and Elmina, respectively.

B. Composition of mesoplastics litter

The results showed the composition of a particular litter of meso-sized particles. The marine litter was classified into two categories: the physical characteristics and the unidentified (n.a). The physical characteristics included fibre, fragment, foam, styrofoam, and film; a detailed composition is in Table 3 and refer to Appendix B for images.

Seasonal Mesoplastic percentage count

In the rainy and dry seasons, 261 and 910 mesoplastic particles were collected from Tema, respectively, as shown in Figure 8a. Five physical characteristics were sorted, and the percentage count ranged from 1.9 % to 55.6 % for the rainy season, with fibre being the least dominant, and fragment being the most dominant. For the dry season, the percentage count ranged from 1.2 % to 78.6 %, with film being the least prevalent and Styrofoam being the most dominant.

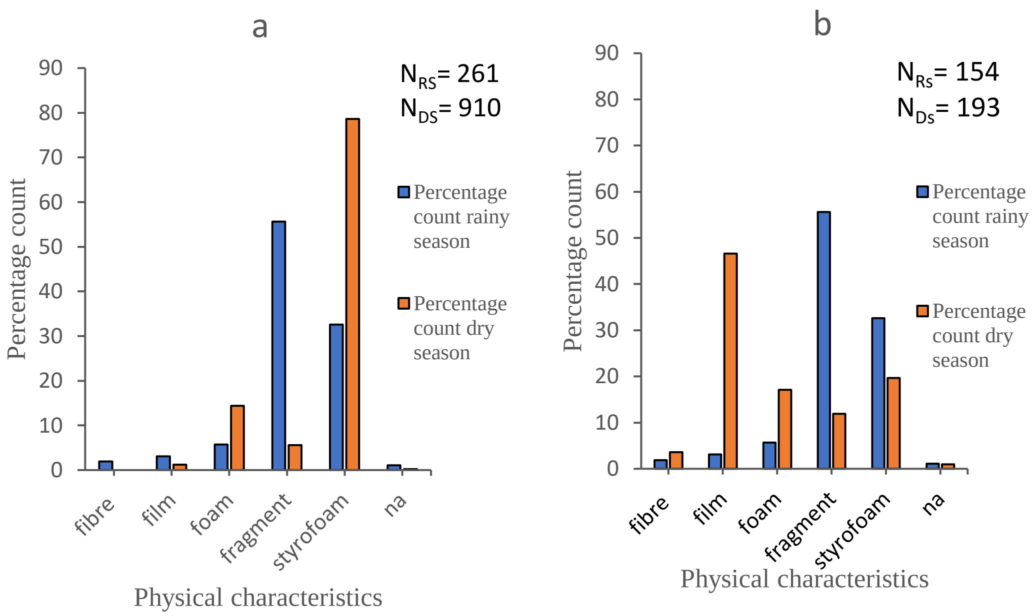

Figure 8: Seasonal Mesoplastic percentage count a). Tema b). Elmina beaches (N_{RS}- Number in the rainy season; N_{DS}– Number in the dry season)

In Elmina (Fig. 8b), 154 and 193 mesoplastics were found in the rainy and dry seasons, respectively. The percentage count of physical characteristics for the rainy season ranged from 1.1 % to 55.6 %. The dominant physical characteristic was fragment and the least the na group. In contrast, in the dry season, the percentage count of physical characteristics ranged from 1.0 % to 46.6 %, with the film being the most dominant and the n.a. group being the least dominant. Fibre was the least dominant physical characteristic in the rainy season, while styrofoam was the most prevalent in the dry season.

Weight of Physical characteristics

The seasonal weight variation of mesoplastic physical characteristics for the Tema rainy season ranged from 13.7 ± 1.1 to 8765.5 ± 98.4 milligrams. The heaviest physical characteristics were fragments, and the lightest were fibres.

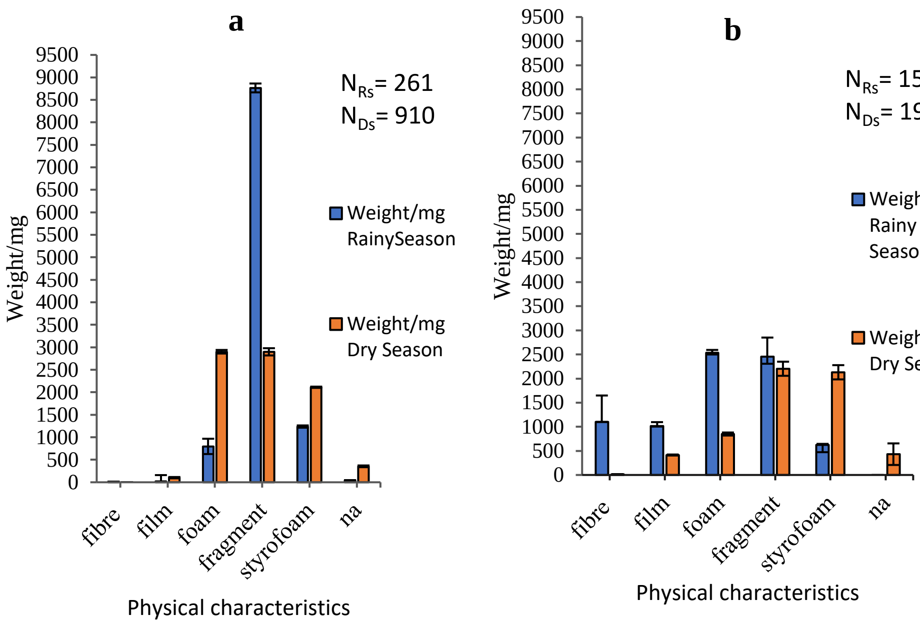

Figure 9: Seasonal mesoplastics weight in milligrams a). Tema b). Elmina beaches (N_{RS}- Number in the rainy season; N_{DS}– Number in the dry season).

Observations in the dry season were that the foam was the heaviest while the na group was weightless. The weights of physical characteristics of mesoplastics ranged from 354.7 ± 19.3 to 2901.5 ± 39.6 milligrams.

Elmina's results on the physical characteristics were as follows: the total weight of each group ranged from 620.5 ± 24.5 mg to 2531.2 ± 62.9 mg. As shown in Figure 4b, foam was the dominant characteristic in the rainy season, and the least was styrofoam. Also, the dry season's results were 12.4 ± 0.9 to 2203.8 ± 146.5 items weight per mg; the least weight was fibre, and the heaviest was fragments.

Seasonal photochemical characteristics of mesoplastics

The outcome of the seasonal photochemical analysis of mesoplastic was as follows: Tema (Fig. 10a) accounted for a total of 29 and 20 for the rainy and dry seasons, respectively. White was the most dominant colour for both seasons at 42.9 % for the rainy season and 79.9 % for the dry season.

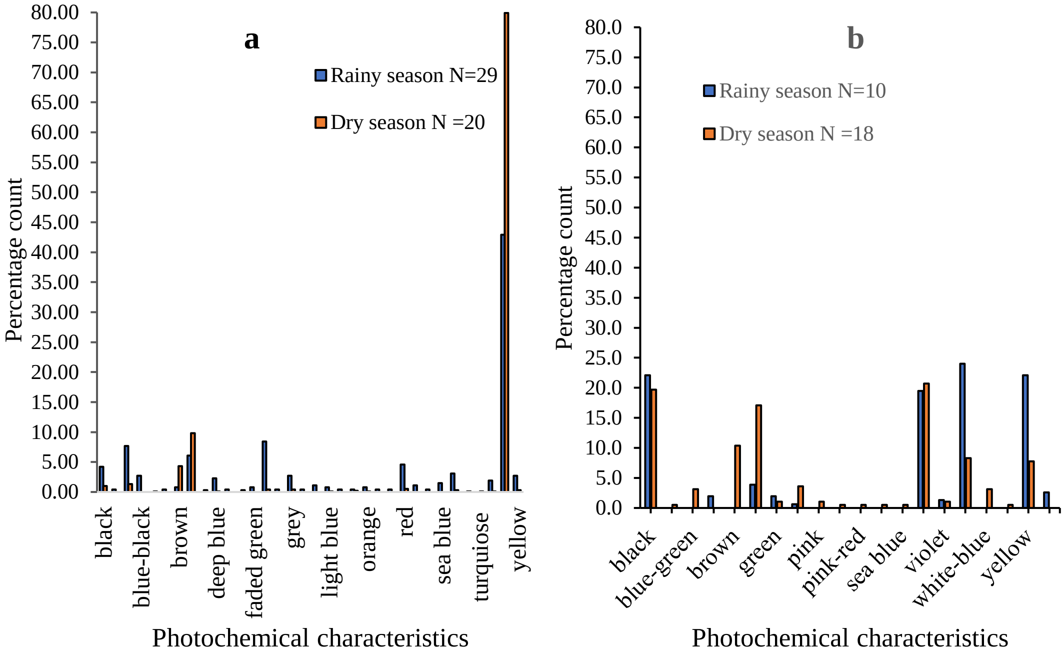

Figure 10: Seasonal photochemical characteristics of Mesoplastic a). Tema b). Elmina beaches

A variety of colours (photochemical characteristics) (Fig 10) were not dominant during both seasons, and each accounted for between 0.1 % and 0.4 %. For both seasons, 14 colours (black, blue, brown, cream, deep blue, green, grey, light blue, orange, red, transparent, violet, white and yellow) were common, whereas 20 differed (black-grey, blue-black, blue-white, bright green, dark red, deep green, faded green, green-yellow, grey-wine, lemon green, light pink, na, peach, purple, red-brown, red-grey, sea blue, transparent-yellow, turquoise).

A total of ten different colours were observed from Elmina during the rainy season and 18 for the dry season. As was found for Tema, the dominant colour was white in the (24.0 %) rainy season and transparent (20.7 %) in the dry season. The least dominant colour was violet, 1.3 %, whereas six colours were the least dominant in the dry season. Comparing both seasons, six colours (black, cream, transparent, violet, white, and yellow) were common, while 11 differed (blue, blue-green, blue-white, brown, pink, pink-black, pink-red, red, sea blue, wine and yellow-black).

In total, 13 colours (Black, blue, blue-white, brown, cream, green, pink, red, sea blue, transparent, violet, white, and yellow) were common to the two sampling sites (Tema and Elmina), and 13 were not common (black-grey, blue-black, blue-green, bright green, dark red, deep blue, deep green, faded green, green-yellow, grey, grey-wine, lemon green, light blue, light pink, orange, peach, pink-black, pink-red, purple, red-brown, red-grey and yellow-black).

Statistical analysis results

Using the Kolmogorov-Smirnov test, the data (weight) was not normally distributed ($p > 0.05$) Table 4. In this instance, the significant value was 0.000, suggesting a violation of the normality assumption. This outcome was true for all the categories tested.

Table 4: Tests of Normality

	Location	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statist	Df	Sig.	Statist.	df	Sig.
Weight	Elmina	0.195	233	0.000	0.811	233	0.000
	Tema	0.203	478	0.000	0.793	478	0.000

a. Lilliefors Significance Correction

Hence, t-tests and ANOVA were used to compare the mean mesoplastics abundance study sites, photochemical characteristics (colours), and physical characteristics (shape), and significance levels of 0.05 were used for all statistical analyses. Summary data were presented as mean ± SD (Table 5).

Table 5: Distribution of different types of mesoplastic weight (mg) along the coastal beaches of Elmina and Tema

Physical characteristics	The mean number of items at each location			
	Elmina		Tema	
	Dry season	Rainy season	Dry season	Rainy season
Styrofoam	18.38 ± 2.81^{a}	25.39 ± 8.86^{a}	2.11 ± 0.54^{b}	2.24 ± 0.11^{b}
Foam	15.12 ± 5.38^{a}	39.03 ± 8.86^{b}	12.91 ± 2.84^{a}	14.28 ± 3.74^{a}
Fragments	26.81 ± 5.14^{a}	34.41 ± 39.10^{a}	33.59 ± 7.66^{a}	27.80 ± 1.76^{a}
Film	2.32 ± 0.10^{a}	3.95 ± 1.07^{a}	4.52 ± 1.92^{a}	4.52 ± 1.91^{a}
Fibre	1.83 ± 0.24^{a}	ND	ND	ND

Values with different letters (a or b) are significantly different at p<0.05. Arithmetic mean ± SD are based on triplicate sampling.

The chi-square test (Pearson Chi-Square) showed a significant difference between the locations and seasons in mesoplastic occurrence with a p-value of

0.023. They produce approximately similar p-values, which, supports the accuracy of the chi-square test for these data.

A Mann-Whitney U Test revealed a significant difference in the weights for locations Elmina and Tema as shown in Table 6.

Table 6: A Mann-Whitney U Test result for weights per location

Location	Total number of cases (*n*)	Median (*Md*)	Mann Whitney U Test	Standardized Test Statistic (*z*)	Asymptotic Significance (*p*)	Correlation coefficient (*r*)
Elmina	347	912.98	129090.5	9.301	0.000	0.24
Tema	1111	672				

Table 7: A Mann-Whitney U Test result for weights per season

Season	Total number of cases (*n*)	Median (*Md*)	Mann Whitney U Test	Standardized Test Statistic (*z*)	Asymptotic Significance (*p*)	Correlation coefficient (*r*)
Rainy	411	100.45	328984.5	15.739	0.000	0.4
Dry	1047	620.78				

Table 7 shows that a Mann-Whitney U Test revealed a significant difference in the weights for seasons Elmina and Tema.

A Kruskal-Wallis Test revealed a statistically significant difference in Physical characteristics (FB = 2.15, n = 18, FL = 2.5, n = 187: FO = 9.2, n = 207, FR = 33.2, n = 222, ST = 1.3, n = 817). $\chi 2$ (4, n = 1450) = 592.602, p = 0.000. The fragment recorded a higher median score.

Post-hoc test: Bonferroni correction for multiple tests determined a pairwise comparison between each independent group, proving statistically significant differences.

DISCUSSION

Mesoplastic litter was prevalent in sediments at both Tema and Elmina. The litter showed differences in seasonal concentration and abundance in sampled areas, with clear variation in Tema but the values in Elmina were fairly constant. The number of mesoplastics significantly differed per transect ($p < 0.05$ Table 5). Tema recorded the highest mesoplastic litter contamination in the dry season, ~4x more than in the rainy season. Unfortunately, few studies such as Blettler et al., 2017, Jeyasanta et al. (2020), Shahul Hamid et al. (2018) have addressed mesoplastic pollution and those that focus mainly on seasonal observations to compare results. Shahul Hamid et al. (2018) stated that weather patterns may influence mesoplastic distribution and abundance in sediment and water. However, this may be explained by the reduced runoff during the dry seasons. Mesoplastic litter is left unwashed and buried in sediments through beach users and wave actions. According to the Cheshire and Adler (2009) and OSPAR Commission (2007), factors contributing to increased litter on the coast include local currents, beach topography (slope, particle size), weather conditions and coast dynamics, and proximity to settlements. Unlike the rainy seasons, such particles are easily washed away, with few remnants buried in sediments. Tema can be identified as a recreational beach, but Elmina is non-recreational. Tema was an open beach with free access to all, whereas Elmina had restrictive access to users, which may explain why there were fewer mesoplastic items in Elmina Beach sediment. However, it may be argued that the busiest beaches should comprise higher levels of mesoplastic litter due to consistent usage by users. Research by Jayasiri et al. (2013) indicated that mesoplastic litter (small-sized fragments) is the dominant type of plastic in recreational beaches, which may be the case at Tema (styrofoam).

For example, Tema has a small village community inhabiting the beach, which is just about $\leq$ 50 m from the sea. The concentration of plastics in beach sediments, however, is attributed to anthropogenic and fishing activities (Davis & Murphy, 2015; Graca et al., 2017; Lozoya et al., 2016; Stolte et al., 2015). Therefore, the highest mesoplastic concentration at Tema may also be due to the easy accessibility and proximity to the village (Blettler et al., 2017) as well as the waste produced during recreational activities.

Mesoplastic litter reported from literature (Blettler et al., 2017) are categorised according to the "'shape' as reported as the physical characteristics in this study. The physical characteristics were presented in the percentage count (Fig. 8) and the average weights (mg) (Fig. 9). This study observed the same shapes reported in the literature (Bletter et al., 2017; Brate et al., 2016; Jeyasanta et al., 2020; UNEP, 2016), where all the shapes (fibre, film, foam, fragment and styrofoam) were observed in all the study sites and all the seasons. Slight variations with statistically significant differences were observed in their abundances according to the Kruskal-Wallis analyses. The composition of items that fell in the category description of the physical characteristics is defined in Table 3.

Seasonal variations were observed in the abundance of each physical characteristic. The general outlook for the rainy season (blue bar graph) for Tema (Fig. 8a) and Elmina (Fig. 8b) followed the same order of percentage count for the physical characteristics. The order observed (Site Tema & Elmina): fragment > Styrofoam > foam > film > fibre. However, the physical characteristics in Elmina recorded higher percentage counts than in Tema. The order differed from both sites in the dry season (orange bar graphs). Tema (Fig. 8a) was as follows: styrofoam > foam > fragment > film, but no fibre was recorded, whereas in Elmina (Fig. 8b) the following order was recorded: film > styrofoam > foam > fragment > fibre.

The observation of the physical characteristics according to weight (Fig. 9) was different due to the nature of the plastic particle. Fragment sources are mostly from high-density polyethylene (HDPE) and are generally heavier than the others. Tema's (Fig. 9a) weight distribution matched with the order of its physical characteristics. Meanwhile, in Elmina (Fig. 9b), the order varied as follows: foam > fragment > fibre > film > styrofoam. Here, foam, mostly from refrigerator insulators and bed mattresses, was weightier than fragments. This slight difference may be due to leftover sand particle load embedded in foams, as observed during the laboratory analysis.

In the dry season, though, styrofoam was the most abundant (almost 80 %), its plastic nature was low density. The source of the Styrofoam was mostly from packages, such as disposable food packages (takeaway) and electronic packages (see Appendix B). The average weight order observed was: foam > fragment > styrofoam > film in Fig. 9a (orange bars) Tema. Conversely, Elmina recorded film as the most abundant physical characteristic. However, belonging to the low-density polyethylene (LDPE) group, its average weight was low and did not reflect its percentage count (almost 50 % Fig. 8). Furthermore, the average weight outlook was in this order: fragment > styrofoam > foam > film > fibre as shown in Fig. 9b (orange bars graphs). In furtherance of the ongoing discussion, styrofoam dominance has been reported in the literature (Blettler et al., 2017; Driedger et al., 2015; Lee et al., 2013, 2015; Zbyszewski et al., 2014), though not seasonally observed. Several studies have reported the presence of styrofoam as a serious pollution problem in the world: Hinojosa and Thiel

(2009) found approximately 80 % of mesoplastic debris to be styrofoam. They traced the source to mussel farms in Chile's northern region but none in the southern region. According to Hinojosa and Thiel (2009), these styrofoams are used as floating devices in mussel farming. Additionally, Heo et al. (2013) reported that 90.7 % of mesoplastic debris in Korea were styrofoam spherules. Similarly, Lee et al. (2013) reported that 90 % of the microplastic and mesoplastic debris in South Korea were made of styrofoam. Studies in Korea, Japan, and Chile linked Styrofoam pollution to oyster and mussel aquacultures (Hinojosa & Thiel, 2009; Lee et al., 2013). Statistical analysis for weights (physical characteristics and seasons) shows statistically significant differences in Tables 6 and 7.

The seasonal photochemical characteristics occurrence in mesoplastics were presented in Figure 10 and were consistent with the results of other studies on mesoplastics (predominately white) (Blettler et al., 2017; Nor & Obbard, 2014; Zhao et al., 2014). Twenty-six colours were recorded in this study, which factored both study sites and the two seasons. Significant differences were observed in the photochemical characteristics for both locations and seasons. Observations indicated that white was the most dominant in both seasons for Tema (Fig. 10a). The colour dominance reflected the type of physical characteristics analysed. From the physical characteristics (Fig. 8a), styrofoam was the most dominant, and these were mainly white. Also, fragments and other physical characteristics contributed to the abundance of white mesoplastics particles. Elmina was dominated with white plastic particles during the rainy season (Fig. 10b). Predominantly, fragments and Styrofoam (Fig. 8b) are likely to be the major contributors. The dry season was mainly characterized by transparent photochemical types (Fig. 10b). The film was the predominant physical characteristic, mainly plastic bags from the polyethylene group. The findings agreed with other beach sediment studies (predominantly made of films, hard plastic fragments, and foam) (Blettler et al., 2017; Heo et al., 2013; Young & Elliott, 2016). Table 3 highlights the composition of the mesoplastic litter observed, its source or origin and their respective polymer group. According to Wessel et al. (2016), polyethylene, polypropylene, polystyrene, polyester, and polyamide are consistently more prevalent in marine environments than in the riverine environment. Therefore, the findings from this study were consistent with Wessel et al. (2016)'s observations.

Chapter Summary

This chapter reviewed mesoplastic debris (0.5 mm – 24 mm) in the marine environment. Plastic debris within this size range is usually hidden or buried in the sediments, especially on beaches. The seasonal examination was conducted at two marine fishery hotspot locations (Tema and Elmina) within a 500 m^2 area. Sediment within each 50 x 50 cm^2 quadrat was dug out to 5 cm deep and sieved to retrieve these plastics. Particles were analysed based on their physical characteristics, and the photochemical characteristics and the polymer of origin were identified. Results showed an abundance of mesoplastics in the dry season compared to the rainy season and it was found to be significant in the two locations. Styrofoam, mostly white, was the most prevalent physical characteristic at Tema.

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CHAPTER FIVE

MICROPLASTIC CONTAMINATION IN TWO MARINE FISH SPECIES IN GHANAIAN WATERS

INTRODUCTION

Plastic waste has become a global environmental problem, with an estimated 19-23 million metric tons entering aquatic ecosystems annually (Borrelle et al., 2020; Geyer et al., 2017). Plastics currently comprise around 80 % of all litter found in marine environments (Galgani et al., 2015; Moore et al., 2002). It is a concern because plastic waste is found in all environments, from terrestrial to freshwater and marine habitats, including the deep sea (Courtene-Jones et al., 2017; Jamieson et al., 2019; Lusher et al., 2014; Thompson, 2015).

African countries, including South Africa, Algeria, Egypt, Morocco, and Nigeria, are among the top 20 producers of plastic waste worldwide (Jambeck et al., 2015). Ghana alone generates over 3000 tons of plastic waste per day, with more than 250,000 tons disposed of in the Atlantic Ocean annually (Effah, 2019: in Adika et al., 2020).

Microplastics (MP) are of particular concern, with Frias and Nash (2019) defining them as "any synthetic solid particle or polymeric matrix with a size ranging from 1 mm to 5 mm." They can be classified as either primary or secondary microplastics, with primary microplastics being intentionally manufactured in small pieces and secondary microplastics arising from the fragmentation of larger pieces (Thompson & Napper, 2018). Over time, physical, biological, and chemical processes degrade these particles (Frias & Nash, 2019), making them available to many marine organisms, including marine fish (Adika et al., 2020; Pappoe et al., 2022), invertebrates (Imhof et al., 2013; Setala et al., 2014), and marine mammals. (Eriksson & Burton, 2003). Barboza et al. (2018), Desforges et al. (2019) and Rochman et al. (2015) have indicated that microplastics can be ingested through different mechanisms, such as filter feeding, contaminated prey, or simply mistaking them for food. According to Frias and Nash, (2019) and Rochman et al. (2019), microplastics can vary in type, shape, colour, and chemical composition. Other studies have shown that this could cause physical and physiological disturbances to the fauna (Auta et al., 2017; Avio et al., 2017). Thus, once consumed, microplastics can accumulate in the digestive tract and cause physical blockage, tissue damage, and nutrient absorption impairment (Galloway et al., 2017; Wright et al., 2019).

Moreover, studies have shown that microplastics can transfer across trophic levels, implying that humans may be exposed to microplastics by consuming contaminated seafood (Lusher et al., 2017; Van Cauwenberghe et al., 2019). Although the direct effects of microplastic ingestion on human health are still being investigated, recent evidence suggests that the presence of microplastics in the gastrointestinal tract could lead to the release of toxic additives or the absorption of persistent organic pollutants (POPs), as suggested by Hartmann et al. (2019) and Rillig (2020).

Given that Ghana's economy relies heavily on fisheries and has a culture of consuming seafood, the extent and implications of microplastic ingestion must be understood. However, despite research efforts investigating plastics in the oceans, freshwater, and beaches, (Blankson et al., 2022; Chico-Ortiz et al., 2020; Gbogbo et al., 2020) relatively few studies have focused on plastic ingestion by marine organisms (Adika et al. 2020; Pappoe et al., 2022), especially in Ghana, making this issue even more important to investigate. Previous studies in Ghana have focused on microplastic identification using simple methods like the ‘hot pin test’- a method which has limitations in identifying plastic polymers. Therefore, this study aims to examine the gastrointestinal content of two commercially important marine fish species for microplastic contamination in Ghana waters. The specific objective was to use FTIR spectroscopy to identify the plastic makeup (polymer analysis), which is missing in early studies and to characterise the types of microplastics.

MATERIALS AND METHODS

Study Area and Study Map

Sampling occurred in two coastal regions of Ghana: the selected areas are known for their vibrant fishing activities. Tema fishing harbour is located in the Tema metropolis-Greater Accra region (5°38'36.17"N, 0°1'10.28"E), whereas Elmina fish landing quay beach is located in the Central region (5°4'56.51 "N, 1°20'50.11" W) of Ghana. Based on the Canoe Frame Survey conducted in 2016, it was found that the majority of canoes (56.3%) in the 304 beach landing sites along the coast of Ghana are operated in two specific regions.

These two regions are of great significance to the artisanal fisheries in Ghana as they are essential landing sites. The survey also revealed that the Central region

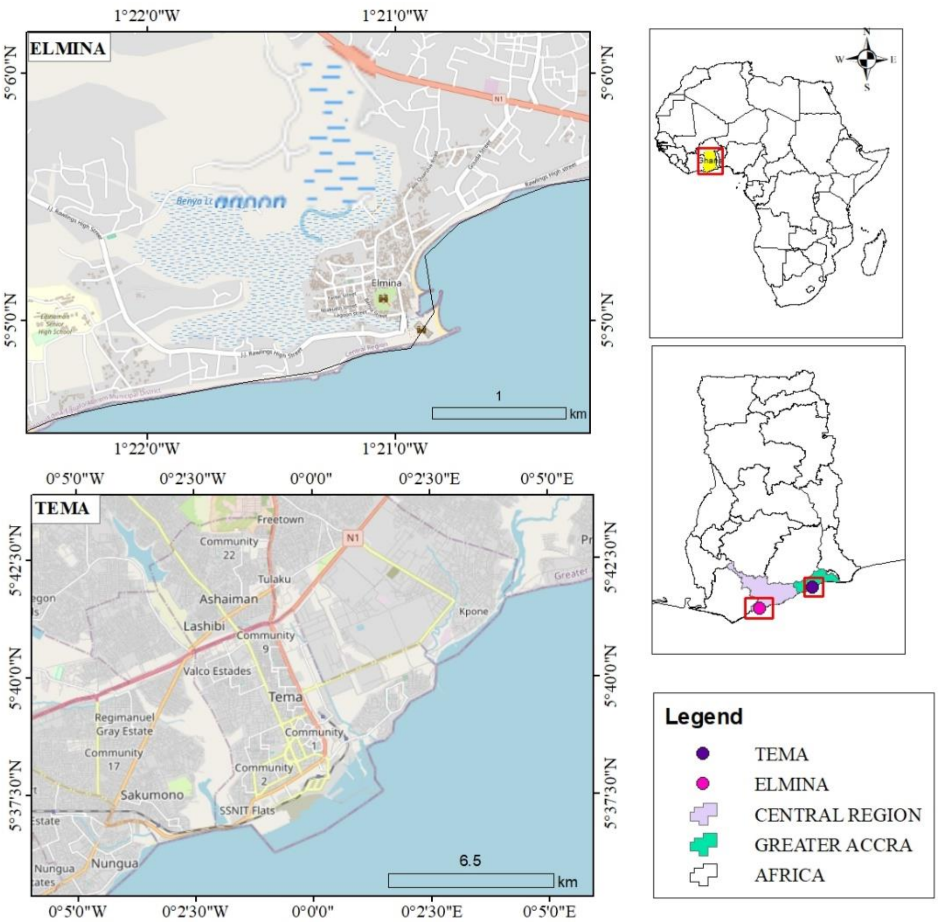

Figure 11: Map of the study area indicating the study sites Elmina and Tema

has over 31% of all fishers and more than 33% of all canoes, whereas the Greater Accra region has around 24.0% of fishers and 23.0% of canoes.

Field sampling

On a bi-monthly basis, two fish species were purchased from Tema and Elmina fish landing sites (Fig. 11). The *Dentex angolensis* (Angola dentex) is a demersal species, and the *Sphyraena sphyraena* (the Barracuda) is a pelagic species. The first and third weeks of each month were assigned as sampling periods for each location. In both areas, fishermen were identified and contacted in advance to supply these fish species. Each fish purchased was individually wrapped in aluminium foil, preserved on ice in a fitted chest and transported to the University of Cape Coast, Department of Fisheries and Aquatic Sciences Research Laboratory for analysis.

Laboratory analysis

In the laboratory, samples were sorted and identified and morphometric measurements such as body length (L/cm) and weight (W/g) were taken (Liet al., 2023). The samples were rinsed (individually) with filtered distilled water. Each fish's digestive tract (DT) (stomach, gut, intestine) was removed under a fume-hood chamber. The body parts were weighed rinsed with distilled H_2O and wrapped in aluminium foil. They were then, labelled and preserved in a ThermoScientific FORMA temperature control freezer (at -20 degrees).

Digestion of samples

Frozen samples were thawed and transferred to a clean (filtered distilled water) labelled glass beaker. Beakers were transferred to a fume-hood chamber, where chemical solutions were added (all chemical solutions were filtered using a 90 mm diameter, 0.2 mm regenerated cellulose membrane filter) (Bakir et al., 2020) (See Appendix C).

For the organic digestion procedure, a 40mL of 30%Potassium hydroxide (KOH) solution (Courtene-Jones et al., 2017a) was added, and the beaker was placed on a magnetic stirrer for an hour at a speed of 325 rpm.

Afterwards, 5 mL of 30 % KOH solution was added to the beaker and stirred for 30 minutes. The solution was allowed to sit for 24 hours to ensure thorough digestion of all organic materials. (NB: full stomachs especially for *D. angolensis* took longer time to digest, therefore those were left overnight to ensure thorough digestion. Unlike the stomachs of *S. sphyraena* which were more readily digested).

The digested sample was sieved over a 125-micron mesh sieve and washed with de-ionised water. Washed residue was rinsed from the sieve into the same beaker where 20 ml of 0.05 M of *Iron(II)hydroxide* and 20 ml of 30 % *Hydrogen peroxide* solution were added, causing an oxidative reaction. The content in the beaker was stirred for 30 minutes. Filtrate was drained using a Buchner funnel fitted with a pump onto a 47 mm micro-glass fibre with 1.2 µm pore size filter paper. Filter paper with residue was allowed to dry in the oven and preserved in sealed and well-labelled Petri dishes (Appendix C). The packaged samples were sent to the Scottish Association for Marine Science (SAMS), Scotland, United Kingdom, for microplastic polymer identification procedures. The ThermoScientific Nicolet iN 10 Fourier Transform Infra-Red spectroscopy (FTIR) was used to identify the various polymers.

The FTIR procedure

The samples were treated as recommended by the SAMS microplastic laboratory to ensure quality control and reduced contamination (detailed under Quality Control/Quality Assurance).

Contamination Assessment and Quality control /Quality Assurance

In the laboratory, new and modified methodologies for microplastic analysis protocols were observed using ultra-clean techniques (Bakir et al., 2014; Courtene-Jones et al., 2017a; Courtene-Jones et al., 2019; Doyle, 2018; Maes, 2020 and Wieczorek et al., 2018) to minimise or avoid contamination.

Before fish processing, microplastic extraction and other examinations of the filters were performed using microplastic contamination prevention methodologies (Bakir et al., 2020; Wesch et al., 2017; Wieczorek et al., 2018; Woodall et al., 2015). The laboratory bench was cleaned with 70 % ethanol and repeated three times to limit external contamination. All equipment (glassware and dissection kit) were rinsed with 0.2 µm filtered distilled water before use. Only cotton laboratory coats were worn during laboratory work. Also, samples and filters were kept under a clean air Purair Ductless fumehood to avoid exposure to contaminated open air. Finally, moist filter paper in a petri dish was set up daily during laboratory analysis as a control. This setup was to trap external contaminants, these such microplastic particles were analysed. During the analyses, similar MP particles identified in the fish's stomach and controls were exempted, with the assumption that the particles may not have come from the fish.

Data Analysis

SPSS v.26 and Excel were used to perform all statistical analyses and prepare graphs. Kolmogorov-Smirnov test was used to check the normality of the data. If the data distribution was normal ($p > 0.05$) a, T-test and an ANOVA were used to compare the mean MP abundance between each fish species, study sites, photochemical characteristics (colours), and physical characteristics (shape) and evaluate the difference in MP abundance between blank and standard samples. The Pearson correlation test was used to determine the relationship between the MP abundance of different fish tissues and the fish length. Significance levels of 0.05 were used for all statistical analyses. Summary data were presented as mean ± SD.

RESULTS

Out of 496 individual fishes sampled within the study period, 306 fish individuals were obtained from Elmina and 190 from the Tema fishing harbours. Of these, 253 were *Dentex angolensis* (Angola dentex sp.) and 243 were *Sphyraena sphyraena* (Barracuda) shown in Figure 12. In summary, Tema dentex species were 70 fishes against 120 S*phyraena* sp. fishes. From Elmina, dentex species were 183, and *sphyraena* were 123 individual fishes Figure 12 illustrates the absolute and relative counts of individual fishes obtained from the study areas. Specifically: - Colored bars represent the absolute count of individual fishes. - Patterned bars represent the percentage count of individual fishes.s

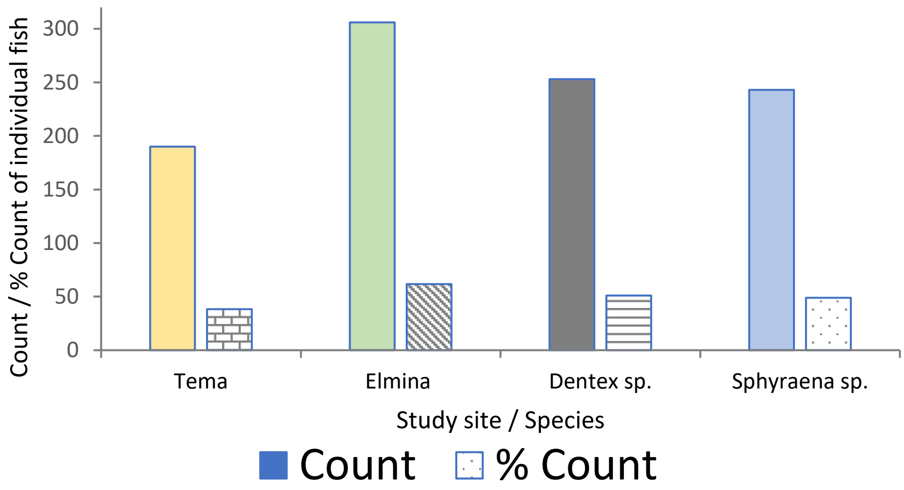

Figure 12: A total summary of the quantity of fish species collected from the two sampling sites by count and % count.

Microplastic (MP) analysis

Category of observed microplastics

Five individual fishes of each species were selected each month per season to investigate the presence of microplastics. Microplastics were categorised by size, photochemical, and physical characteristics and recorded for each particle. The type of the microplastic polymer was identified using the Nicolet iN10 Fourier Transform Infrared Spectroscopy (FTIR) by ThermoScientific. (Imhof, 2016; Lebreton et al., 2017; Qiu, 2015)

Category by Size and by photochemical characteristics (colour)

The suspected plastic particles measured retrieved from the gastrointestinal part of the species had sizes ranging from 0.0001 mm to 2.574 mm and were classified as microplastics.

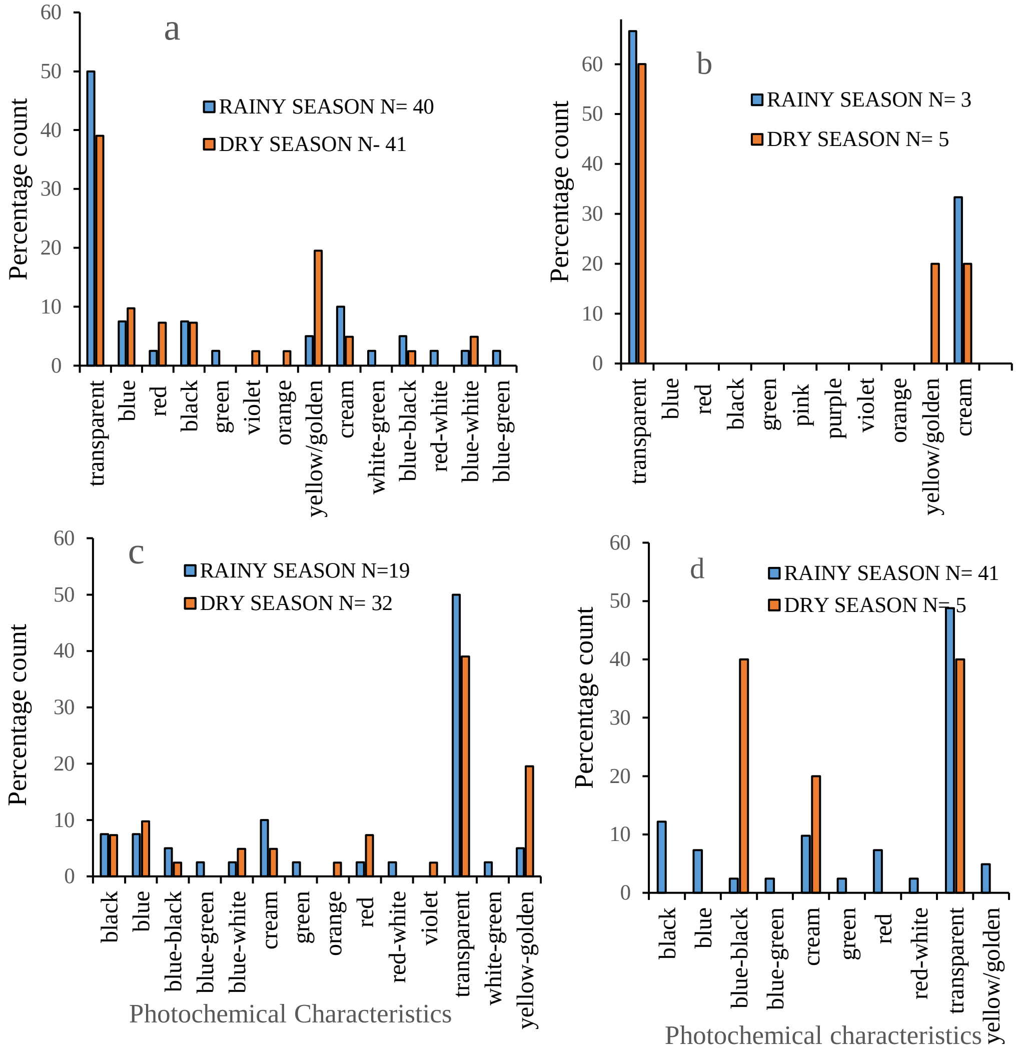

Figure 13: Percentage of photochemical occurrence of Microplastic particles in the two fish species a. Angola dentex-Elmina, b. Angola dentex- Tema; c. Barracuda-Elmina, and d. Barracuda- Tema

These plastic particles were made of 14 colours comprising whole and multi-colours (black, blue, blue-black, blue-green, blue-white, cream, green, orange, red, red-white, transparent/white, violet, white-green and yellow-golden). The percentage of colour count for the species was compared vis-à-vis study sites and the seasons (Fig. 13). Generally, the dominant colour observed was transparent/white. The colour dominance range was 48 % to 67 % of the pelagic and the demersal species in both sampling sites and seasons.

Category Physical characteristics

Six microplastic physical characteristics were observed and presented in Fig. 14. These were fibre, film, foam/Styrofoam, fragment, pellet, and metal.

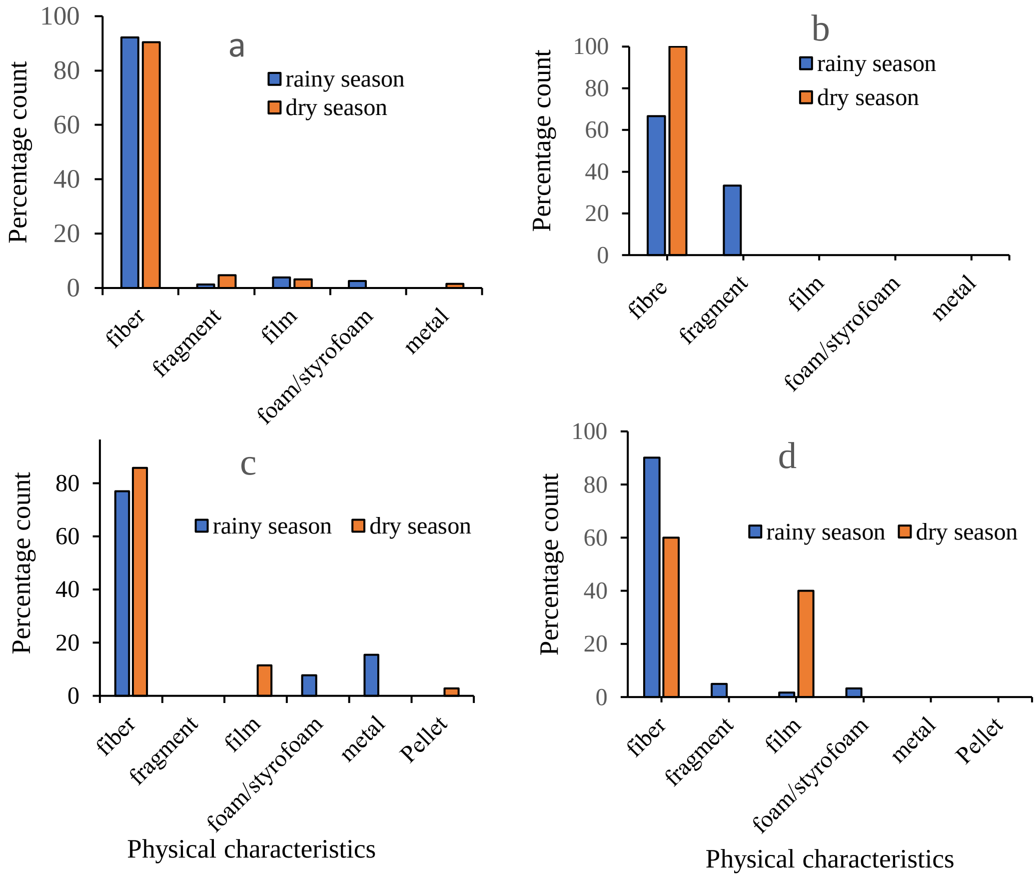

Figure 14: Seasonal percentage count of physical characteristics of micro-plastic ingested by: a).Angola dentex- Elmina; b).Angola dentex- Tema; c). Barracuda fish –Elmina and d). Barracuda fish- Tema (a & b-Demersal

The results from the study indicated fibre as the most dominant microplastic particle found. The observation was consistent in all categories, such as the fish species, the sampling sites and the seasons (rainy/bumper and dry/lean seasons). Figure 14a represents *Angola dentex* from Elmina, highlighting the physical characteristics of the particles as well as their occurrence in each season, of which 92.2 % and 90.5 % fibre were recorded in the rainy and dry seasons, respectively. Sixty-six and 100 % of microfibres recorded in *Angola dentex* from Tema are indicated in Fig. 14b, whereas the other physical characteristics (fragment, film, foam/styrofoam, pellet and metal (the only non-plastic item found in the stomach)) were either absent or present but in low quantities (0-40%), Fig. 14c and 14d show Barracuda from Elmina and Tema respectively. More than 75 % and 85 % of fibres were reported in rainy and dry seasons (Fig. 14c) and 90.2 and 60 % in the rainy and dry seasons, respectively (Fig. 14d.). The other physical characteristics were either absent or present. When present, they were below 50 %. Fibre was observed to be at least 60 % more likely to be ingested comparable to other particles.

Type of plastic polymers

Plastic micro-particles were identified using the FTIR spectrometer at 75% and above accuracy. A total of 80 fish were reviewed for microplastics, of which 126 suspected particles were observed. Plastic analysis using the FTIR identified 20.6 % of the particles as microplastics which were absent from the control. The rest of the polymers were natural cellulose.

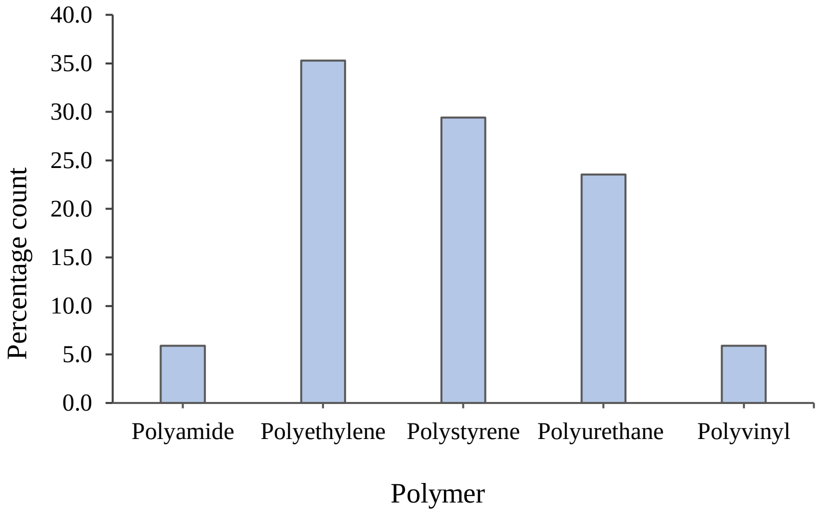

Figure 15: Overall polymer occurrence in the gastrointestinal of marine fish species (*D. angolensis and S. sphyraena*)

Also, the control setup particles were about 100 suspected particles 80%mainly natural fibre/ cellulose, polypropylene (PP) and polyethylene terephthalate (PET). These polymers were exempted, as mentioned in the methodology. Figure 15 shows the types of polymers and their percentage counts.

The general overview of five plastic polymers namely Polyamide (PA), Polyethylene (PE), Polystyrene (PS), Polyurethane (PU) and Polyvinyl (PV) was identified (Fig. 15). The 35.3 % was polyethylene, which was the most common and the least dominant were-polyamide (nylon) and polyvinyl, at 5.9 %.

The seasonal polymer output for each species was as follows (Fig. 16): Out of the five polymers identified, four were found in *D. angolensis* from Elmina (Fig. 16a). Three polymers (*polyethylene*, *polystyrene* and *polyurethane*) were present in the rainy season. Three polymers were also found in the dry season (*polyethylene*, *polystyrene* and *polyvinyl*). dominant in *D. angolensis* from Tema and *S. Sphyraena* species from both Elmina and Tema, except for *D. angolensis* from Elmina.

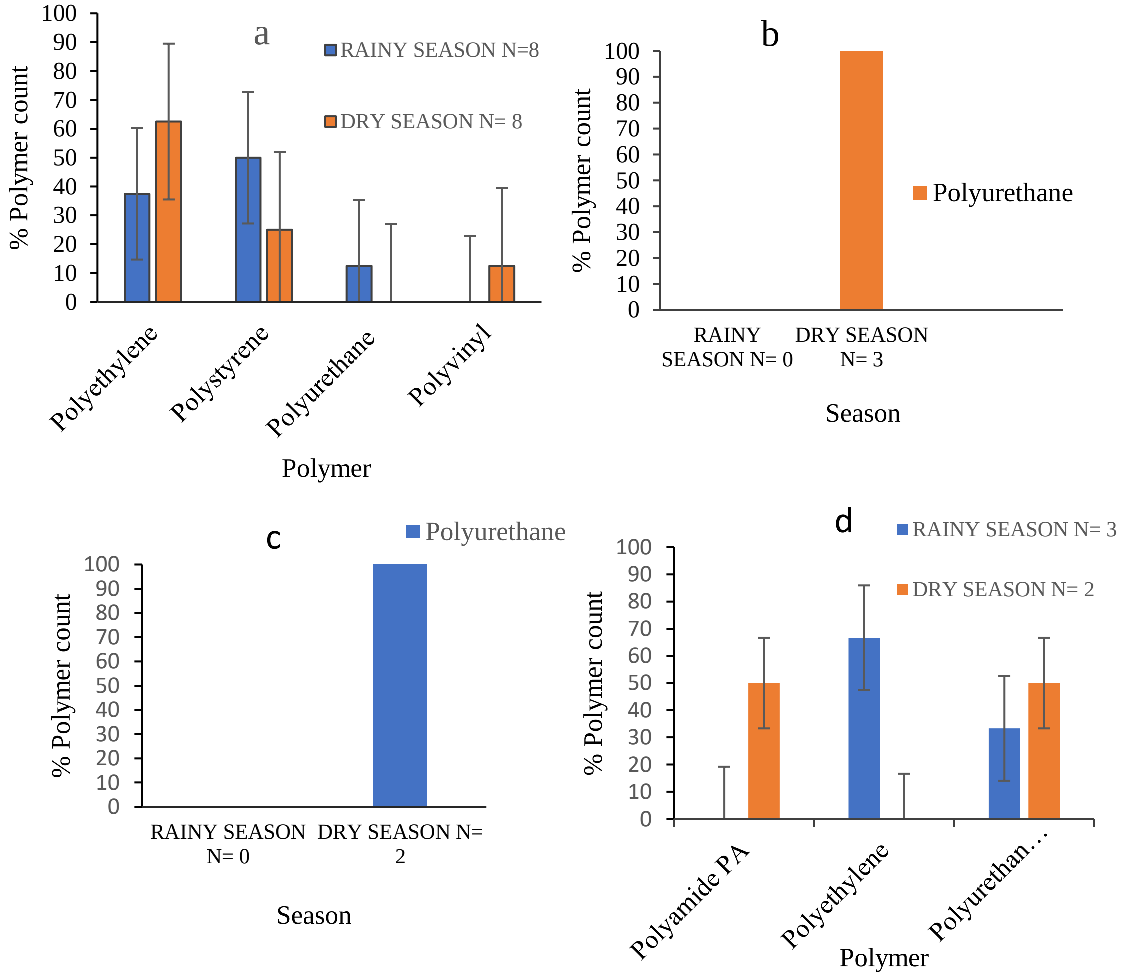

Figure 16: Seasonal Percentage Polymer count in gastrointestinal tract of a). *Dentex angolensis*- Elmina; b). *Dentex angolensis*- Tema; c). *Sphyraena sphyraena*- Elmina and d). *Sphyraena sphyraena*- Tema.

Figure 16a shows a 50 % dominance of polystyrene in the rainy season, while polyethylene is 62.5 % during the dry season. *Polyurethane* and *Polyvinyl* remained the least dominant in both seasons, at 12.5 % each. Figure 16b represents *D. angolensis* from Tema. One polymer type was identified in the ingested diet of the species, which was *Polyurethane* for only the dry season. *S. sphyraena* species from Elmina (Fig. 16c) ingested one polymer type - *Polyurethane*, which was recorded only in the dry season. Figure 16d. also indicated one (1) polymer type (*Polyurethane*) ingested for *S. Sphyraena* from Tema. Three polymers were identified, and one type was absent in each season (Fig. 16d). The dominant polymer in the rainy season was PE at 67 % and the least was PU at 33 %, whereas in the dry season, PU was dominant in *D. angolensis* from Tema and *S. sphyraena* from both locations, except for *D. angolensis* from Elmina.

DISCUSSION

Microplastics were found in both fish species from the sampling sites, Elmina and Tema, for both seasons. The total number of species varied from site to site, which was dependent on the available catch by the local fishermen. Notably, the variation and susceptibility of fish to the ingestion of microplastics are often attributed to their eating habits (Aiguo et al. 2022; Dantas et al., 2020). This results in either direct or indirect ingestion in the process of feeding and through other physiological activities like respiration (James et al., 2020; Macieira et al., 2021; Pappoe et al., 2022; Welden et al., 2018; Zhang et al., 2021)**.** The highest concentration of MPs was registered in *Dentex angolensis* from Elmina, whereas the lowest was found in the same species but, from Tema. There were statistically significant differences among all sampling sites in the values of concentration of microplastics ($p < 0.05$).

The observed microplastics varied mainly in physical (shape) and photochemical characteristics (colour), with sizes within the definition propounded by Cheshire et al. (2009). The average size ranged from 0.0001 mm to 2.574 mm in all the sampling sites. Microplastics of < 1 mm in size were the most common, and they comprised ~90 % of the total microplastics calculated from fish samples ($p < 0.05$), whereas ~10%was recorded for those that were >1.0mm in size. These results are supported by those found by Zhang and Liu (2018), who reported that 95 % of the sampled microplastic particles were in the 0.05 to 1 mm size range and only 5 % of sampled plastic. Fendall and Sewell (2009) described microplastics as elements which are small in size and also pose threats to marine biota. This is because they resemble sand grains and mimic zooplankton, which can confuse fish and other predators.

In both Elmina and Tema, microplastics were present in numerous colours (Fig. 13), consistent with the results of other microplastic studies (Abidli et al., 2017; Nor & Obbard, 2014; Zhao et al., 2014). In this present study, an average of 52.2% and 44.5% of the microplastics collected were white/transparent in the rainy and dry seasons respectively and corresponded to findings in other studies (Corcoran et al. 2015; Heo et al. 2013; Turner and Holmes 2011; Veerasingam et al. 2016; Young & Elliott 2016). The two species, *D. angolensis* and *S. sphyraena* are demersal and pelagic, respectively. The two species have distinct feeding mechanisms: *D. angolensis*, an omnivorous species, and *S. sphyraena*, a carnivorous species. Based on their feeding habits, pelagic species are reported to have higher microplastic ingestion than demersal (Güven et al., 2017). However, this study's findings were the opposite of Güven et al.'s outcome (Fig.16).

Blettler et al. (2017) observed that filter feeders, scrapers (grazers), and shredders ingest microplastics from the water column and sediments indiscriminately. Shaw and Day (1994) also noted that some visual predatory planktivorous fish might mistakenly feed on microplastics due to their close resemblance to zooplankton prey. Additionally, Wright et al. (2013) noted that prey items resemble microplastics due to colour, which may contribute to the likelihood of ingestion. A study at the North Pacific Central Gyre conducted on mesopelagic fish stomach contents examination revealed microplastic colour frequencies of 75 % white/ transparent (Boerger et al., 2010). Greene (1985) also suggested that microplastic ingestion due to food resemblance may also apply to pelagic invertebrate planktivores that are visual raptorial predators. Microplastic ingestion by *D. angolensis* was reported by Adika et al. (2020) in

Ghanaian waters with a consumption rate of 32.0 ± 2.7 particles per total fish. Relatively little is known about *S. sphyraena* microplastic ingestion. Nonetheless, according to this study, *S. sphyraena* ingested an average of two microplastic particles, which were primarily white or transparent in colour (Fig. 3c and 3d (Elmina, Tema respectively)). Similarly, other Sphyraena spp- *Sphyraena putnamiae* have been reported to ingest microplastics in the Persian Gulf (Hosseinpour et al. 2021). Comparatively, the total ingested microplastic in *S. sphyraena* in this study was consistent with Hosseinpour et al.'s (2021) findings (5.67 ± 2.08 particles per total fish), though a different species, (*S. putnamiae)* was studied. Plastic particles consumed by fish may cause injuries, stress, and contaminant bioaccumulation (chemicals inherent in plastic), as highlighted in Biginagwa et al. (2016). Imhof et al. (2013), Rosenkranz et al. (2009), and Sanchez et al. (2014)

The quantity and colours of plastics observed were diverse in appearance, as reported in Figure 14. Fibres, films, fragments, and foams/styrofoam were the physical characteristics of plastic particles observed most frequently (Fig. 14); however, pellets were observed once. Fibre was significantly higher in all categories (fish species, sampling sites and the seasons). The demersal species *D. angolensis* recorded higher consumption of microplastic, mainly fibres, than the pelagic species *S. sphyraena.* These findings were inconsistent with other studies (Adika et al., 2020; Bessa et al., 2018; Phaksopa et al., 2021; Sparks & Immelman, 2020). However, as observed in this study, Aiguo et al. (2022) and Kühn et al. (2020) indicated a higher ingestion rate of microplastics for demersal fishes. Trends observed by other studies revealed that fish from the pelagic zone ingest slightly more microplastic particles than fish from other habitats (Güven et al., 2017). Studies such as Adika et al. (2020), Bessa et al. (2018), Phaksopa et al. (2021), lastly, Sparks and Immelman (2020) recorded larger quantities of microplastics in pelagic fishes. However, Lusher et al. (2013) observed equal microplastic ingestion between pelagic and demersal species even though their diet varied. Adika et al. (2020), Hosseinpour et al. (2021), Lusher et al. (2013) and Pappoe et al. (2022) identified black fibres as the most dominant physical character. According to Arthur et al. (2008), filter feeders may consume particles directly from the water column, whereas benthic organisms consume them after they settle at the bottom sediment. Based on this observation, Leslie et al. (2014) observed that filter feeders have more prolonged exposure to microplastics than other feeding methods. However, if carnivorous pelagic or omnivorous demersal feeds on any filter feeders (small pelagic fish-foraging), their long exposure to ingested particles is easily transferred. In this case, an indirect transfer of microplastic consumption happens, which in this study may be attributed to indirect rather than direct intake and may be based on the argument by Arthur et al. (2008) and Leslie et al. (2014).

Moreover, fishing gear and sewage dumping are considered important sources of fibres (Browne et al., 2011) due to their lightweight and higher potential for long-distance transport. Following several other studies, fibres are identified as the predominant type of microplastics in fish samples and other aquatic organisms (Adika et al., 2020; Browne et al., 2008; Cole et al., 2011; Courtene-Jones et al., 2017; Hall et al., 2015; Imhof et al., 2013; Setala et al., 2014; Thompson et al., 2004; Wright et al., 2013b). Similar works have reported microfibres in beach sediment samples (Claessens et al., 2011; Graca et al., 2017; Hidalgo-Ruz et al., 2012; Stolte et al., 2015; Van Cauwenberghe et al., 2013). Aside their weightless nature, fibres, by their strand-like or filamentous appearance, might have been mistaken for worms and other fibrous prey (plankton) drifting in open water and near the bottom. The predominance of fibres in the ascertained shapes are unsurprising, given their established status as a principal constituent in the microplastic milieu (Barrows et al., 2018; Mizraji et al., 2017; Neves et al., 2015; Thushari & Senevirathna, 2020). Also, fibres hold considerable potential for uptake by marine organisms. The dominance of fibres in this study is consistent with the aforementioned studies where 60 – 92 % of fibres were observed in waters around South Africa (Bakir et al., 2018), Portugal (Neves et al., 2015), Ghana (Pappoe et al., 2022) and Chile (Pozo et al., 2019; Sparks & Immelman, 2020).

Using an FTIR spectrometer, the types of polymers ingested were identified (Fig. 16). Microplastic numbers were meagre compared to other works (Adika et al., 2020; Hosseinpour et al., 2021; Pappoe et al., 2022). The consumption rate could be due to the number of individual fish analysed.

In the samples from Elmina and Tema, five plastic polymers were identified: *Polyamide* (PA), *Polyethylene* (PE), *Polystyrene* (PS), *Polyurethane* (PU) and *Polyvinyl* (PV) (Fig. 15). This study shows Polyethylene (35.3%) to be the most frequent polymer type (Fig. 15), and it is one of the most commonly used plastics, according to Jambeck et al. (2015). According to Caitlin et al. (2016), PE, PP, PS, PES, and PA are consistently more prevalent in marine waters than riverine. However, three of these (PE, PS, and PA), observed by Caitlin et al. (2016) were consistent with this study. Figure 6 indicates the type of polymer ingested by the two species, and their selection may play a role in their habitat preference. Yang et al. (2021) explained the density nature of microplastic polymers. Therefore, PE and PU have low density and are likely to float, whereas PA, PS, and PV may sink in marine water due to their high density. *D. angolensis*, a demersal omnivore, ingested three denser polymers, PA, PS and PV, available at the bottom of the sea. They may have mistakenly ingested these particles due to their feeding habit. Also reported in this study was the ingestion of PE and PU, which are less dense and are more likely to float in the water. Based on Yang et al. (2021) report, a demersal species can have access to these microplastic polymers in two ways: firstly, it may be due to microorganisms adhering to PE and PU surfaces, causing them to be heavy and sink to the bottom, where *D. angolensis* generally inhabits. It may also be attributed to the demersal species' indirect transfer from ingested prey (Gamarro et al., 2020; Mallik et al., 2021).

The *S. sphyraena* equally ingested one denser and two less dense microplastic polymers, PA, PE and PU, respectively. In this observation, habitat and food selection are the major contributing factors at play *Sphyraena* spp. are carnivorous, have a broad food spectrum, and include worms. As mentioned, these worms are primarily bottom dwellers and are likely to ingest microplastics within the sediments, especially the denser types. However, *S. sphyraena* might consume the worm, resulting in indirect microplastic transfer. Equally, the less dense microplastic polymers, such as PE, float freely in water, which makes them accessible to various species. Some polyethylene is filamentous in shape and might resemble the worms preferred by *S. sphyraena*. Hence, in the feeding process, there may be a probability of direct ingestion of these microfibres mistaken as food. The mechanism of microplastic ingestion by pelagic fish species is elaborated on by Gurjar et al. (2021) and Khalid et al. (2021). Finally, Pappoe et al. (2022) also identified Polyethylene (PE), polyvinyl acetate (PVA) and polyamide (PA), where PE was the most prevalent, as observed in this study.

Chapter Summary

This chapter reviewed fish contaminated by microplastics. These plastic sizes occur due to the continuous breakdown of bigger-sized plastics. The study analysed some marine fish species due to reports indicating microplastic ingestion/consumption by these organisms. Such plastics are harmful to marine species, invariably affecting their lifecycle. Their reproductive and growth patterns are influenced by plastic consumption. Therefore, the study analysed two fish species of different feeding habitats to ascertain whether they were contaminated. Results showed that both species ingest microplastics, but the study identified them in smaller quantities than other studies. This research, however, confirmed that fishes mistake plastics for food, which ultimately makes it only potentially dangerous to humans if consumed.

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CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

This study was about seasonal observation of plastic pollution in two hotspot locations in Ghana- precisely, Tema Fishing Harbour and Elmina Fishing Quay. The focus of the study has been centred on three size classes of plastics: a). macroplastics *along the coastal beaches,* b). mesoplastics *within sediments,* and c). microplastics *in marine fish species*. The adopted OSPAR (2010) guidelines for plastic pollution and data were analysed using the Clean Coast Index and statistical analyses. This study's outcome was that Elmina's coastal beach was more polluted compared to Tema. Seasonal observations indicated more plastic debris in the dry season compared to the rainy season. Within sediments, Tema had the most pollutants. Plastic pollutant types and weights observed for both seasons and locations indicated statistical significance. The variations were observed in their abundance. In marine fish species, an analysed gastrointestinal (GI) tract revealed ingestion of microplastics which were, varied in types (physical), colour (photochemical characteristics), polymer types and abundance. Five physical characteristics identified as fibre, film, foam, fragment and styrofoam, were consistent with all three areas. Further, numerous colours, whole and multi-colours were observed; the commonest were transparent, white and black. Polymer types were five in number: PE PU PA PV and PS. PE was the most prevalent in this study.

CONCLUSIONS

To conclude, plastic pollution is a real and prevalent problem in Ghana. Along the beaches, in the sediment and water bodies – where there is evidence from this study that marine species are ingesting (plastics) – plastic pollution abounds. The study also confirms the issue of plastics permeating the world's oceans and impacting the marine food web structure.

Plastic Polymer type

The polymer groups identified in this study were consistent within all areas sampled (in sediment, along the beach, and 'in fish'). From the perspective of microplastic observation *viz., Reviewing ingestion processes*, the research output confirmed that marine fish consume microplastics. Unfortunately, the research cannot emphatically establish how these plastics get into the stomachs of the species. However, it has been established from the literature that marine organisms may directly or indirectly ingest microplastics.

From the angle of *species to species*, there is no conclusive note on whether a demersal species may consume more microplastics than a pelagic species. The outcome from the literature is divided on which trophic level may be most exposed to microplastic pollution. On that note, extensive and future research may answer the problem.

A view from one location to location

Samples collected from two sampling areas, Elmina and Tema, may or may not have contributed to the final results. To justify, in Ghana, fisheries resources are said to be accessible to all, irrespective of one's region of origin, as the same stocks are exploited. Further on, fish species have no boundaries and can migrate to any location, especially the pelagic species (active swimmers, except the demersal species noted to be 'localised' (not highly migratory). To confirm, personal communication with some fishermen from the two study areas about their fishing grounds indicated that they travelled to certain parts to exploit those fishes (demersal). From their account given, it indicated that they exploit fish from the same locations, but they land or sell at their respective landing beaches. This, however, concludes that a contaminated fish may be accessible to all fishers irrespective of one's landing site or region of origin. It may be said that the marine environment may be generally contaminated with microplastics, as reported worldwide.

Nuances in mesoplastic debris based on location

Mesoplastic pollution was higher at Beach Five in Tema than at Elmina Castle Beach. This observation may be significant because Tema Beach Five is an open beach with no restrictive access, unlike Elmina Castle Beach. The concentration of mesoplastic debris seasonal output showed higher concentration in the dry season compared to the rainy season. Five physical characteristics were observed: fibre, film, foam, fragment, and Styrofoam. The dominant physical characteristic was styrofoam in the dry season and fragment in the rainy season, Tema. In Elmina, the dominant physical characteristics were fragment in the rainy season and film in the dry season. This may establish that similar pollutant types are available to both locations but in different quantities.

Nuances in macroplastic debris based on location

Macroplastic debris was higher at Elmina Beach compared to Tema Beach five. This was statistically significantly different because a cleaning agent randomly cleans Beach Five, unlike Elmina Beach. There was a period when less plastic debris was collected, which clashed with a cleanup day for the agency. Upon engagement with them, they confirmed cleaning the beach but depended on how frequently their salaries were paid. Their cleaning procedure involved the use of brooms only. From closer observation, it was observed that, in the sweeping process, the sand covered some of the debris ashore.

RECOMMENDATIONS

In conclusion, plastic waste management in Ghana is a significant challenge that requires urgent attention. Addressing Ghana's plastic waste management challenge requires a multifaceted approach involving government intervention, private sector involvement, scientists (academia), health, and community participation. Based on the findings, the following recommendations are proposed:

i. *Strengthen Waste Management Policies*: Implement stricter regulations on single-use plastics, focusing on reducing polyethylene and polystyrene packaging materials.

ii. *Enhance Community-Based Cleanup Initiatives*: Encourage regular beach cleanups and waste collection efforts, particularly in Elmina, where pollution levels are highest.

iii. *Improve Public Awareness and Education*: Develop targeted campaigns to inform fishing communities and the general public about the impacts of plastic pollution and promote sustainable waste disposal practices.

iv. *Invest in Recycling Infrastructure*: Establish more accessible plastic recycling facilities, especially near coastal communities, to reduce the reliance on landfill disposal and open dumping.

v. *Encourage Sustainable Fishing Practices*: Work with fisheries management organizations to promote biodegradable fishing gear alternatives and discourage synthetic fishing nets that contribute to microplastic pollution.

vi. *Expand Research on Microplastic Contamination*: Conduct further studies on trophic transfer mechanisms, long-term health implications, and the potential accumulation of plastics in commercially important fish species.

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APPENDIX

Appendix A: Macroplastics debris collected from the two study areas

Note: Macroplastics sampled: Elmina beach behind the castle looks clean onsite but with buried debris (a); some debris collected dominated with films-single-use plastics (b, c, e); some kids engaged during sampling (d); a group of beach cleaners met during a sampling period (f)

Note: Plastic debris on Tema Beach Five (single-use plastics and bottles) (g, h, i); some debris collected washed and dried analysed (slippers, sack, fragment of hard plastics, caps and lids of bottles, cutlery, electronics, biscuit wrappers) (j, k, l)

Appendix B: Mesoplastics collected from beach sediment

Note: Mesoplastic debris were mostly dominated with hard plastics with variety of colours indicating different types of resins (a, b, c). The dominant photochemical characteristic were the black and white/transparent which were the films (d) and styrofoam (takeaway packs) (c, d) respectively. This debris composition is listed in Table 3 of Chapter Four. (Phone camera shot)

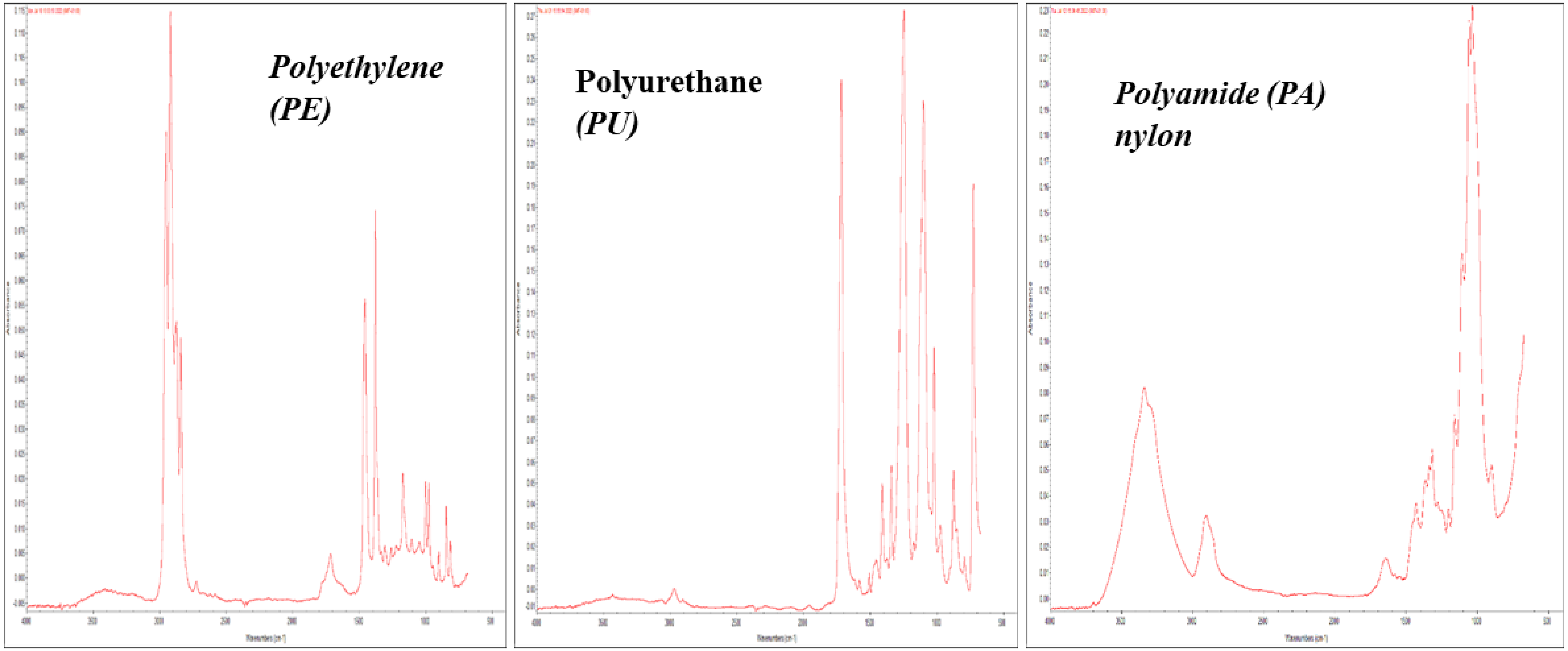
Note: Films black in colour (e); fibre- fishing line/rope (f); styrofoams (white) and fragments of different colours (g, i, j); transparent films (h, k, l) and fragments in laboratory trays during analyses. (Phone camera shot)

Appendix C: Microplastic retrieved from the two fish species

Note: The two fish species were the Angola dentex (a) and Barracuda (b); the laboratory setup worked under a fumehood chamber (c) to minimise external contamination

Note: Microplastic debris were mostly dominated with fibres (strand-like/ filamentous) a fibre on a slide (d); a view using FTIR spectroscope (e); Fibres were of variety of colours but white/transparent was the commonest multiple strand-like particles (f); Pellet spherules (g); Few fragments (blue) (h); Image magnification 25X

Appendix D: Microplastic polymer identified by FTIR spectrometer analysis



Note: some of the microplastic polymers identified in the GIT of the two fishes. The most dominant polymer was polyethylene (Chapter Five).