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Chapter in the book:

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Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). *Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island*. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

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New record of seven marine crabs from Saint Martin's Island of the northern Bay of Bengal, Bangladesh

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Abstract. Habib KA, Sarkar S, Islam MJ. 2021. New record of seven marine crabs from Saint Martin's Island of the northern Bay of Bengal, Bangladesh. *Indo Pac J Ocean Life* 5: 41-49. The present study reports the first occurrence of seven marine crabs species, *Camposcia retusa*, *Conchoecetes artificiosus*, *Cyclodius obscurus*, *Eucrater indica*, *Halimede ochtodes*, *Petrolisthes boscii*, and *Prismatopus aculeatus* collected from Saint Martin's Island, Bangladesh. These species belong to the seven families: Inachidae, Dromiidae, Xanthidae, Euryplacidae, Galenidae, Porcellanidae, and Majidae. The specimens were identified by examination of morphological characters.

Keywords: Anomura, Brachyura, distribution, morphology

INTRODUCTION

Crabs are decapod crustaceans of a large and diversified group of invertebrate animals with different forms, structures, habits, and habitats. Regarding species richness, they belong to the largest animal phylum, Arthropoda (Oliver 2004; Abbas et al. 2016). Decapod crustaceans are important members of tropical benthic communities, and the Order is predicted to hold around 15000 species under 2700 genera (Hendrickx and Harvey 1999; Vartak et al. 2018). Of all decapods, crabs belong to the infra-order Brachyura and Anomura. Most of the Brachyuran or true crabs can easily be distinguished from the so-called "false crabs" belonging to the infraorder Anomura by having four pairs of well-developed walking legs. In contrast, Anomuran crabs have the fourth (last) pair very short and usually hidden beneath the carapace that is hardly noticeable (Carpenter and Niem 1998).

Brachyuran crabs are the most diverse group and play an important role in benthic communities of marine environments ranging from intertidal to deep waters (Boudreau and Worm, 2012; Abbas et al., 2016). The infra-order Brachyura contains approximately 1271 genera and 6793 species worldwide (Ng et al., 2008; De Grave et al., 2009). On the other hand, Anomuran crabs are less diverse than Brachyuran crabs comprising approximately 1383 species worldwide (McLaughlin et al. 2010; Osawa and McLaughlin 2010).

The southern part of Bangladesh is connected with the long coastline of the Bay of Bengal, which is about 710 km (Quader 2010). Saint Martin's Island is the only sedimentary continental island of Bangladesh situated at the southernmost tip of Bangladesh in the northern Bay of Bengal and separated from mainland Cox's Bazar-Teknaf peninsula by a channel of about 9 km wide (Tomascik

1997). Saint Martin's Island is the only coral-associated island in Bangladesh and is considered an ecologically critical area with the richest biodiversity (Upal 2015; Akash and Hossain 2017). Though St. Martin's Island is known as a biodiversity hotspot, identifying most of the fishery's resources is yet to be explored (Hossain and Islam, 2006; Haque et al., 2015).

In Bangladesh, there are 58 recorded species of marine and estuarine crabs belonging to different families (Johirul 1976; Shafi and Quddus 1982; Ng et al. 1987; Chowdhury and Hafizuddin 1991; Siddiqui and Zafar 2002; Ahmed et al. 2008; IUCN Bangladesh 2015; Akash and Chowdhury 2017; Akash and Hossain 2017; Habib et al. 2017; Sharifuzzaman et al. 2018; Alam et al. 2020; Chowdhuri et al. 2020). Except for Alam et al. (2020) and Sharifuzzaman et al. (2018), all other literature results from individual survey efforts or opportunistic findings. Due to limited economic potential (except for estuarine *Scylla* spp.), marine crabs have not been prioritized as an important subject of study in the country's systematic fisheries surveys. While indicating the need for a national effort to survey estuarine and marine crabs, the present study reports the new occurrence and geographic range of one anomuran and six brachyuran crabs collected from Saint Martin's Island, thereby determining the under-surveyed and on-studied marine crab fauna of Bangladesh.

MATERIALS AND METHODS

Study area and sample collection

Specimens were collected from local fishermen, local fish markets, and direct hand-picking from the shore of Saint Martin's Island (20° 34' N - 20° 38.8' N and 92° 18' E - 92° 20.8' E), Bangladesh (Figure 1) on February 2019 to

December April 2020. All the specimens were preserved in an icebox and later brought to the Aquatic Bio-resource Research Lab at Sher-e- Bangla Agricultural University, Dhaka. The specimens were cleaned with brush and freshwater, photographed, and subjected to species-level identification. Specimens were identified to the species level using different identification keys and standard references of Selvakumar and Khan (1993), Galil (2000), Jeyabaskaran et al. (2000), Rajkumar et al. (2009), Castro and Ng (2010), Hiller et al. (2010), Pillai et al. (2013), Trivedi and Vachhrajani (2013), Lasley Jr (2014), Wongissarakul and Jantrarotai (2014), Lasley Jr et al. (2015), Beleem et al. (2016), Silambarasan et al. (2017), Beleem et al. (2017), McLAY and Naruse (2019). The external morphological features of those crabs were distinguished by the following parameters: shape, color, and carapace measurements. The carapace length and width measurements were taken using a standard Vernier caliper to the nearest 0.1 millimeters (mm). The carapace length (CL) was measured from the tip of the medial frontal teeth; along the median axis to the posterior border of the carapace. The carapace width (CW) was measured across

the widest points, usually found between the last pair of anterolateral teeth. Teeth on the anterolateral margin of the carapace, as well as teeth or ridges of the carapace, were also observed.

RESULTS AND DISCUSSION

We have identified seven crab species from seven families for the first time in Bangladesh. Among the seven crab species, *Petrolisthes boscii* (Audouin 1826) from the infra order anomuran, and five species, *Camposcia retusa* (Latreille 1829), *Conchoecetes artificiosus* (Fabricius 1798), *Cyclodius obscurus* (Hombron and Jacquinot 1846), *Eucrate indica* (Castro and Ng 2010), *Halimede ochtodes* (Herbst 1783), and *Prismatopus aculeatus* (H. Milne Edwards 1834) from the infra-order Brachyura were identified. These species belong to the seven families, Porcellanidae, Inachidae, Dromiidae, Xanthidae, Euryplacidae, Galenidae, and Majidae. Diagnostic characters of all seven species are given below.

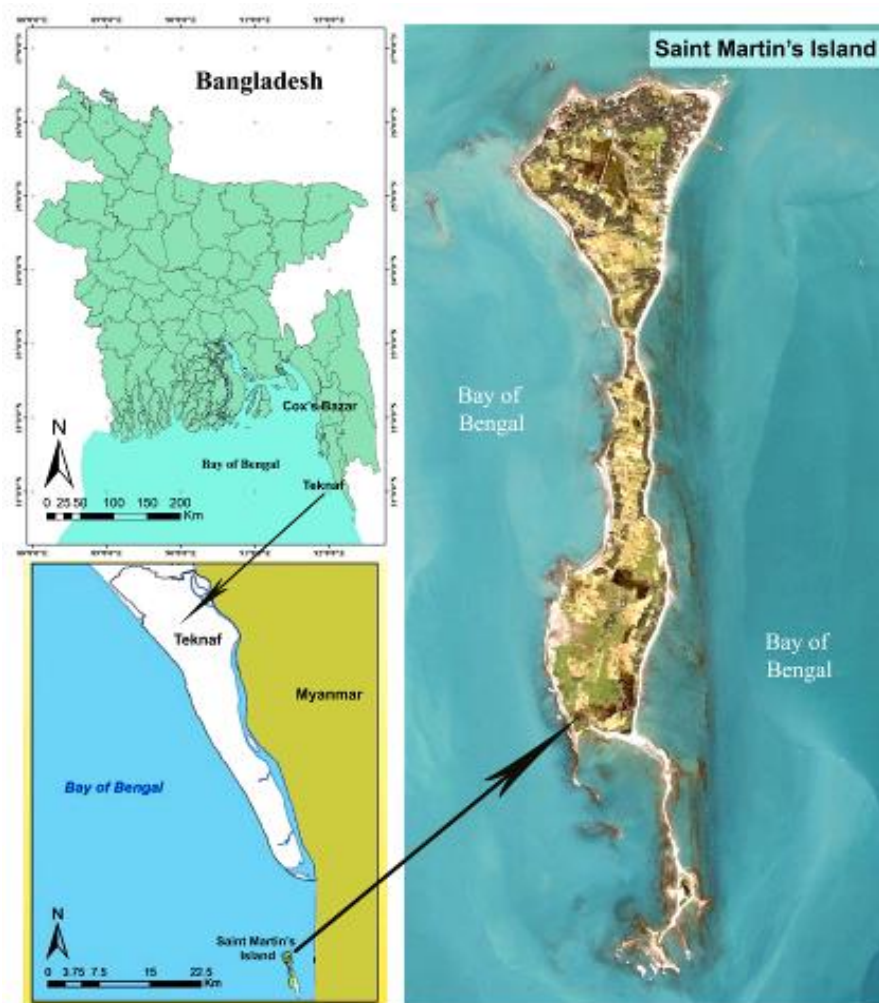


Figure 1. Location of Saint Martin's Island, Bangladesh, from where samples were collected (20° 34' N - 20° 38.8' N and 92° 18' E - 92° 20.8' E)

Infra-order: Anomura MacLeay 1838**Family: Porcellanidae Haworth 1825****Genus: *Petrolisthes* Stimpson 1858****Species: *Petrolisthes boscii* (Audouin 1826) (Figure 2A-2B)***Specimen examined*

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1). One female (Voucher no. C1912SM-03, CL: 10.5 mm, CW: 10.1 mm).

Diagnosis

The carapace is depressed and slightly longer than the width; the surface of the carapace is pubescent and covered with different kinds of flattened granules and striated lines; the carapace is rounded in shape along the brachial margins; the front part of the carapace is triangular, and the apex is innvated downward. Small acute epibranchial spine present. Eyes are relatively large and located in shallow orbits. Chelipeds are almost equal in size and armature, completely covered with transverse striped lines; merus is somewhat rugose with a serrated lobe on the anterior margin and with one acute spine; carpus two times longer than width, armed on anterior margin with three broad, serrated teeth proximally and armed on posterior margin with a strong spine distally, followed by two smaller ones; Chelae broad, with transverse striations, outer margin evenly rounded, spineless. Walking legs are covered with hair; carpus spineless; small spine is present on the merus of 1st and 2nd pair of walking legs; no spine is observed on merus of other pairs of walking legs; spinules are present on the posterior end of propodus; dactylus large with curved claws, and inner border of the dactylus have some spinules.

Color

The dorsal surface of the carapace is chocolaty red with white striations, and the ventral surface is maroon.

Habitat

The species is mostly found in the upper intertidal zone, sandy-muddy substratum, sand near low watermark, or in rocky pools under large steady boulders (Beleem et al. 2016; Mustaqim 1972). It was also reported from shallow water to 18.3 m depth, from rocks, boulders, and corals (Lewinsohn 1979). Hiller et al. (2010) found it among boulders in the deeper intertidal and the subtidal water.

Remarks and distribution

The morphological description and coloration pattern of our studied specimen are in agreement with the description of Hiller et al. (2010), Trivedi and Vachhrajani (2013), and Beleem et al. (2016). The species is widely distributed in the Indo-west Pacific region; South China Sea, Taiwan, Hong Kong, Korea, Japan, Indonesia, Thailand, Philippines, Australia, Mergui Archipelago, Madagascar, Red Sea, Persian Gulf, Oman, Pakistan, and India (Henderson, 1893; Komai 2000; Siddiqui and Kazmi 2003; Hiller et al. 2010; Prakash et al. 2013; Trivedi and Vachhrajani 2013; Beleem et al. 2016, GBIF.org 2021). The nearest distribution of this species is the south-western

part of the Bay of Bengal, India (Hiller et al. 2010). Therefore, this study confirms the occurrence of *P. boscii* species in the northern Bay of Bengal, Bangladesh.

Brachyura* Latreille 1802*Inachidae MacLeay 1838*****Camposcia* Latreille 1829*****Camposcia retusa* (Latreille 1829) (Figure 2C-2D)***Specimen examined*

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1); one specimen (Voucher no. C1903SM-II-09, CL: 29.5 mm, CW: 21.3 mm).

Diagnosis

The whole body is thickly setaceous. The carapace is somewhat triangular, longer than broad, dorsal surface not smooth and thoroughly covered with hair; Eye-stalks are long and slender. Chelipeds are short, slender, and setaceous; merus is two times longer than carpus; merus and carpus both are denticulated; fingers with teeth throughout in inner margin. Walking legs are thickly setaceous and densely encrusted with sponges, algae, etc. The second walking leg is shorter than the third one; the third walking leg is shorter than the fourth one; the fifth leg is as long as the third; the merus and propodus of each walking leg are longer than the carpus and dactylus; each dactylus with a sharp curved distal end.

Color

Entire carapace brownish; cheliped reddish white.

Habitat

Usually inhabits a muddy area of the lower intertidal zone, coral reefs, rocky weedy bottoms, under big boulders and rocks (Jeyabaskaran et al. 2000; Beleem et al. 2017).

Remarks and distribution

The species is commonly called the decorator crab. It can be differentiated from other closely related species by the tendency to have highly decorated walking legs and a fairly uniform amount of material over the whole carapace (Brooker et al., 2018). The species is widely distributed in Indo-West Pacific (Sakai 1965; Griffin 1966); including India (Andaman and Nicobar Islands, Pearl banks, Gulf of Mannar, Tamil Nadu, and Gujarat) (Alcock 1895; Laurie 1906; Jeyabaskaran et al. 2000; Apel 2001; Roy 2008; Beleem et al. 2017); Pakistan (Tirmizi and Kazmi 1986); Sri Lanka, Cocos Island (Alcock 1895); Philippines (Adams and white, 1850); South Africa, Christmas Island, Gulf of Oman, Indonesia, Japan, Australia (Apel 2001); also distributed in East Africa, Red Sea, Malay Archipelago, eastwards to Samoa and Fiji (McNeill 1968); Mauritius, Chagos Archipelago (Barnard 1950). The nearest location of this species is in Tamil Nadu, the Southwestern part of the Bay of Bengal, India (Roy 2008). The present study confirms the occurrence of *Camposcia retusa* in the northern Bay of Bengal, Bangladesh.

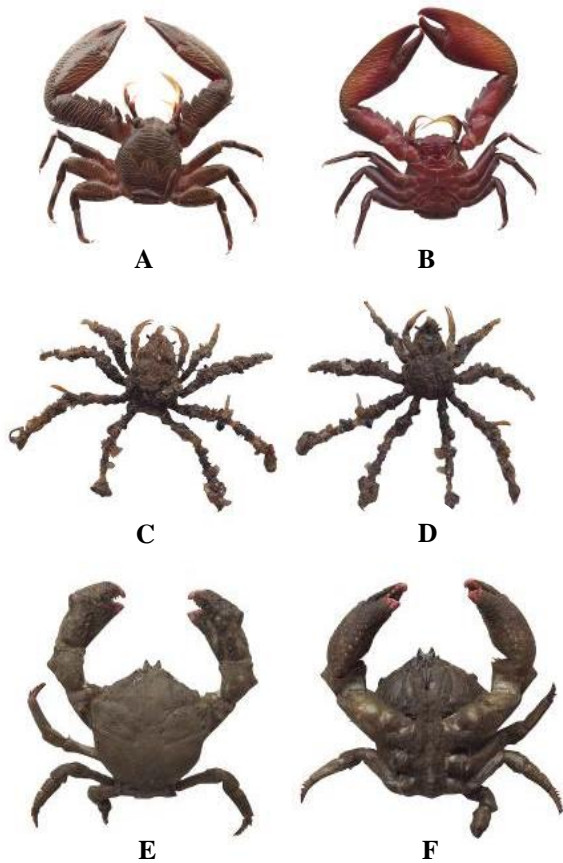


Figure 2. Photographs of *Petrolisthes boscii* (C1912SM-03; CL: 10.5 mm, CW: 10.1 mm): A. dorsal view, B. ventral view; *Camposcia retusa* (C1903SM-II-09, CL: 29.5 mm, CW: 21.3 mm): C. dorsal view, D. ventral view; *Conchoecetes artificiosus* (C1910SM-13, CL: 37.2 mm, CW: 38.9 mm): E. dorsal view, F. ventral view.

Brachyura Latreille 1802

Dromiidae De Haan 1833

***Conchoecetes* Stimpson 1858**

***Conchoecetes artificiosus* (Fabricius 1798) (Figure 2E-2F)**

Specimen examined

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1); one male (Voucher no. C1910SM-13, CL: 37.2 mm, CW: 38.9 mm).

Diagnosis

The carapace's pentagonal shape is slightly wider than the long, upper surface of the carapace velvety due to the presence of sponges. Regions are well defined by distinct grooves and tomentum evenly. Frontal, lateral teeth prominent but blunt; supraorbital margin also with a prominent blunt tooth. The anterolateral margin is convex with two teeth; these anterolateral teeth mark the widest point of the carapace; all margins are granular. Chelipeds are thick and heavy, tuberculate, dactyls of the chelipeds with large notched movable teeth. The upper portion of the propodus has many tubercles, including distinctly rounded

large ones; carpus and merus are thick and somewhat triangular; carpus with a large rounded tubercle and many other small tubercles. The second to fifth pereopods are slender and not as long as a chela. The fourth and fifth pereopods are shorter than the second and third ones; the tip of the dactyl of the second and third pereopod is hairy, and the dactyl of the fifth pereopod is minute. Although the fourth pereopod is absent in our studied specimen, the dactyl of the fourth pereopod is usually hook-shaped and firm.

Color

Due to the coverage of sponges, our specimen looks black. Fingers of the chelipeds reddish.

Habitat

Inhabits the muddy bottom with patches of sand and shells (McLAY and Naruse 2019).

Remarks and distribution

It is commonly known as sponge crab and may carry bivalve shells for camouflage (Ahyong et al., 2009; Pillai et al., 2013). The species is widely distributed in the Indo-West Pacific region, including India (East coast - West Bengal, Orissa, Tamil Nadu; West coast - Maharashtra; Islands - Andamans and Nicobars), Pakistan, Sri Lanka, Persian Gulf, Thailand, Singapore, China, Taiwan, Vietnam, Hong Kong, Japan, Cambodia, Australia, South Africa, and Madagascar (Naiyanetr 2007; Roy 2008; Ahyong et al. 2009; Naruse et al. 2014; McLAY and Naruse 2019). The nearest distribution of this species is the northern, southern, and western parts of the Bay of Bengal (Roy 2008). However, the present study confirms the occurrence of *Conchoecetes artificiosus* species in Bangladesh marine waters.

Brachyura Latreille 1802

Xanthidae Macleay 1838

***Cyclodius* Dana 1851**

***Cyclodius obscurus* (Hombron and Jacquinot 1846) (Figure 3A-3B)**

Specimen examined

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1); one male (Voucher no. C1903SM-II-08, CL: 53.8 mm, CW: 69.9 mm).

Diagnosis

Carapace transversely hexagonal in shape and wider than long. The dorsal surface of the carapace is convex and granulated, which looks bulging; broad depressions define regions. The frontal lobe is relatively larger than the lateral lobes; sub-median lobes are joined medially and form a V-shaped notch. Antero-lateral margins with four teeth excluding the outer supra-orbital tooth; teeth 1 and 2 are small and obtuse; teeth 3 and 4 are large and acute. Chelipeds are long, nearly equal, stout, and heavy; the outer surface smooth and covered with small granules; the fingers of the chelipeds black and gaping. Ambulatory legs are shorter than chela and covered with numerous plumose

setae, the tip of the dactylus with a long, sharp chitinous spine.

Color

The dorsal surface of the carapace is chocolaty brown. Chela and ambulatory legs are reddish-brown. The tip of the chelipeds is black.

Habitat

Usually inhabits coral reefs, mostly found in live corals but rarely under dead corals (Roy 2008).

Remarks and distribution

The species can be differentiated from its closely related species *Cyclodius unguates* by its narrower carapace, more convex gastric region, and more projecting lateral lobes (Gordon 1934). The species is distributed in the Indo-West Pacific region, India (Tamil Nadu, Andaman, and the Nicobar Islands), Japan, Indonesia, Philippines, Palau, Micronesia, Marshall Islands, South Africa, East Coast of Africa, Djibouti, Red Sea (Egypt), Madagascar, Reunion Island, Mauritius, Seychelles, Europa Island, Hawaii, New Caledonia, Samoa, Tuvalu, Kiribati, Fiji, Australia, and French Polynesia (Roy 2008; Poupin et al. 2013; Lasley Jr 2014; GBIF 2021). The present study confirms the occurrence of *Cyclodius obscurus* species in the northern Bay of Bengal, Bangladesh.

Brachyura Latreille 1802

Euryplacidae Stimpson 1871

***Eucrate* de Haan 1835**

***Eucrate indica* (Castro and Ng 2010) (Figure 3C-3D)**

Material examined

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1). One male (voucher no. C1910SM-16, CL: 22.3 mm, CW: 26.7 mm).

Diagnosis

Carapace transversely rectangular in shape, slightly broader than long; dorsal surface convex and smooth. The anterolateral margin of the carapace is armed with three teeth, including the external orbital tooth; the second tooth is a bit triangular, and the third anterolateral tooth is large, sharp, and well separated from the 2nd tooth. The fissures on the dorsal orbital margin are inarticulate; the posterolateral borders of the carapace are relatively long. Walking legs are slender and long, without spines.

Color

The entire specimen is somewhat reddish-brown because of tiny reddish scattered spots on the frontal part of the carapace and walking legs. In addition, eight irregular, large, red-brown spots are present on the median portion of the dorsal surface of the carapace, each flanked by two smaller, vertically placed spots.

Habitat

It inhabits 40-60m depth in the marine environment (Silambarasan et al., 2017).

Remarks and distribution

The present male specimen from the Bay of Bengal, Bangladesh, agrees well with the previous description of Rajkumar et al. (2009), Castro and Ng (2010), and Silambarasan et al. (2017). The coloration pattern of our specimen is slightly different but agreed with Silambarasan et al. (2017). The species is widely distributed in India, China (coast of the East China Sea to Taiwan Island), the Philippines, Vietnam (Nhatrang Bay), the Gulf of Thailand, Malaysia, and the Andaman Sea (Sakai 1976; Serène 1981; Dai 1991; Ng et al. 2001; Hsueh et al. 2002; Ng and Davie 2002; Castro and Ng 2010). However, the nearest distribution of this species is Chennai coast and Parangipettai coast, the Southwestern part of the Bay of Bengal, India (Rajkumar et al. 2009; Silambarasan et al. 2017). Therefore, this study confirms the occurrence of *Eucrate indica* species in the northern Bay of Bengal.

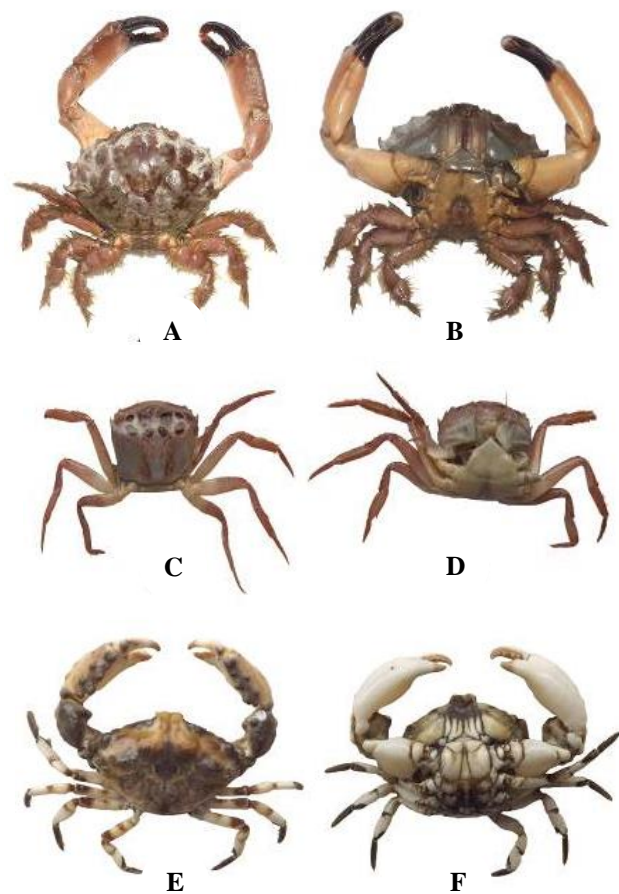


Figure 3. Photographs of *Cyclodius obscurus* (C1903SM-II-08, CL: 53.8 mm, CW: 69.9 mm): A. dorsal view, B. ventral view; *Eucrate indica* (C1910SM-16, CL: 22.3 mm, CW: 26.7 mm): C. dorsal view, D. ventral view; *Halimede ochtodes* (C1910SM-14, CL: 26.5 mm, CW: 34.8 mm): E. dorsal view, F. ventral view.

Brachyura Latreille 1802**Galenidae Alcock 1898****Halimede de Haan 1835****Halimede ochtodes (Herbst 1783) (Figure 3E-3F)***Specimen examined*

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1); one male (Voucher no. C1910SM-14, CL: 26.5 mm, CW: 34.8 mm).

Diagnosis

Carapace broader than long and smooth, dorsal surface convex and glabrous, regions ill-defined, anterior portion of the carapace tubercular, minutely granulated, and separated by shallow grooves with each other. Anterolateral margins with distinct, apically granulated, rounded knobs decrease in size from posterior to anterior. Chelipeds are unequal in shape and carry many bulbous knobs or lobes. Upper margin of cheliped merus bearing 4 to 6 bulbous knobs. Carpus irregularly gnarled, smoother, and two bulbous knobs on the interior angle. The upper margin of the chela bears many bulbous knobs; the lower external surface and lower margin of the chela are smooth. Upper margin of dactyl bearing two bulbous knobs.

Color

The dorsal surface of the carapace is creamy and blackish; the ventral surface is whitish. The tip of each dactyl of walking legs is black.

Habitat

The species inhabits muddy or sandy substrata in the inshore water (Selvakumar and Khan 1993; Jeyabaskaran et al. 2000).

Remarks and distribution

Halimede ochtodes can be distinguished from its closely related species by the ill-defined posterior regions of the carapace, globular knobs bearing anterolateral margin, upper margin of chela, and nearly smooth lower external surface of the chela (Galil 2000). The species is widely distributed in the Northern half of Australia, Pakistan, India (Madras coast, Parangipettai coast, Gulf of Mannar), Myanmar, Thailand (Gulf of Thailand), Singapore, China (Guangxi, Hainan, Hong Kong), Sagami Bay (Japan), the Philippines, Malay Archipelago, Penang, Indonesia (Dai and Yang 1991; Selvakumar and Khan 1993; Galil 2000; Jeyabaskaran et al. 2000; Davie 2002; Naiyanetr 2007), Cambodia (Naruse et al. 2014), Red sea (Lipej et al. 2017), and the Mediterranean coast of Israel and Egypt (Galil 2000; Lipej et al. 2017). The nearest distribution of this species is the Parangipettai coast and Madras coast, the Southwestern part of the Bay of Bengal, India (Selvakumar and Khan 1993). The present study confirms the occurrence of *Halimede ochtodes* in the northern Bay of Bengal, Bangladesh.

Brachyura Latreille 1802**Majidae Samouelle 1819****Prismatopus Ward 1933****Prismatopus aculeatus (H. Milne Edwards 1834) (Figure 4A-4B)***Specimen examined*

Saint Martin's Island, Bay of Bengal, Bangladesh (Figure 1); one male (Voucher no. C1903SM-10, CL: 26.8 mm, excluding rostrum; CW: 20.1 mm).

Diagnosis

Carapace pyriform in shape, convex dorsally, and with small hooked setae. Five spines are present on the middle line of the carapace's dorsal surface: a gastric region with two acute spines, a single acute spine in the cardiac region, and two acute spines in the intestinal region. In addition, two long, acute spines are present in the branchial region, which is directed to the outside and backside. The rostrum is significantly divergent, hairy, and outwardly curved; antennae almost as long as a rostrum. Pre-orbital and antorbital spines present where the pre-orbital spine is slightly longer than the antorbital spine and directed outwardly. Intercalated spine short. Strong lobe present on the hepatic region and hepatic margin with a small tubercle. Chelipeds are slender, smooth, and not much long; fingers with small blunt teeth; carpus are small and curl; merus is two times longer than carpus. Ambulatory legs are slender, longer than chela except for the last two pairs of legs and covered with hooked setae; carpus with the single spine on the distal end of the upper border only on the first pair; margin of merus with acute curve spine on the distal end, but the last two pairs are reduced in size; dactylus with an acute, curved spine.

Color

The dorsal surface of the carapace is blackish; the ventral surface and appendages are whitish.

Habitat

The species usually inhabits sponges, corals, and algae which help to decorate themselves, camouflage, defense, shelter, or food; they are also found under pebbles (Jaingam et al. 2008; Wisespongand et al. 2012).



Figure 4. Photographs of *Prismatopus aculeatus* (C1903SM-10, CL: 26.8 mm, excluding rostrum; CW: 20.1 mm): A. dorsal view, B. ventral view.

Remarks and distribution

Prismatopus aculeatus is commonly known as spider crab or decorator crab as it can attach materials from an environment with the help of its hooked setae present on its carapace (Gary 2004). It can be distinguished from its closely related species by its different shapes and number of spines present on the carapace (Wongissarakul and Jantraratat 2014). It is widely distributed in the Indo-West Pacific; India (Tamil Nadu, Gulf of Kutch, Maharashtra, Kerala, Karnataka, Lakshadweep); Sri Lanka, Indonesia, Philippines, China, Japan, Mergui Archipelago, Gulf of Martaban, Malacca Strait, Singapore, Gulf of Thailand, Sulu Archipelago, Torres Strait, Australia (Queensland), Cape Jaubert and Thursday Island (Roy 2008; Roy 2013; Wongissarakul and Jantraratat 2014; Beleem et al. 2019; Devi et al. 2019; GBIF.org 2021). The nearest distribution of this species is Tamil Nadu, the South-Western part of the Bay of Bengal, India (Roy 2008). The present study confirms the occurrence of *Prismatopus aculeatus* species in the northern Bay of Bengal, Bangladesh.

In conclusion, the current study successfully identified seven marine crab species under seven families from Bangladesh for the first time. Most of the species are naturally present in the Indo-west Pacific region. All species had previously been recorded from the east coast of India (The western part of the Bay of Bengal), which clarifies that the marine crab inventory of Bangladesh is incomplete. Results of this study exhibit the remarkable addition of new records to the country's crab checklist and uplift the number of known marine species in Bangladesh. At the same time, it also shows the need for systematic, comprehensive, and extensive sampling to better understand the diversity and distribution of marine crab species in the northern Bay of Bengal.

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Macrobenthic infaunal assemblage structure in nearshore and offshore seabeds of Ghana

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Abstract. *Commey NA, Armah AK, Lamptey E. 2021. Macrobenthic infaunal assemblage structure in nearshore and offshore seabeds of Ghana. Indo Pac J Ocean Life 5: 50-60.* This research aimed to compare and contrast the sediment properties and benthic macrofaunal assemblage composition of nearshore and offshore habitats. Also, the existing state of benthic macrofaunal assemblages in the Jubilee Fields, Ghana in 2015 is determined. A baseline is established for these communities before constructing a coal-powered plant in the nearshore area of Ekumfi Aboano, Ghana (deep-sea). The research was conducted in the shallower nearshore Ekumfi Aboano (average depth: 15 m) and deeper offshore portions of the Jubilee Fields (average depth: 1,250 m). A Van Veen grab was used to collect sediment samples from the nearshore area, while a box corer was used to collect samples from the deep water. PRIMER was used to look into the distribution of benthic macrofauna. Using GRADISTAT, it was determined that the nearshore sediment (mean grain size of 99.80 μ m) is fairly sorted with very fine sand. In contrast, offshore sediment (mean grain size of 109.79 μ m) was poorly sorted and comprised of extremely coarse silty fine sand. It was determined from studies of macrobenthic infauna that there were 11,131 individuals in the nearshore environment, with a density of 38 individuals/m², and 22,105 individuals in the deep-sea environment, with a density of 47 individuals/m². Data for the nearshore and offshore environments showed a total of 194 and 983 polychaetes, 827 and 696 crustaceans, 35 and 229 mollusks, 14 and 37 echinoderms, and 43 and 260 "others" (foraminiferans, nematodes, nemerteans, and sipunculids). Crustaceans > polychaetes > molluscs > others > echinoderms dominated the shallow Ekumfi seabed, whereas polychaetes > crustaceans > molluscs > others > echinoderms dominated the offshore Jubilee seabed. There were 116 species discovered close to shore, while 188 were discovered in the deep water. Both locations displayed a high level of diversity (H' > 4; $1-D$ > 0.9) and were evenly distributed (J' > 0.8). The nearshore was dominated by arthropods (74.30%), while the offshore was dominated by polychaetes (44.58%). A greater variety of macrobenthic infauna was found in the deep sea compared to the nearshore, with a difference of 75% between the two environments.

Keywords: Ghana, macrobenthic infauna, nearshore, offshore, seabeds

INTRODUCTION

Seventy percent of the Earth's surface is covered by water (Gray and Elliot 2009), making the marine environment the largest and most diversified biological community (Huston 1994; Garrison 2012). The marine ecosystem consists of continental shelf intertidal zones (0-200 meters), abyssal plains (2000-6000 meters), seamounts (> 1000 meters), and hadal troughs (6000-10000 meters) (Lalli and Parsons 2006). Its most essential characteristic is environmental heterogeneity; as a result, the ocean serves as the habitat for numerous animals found in the water column or connected to the seafloor (Lalli and Parsons 2006).

The two interdependent zones that make up the aquatic ecosystem are the water column (pelagic zone) and the sediment (benthic zone) upon which it rests. Regarding habitat size, the benthic zone is second to the pelagic environment but first in terms of geographical coverage (Bacci et al. 2009). These sediments are either autochthonous (originating where they are found) or allochthonous (originating elsewhere than where they are found) (FAO-FIGIS 2007). The benthic ecosystem is a community of bottom-dwelling creatures interacting with the sediment-water interface or environment. It is driven by

the processes and variables of interdependent connections. Predator-prey relationships and competition are biological interactions (biology-biology relationships) that are capable of altering the biological community structure. Sediment morphology and chemistry can be affected by organism interactions (biology-environment relationships). In most instances, the extent of contact or modification is unknown but can be predicted (Gray and Elliot cit. Elliot et al. 2006). The activities of humans overlay these processes.

The devastation of natural environments (terrestrial and aquatic) has occurred over time as people have sought other energy sources to satisfy growing energy demands. Non-renewable resources (fossil fuels) are currently providing the majority of the world's energy, as reported by the International Energy Agency (IEA) Renewable Energy Working Party (2002). As we continue to mine for them, non-renewable resource quantities will continue to decline, driving up their prices and increasing environmental damage. Clean, renewable energy can meet or even exceed global energy demand while posing less danger to the planet's ecosystems.

Contrary to non-renewable resources, replenished over far longer timescales, renewable resources (such as wind, rain, sunlight, and geothermal heat) are constantly replenished on a shorter human timescale. Most of these

renewable and non-renewable resources are overseen by governments located on continental shelves (Halpern et al. 2008). Submarine noise (Williams et al. 2015; Solan et al. 2016), gaseous emissions (Wilding et al. 2017), and electromagnetic fields are just some examples of the anthropogenic influences on the marine environment (Woodruff et al. 2013).

Human energy demands are concentrated on power generation, air and water cooling and heating, transportation, and rural energy services (REN21 2010).

Sufficient energy is based on energy security, limiting negative environmental effects, maximizing economic gains, and minimizing waste (International Energy Agency 2012). Biomass, hydropower, solar, wind, and geothermal energy contribute to the renewable 19% of world energy consumption (Ellabban et al. 2014; REN21 2016).

Hydropower, marine energy, solar energy, marine energy, and biomass energy are all significant options for energy generation that many African countries may use. For example, more than 30,000 extremely small solar panels are supplied annually in Kenya, making it the likely global leader in solar power system installations per capita. As a result, we save money on electricity while contributing significantly to environmental sustainability (Bullis 2012). In addition, liquid bioenergy (ethanol and methanol) from plant matter is used in several African countries as a domestic cooking stove fuel because it is clean, affordable, sustainable, and renewable. These countries include Ethiopia, Kenya, Mozambique, and Nigeria (REN21 2011). These efforts to use cleaner energy sources can help alleviate and even end poverty. Additionally, industrialization and urbanization can be accelerated (Wesseh and Lin 2016). Ghana's benthic environment has been subject to regular monitoring since the country's initial crude oil finding in 2007 when oil and gas drilling began on the country's continental shelf.

Shipping and maritime sector activities include oil and gas exploration and extraction, sonar systems, fishing methods (bottom trawling), dredging, and offshore mining (Coates et al. 2015; Hawkins and Popper 2016), have the potential to affect marine ecosystems and associated species. Species extinction, physiological modification (tissue damage, congenital disabilities due to chemical ingestion), behavioral modification, ocean acidification, and shifts in community structure and benthic species assemblages are all attributable impacts. However, it is unclear how much humans have an effect on the marine environment, especially the seafloor and related creatures (Halpern cit. Borowski 2001; Mesa et al. 2013). The need for regular assessment arises from the fact that shifts in the composition of marine benthic communities portend the disappearance of important services provided by this ecosystem (Tagliapietra and Sigovini 2010; MacDonald et al. 2012).

Maintaining a balanced maritime ecosystem depends on marine benthic communities and their supporting creatures. Indicator species are used to discover and determine the level of disruption to marine and aquatic habitats, and they play a role in elemental cycling, benthic remineralization, and eventually carbon sequestration (Pavithran et al. 2007;

Jones et al. 2014). Acquiring macrobenthic baseline data will help direct environmental policy and biodiversity management in the deep seas of Ghana's EEZ (Froján et al. 2016). The main objectives include elucidating macrobenthic infaunal community structure and evaluating the connection between nearshore and deep-water seafloors.

MATERIALS AND METHODS

Study area

Ghana has a 550-kilometer (km) coastline. It was bordered by Guinea Current Large Marine Ecosystem (GCLME). Except for a 90 km extension off the coast of Takoradi, the continental shelf begins between 20 and 35 km out (ATFALCO 2012). The study focused on Ekumfi and Jubilee Fields, two major coastal locations in Ghana (Figure 1). Ekumfi Aboano was chosen because it is the intended location for the construction of a coal-fired power plant; as a result, baseline information on macrobenthic fauna is required for future comparisons and assessments of changes following production. Although the Jubilee research site has been operational for nearly a decade, the current status of the macrobenthic fauna within its operational area is unknown because historical reports cannot be used to monitor trends.

Ekumfi Aboano is located 78 kilometers west of Accra and 50 km east of Cape Coast (N 5°12'41.44", W 0°49'51.00"). This location experiences average temperatures of 28°C and approximately 70% relative humidity (Ghana Statistical Service 2014). The district's coastal boundary consists of rocky coasts and cliffs with short stretches of sandy beach. Within the Cretaceous-Eocene marine sands, the coastline contains some limestone and pebbly sand (Ghana Statistical Service 2014).

In 2007, the area between Deepwater Tano and West Cape, known as Jubilee Fields, was discovered. Three Points, which obstructs the Jubilee Fields (N 4°29'34.0", W 2°55'00.0"), is located 60 kilometers off the nearest coast at a depth of approximately 1400 meters (Tullow Ghana Limited 2009). Clays and silts range in hardness from soft to firm and make up most of the relatively smooth bottom (Tullow Ghana Limited *ibid*).

Data collection

Sampling took place at Jubilee Fields in November 2015 at a depth of 1,250 meters and Ekumfi Aboano in January 2016 at a depth of 15 meters. The sediments were sampled by lowering a Van Veen grab (used at Ekumfi Aboano) and a box corer (employed at the Jubilee Fields) to the seafloor using a winch. Both sampling devices had approximately 0.25 m² of surface area. When the descent rate neared the seafloor, precautions were taken to prevent damaging the epibenthos and the surface sediments. Samples were deemed acceptable after retrieval if they had a level surface, the grab or corer had been completely closed, or no significant leakage was seen. During the sampling process, random sediment samples were divided

into two sections, one for biological (benthos) investigations and the other for sediment characterization. The sediment samples labeled for macrobenthic infaunal studies were emptied through a sieve with a mesh size of 0.5 millimeters (mm) and rinsed with seawater using a flotation technique that minimizes stress to the organisms and enables their separation from sediment (Tagliapietra and Sigovini 2010).

The macrobenthic organisms less than 0.5 mm were discarded, while fragile organisms or organisms remaining on equipment, such as ophiuroids, were collected using forceps and placed in labeled containers. In labeled storage containers, the leftover sample was backwashed with seawater.

The obtained specimens were subsequently treated with 10% buffered formaldehyde to preserve and harden some organism tissues. Date, location, sample type (macrobenthos or sediment grain size analysis), and preservation method were recorded on sample labels. Rose Bengal was applied to samples, 10 mL to $5.03 \times 10^{-4} \text{ m}^3$ and 20 mL to $7.54 \times 10^{-4} \text{ m}^3$, to stain the living tissues. Before usage at every sampling location, all equipment was inspected, cleaned, and rinsed.

For laboratory examination, sediment samples were labeled and stored in plastic containers for grain size analysis. Per sampling station, three replicate samples were collected due to the patchy distribution of benthos. There

were a total of 64 samples taken, 29 from Ekumfi Aboano and 35 from Jubilee Fields.

Laboratory analyses

Macrobenthic infaunal analyses

The formaldehyde and other fine particles (lesser than 0.5 mm) were removed from macrobenthic samples by rinsing them with clean water on 0.50 mm-mesh sieves. The samples were equally distributed on a sorting tray with a white background and enough supply of clean water. Then, using fine forceps, the stained material was collected and placed into storage vials containing a 70:30 or 80:20 mixture of alcohol and glycerol. Alcohol permits short-term preservation, whereas glycerol lowers alcohol evaporation during solidification. During sorting, stained material or recognized species were classified into broad taxonomic groups, such as polychaetes, mollusks, and echinoderms (Eleftheriou and McIntyre 2007; Rumohr 2009).

Using a stereomicroscope, the identification of organisms was refined to the species level. As guides, acceptable taxonomic keys such as Nicklès (1950), Fauchald (1977), and Barnes (1994), as well as articles and manuals such as Tebble (1955), Rupert and Fox (1988), Branch and Branch (1998), Martin and Davis (2001), Rouse and Pleijel (2001), and Ardovini and Cossignoli (2004) were utilized.

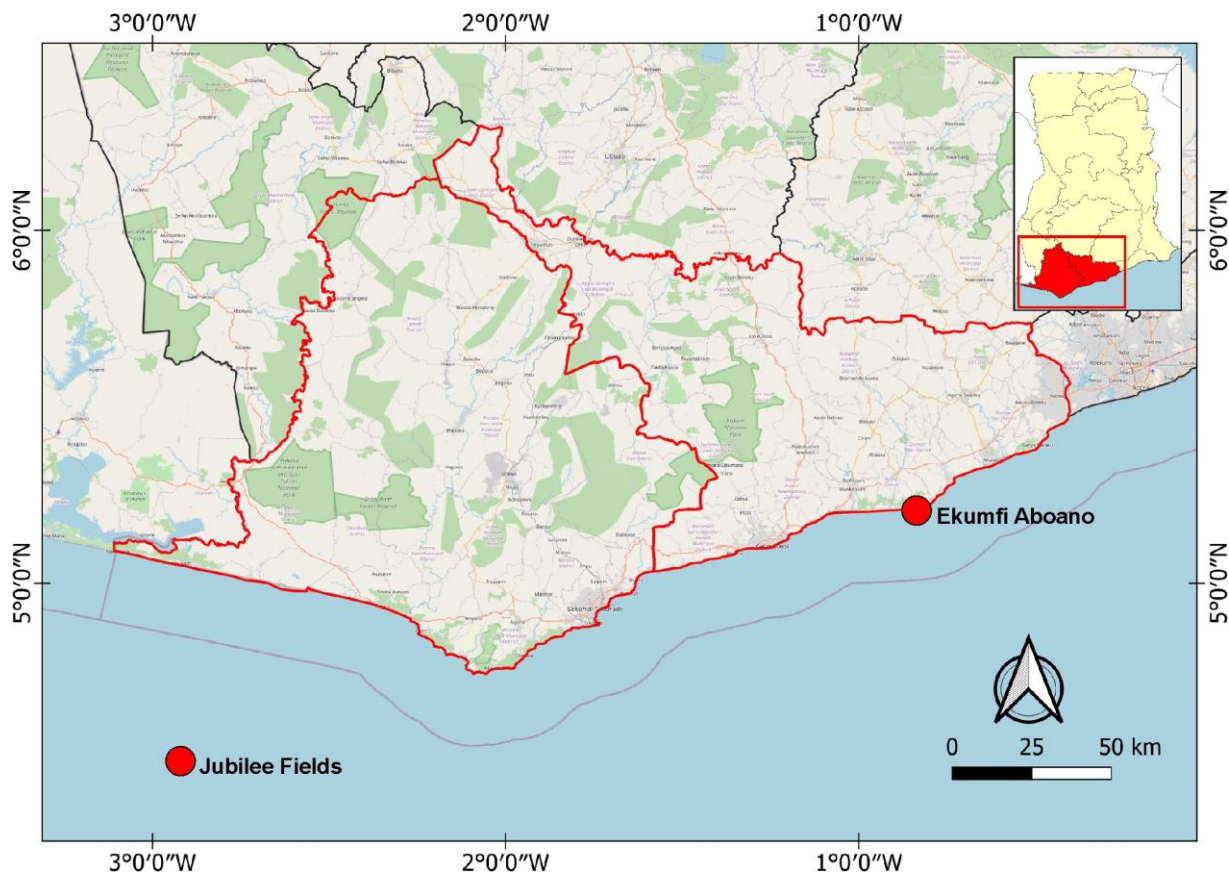


Figure 1. Map of Ghana showing sampling locations (Ekumfi Aboano and Jubilee Fields)

Sediment granulometry

In the Marine and Fisheries Sciences Post-Graduate Laboratory, sediment samples were oven-dried at 60°C for 8 hours at a constant weight of 120 grams (g) and analyzed with the Philip Harris A20002 weighing balance. Using a 63-micron (m) mesh filter, clumped sediment samples were rinsed with a dispersing reagent (1% NaOH(aq.)). Next, the residual sediment was oven-dried to constant weight at 60 degrees Celsius for six hours. The weight differences represented the silt-clay portion of the sediment. Next, 100 g of the dried sediment was weighed and sieved with the Octagon D200 Digital Sieve Shaker via stacked sieves. Following a diminishing geometric scale, the stacked sieves were positioned as follows: 1 mm, 0.5 mm, 0.355 mm, 0.125 mm, 0.063 mm, and the receiver. These sieve mesh sizes hold very coarse, coarse, medium, and fine sand particles. The retainer retains the silt and clay fractions of the sediment, respectively. Using the Philip Harris A20002 measuring scale, the weight of retained silt on each screen was calculated and recorded to the nearest 0.01 g. The collected sediment grain sizes were classified with the Wentworth scale (Blott and Pye 2001; Gray and Elliot 2009).

Diversity indices

Several indices can be used to measure diversity indicators that act as an indicator of community health on spatial and temporal scales (Magurran 2004). In this study, however, diversity indices such as Margalef's species richness, Pielou's evenness index, Shannon- Weiner, and Simpson's diversity index were utilized.

Margalef's species richness (d)

Species richness is the total number of different species found inside a sample without accounting for the proportion and distribution of each species. For example, the following equation represents the Margalef index (Margalef 1958):

$$d = \frac{(S - 1)}{\ln N}$$

Where:

- S = the total number of species, and
- N = the total number of individuals in the sample.

Pielou's evenness (J')

Pielou (1966, 1969) utilized the ratio of the expected number of species to the actual number of species as an indicator of evenness, assuming that all species were represented in the sample. It facilitates the determination of organism distribution among sampled assemblages. A higher score indicates a more even distribution of individuals within the species. Species evenness is based upon species abundance and diversity. The measure of evenness is the ratio of the observed diversity to the greatest that might exist in a sample with the same number of species. The equation used was:

$$J' = \frac{H'}{H'_{max}} = \frac{H'}{\log S}$$

Where:

- H' = the Shannon-Wiener diversity index
- S = the total number of species

Shannon-Wiener's diversity index (H')

The Shannon-Wiener diversity index (or simply Shannon diversity) describes the condition of an assemblage in terms of the number of species present and the relative abundance of those species. It assumes that all species are represented in the sample and that random samples are taken from a large population. The diversity of a community is determined by the obtained value: 0 to 1.5 for low diversity, 1.5 to 2.5 for moderate diversity, and > 2.5 for great diversity. Shannon-Wiener diversity value typically ranges from 1.5 to 3.5 but can reach 4. The indicator rises as community wealth and distribution improve (Magurran 2004). The used equation is:

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

Where:

- p_i = the proportion of individuals found in species i
- ln = natural logarithm
- s = the total number of species

Simpson's diversity index (D)

Simpson (1949) first proposed using this metric to quantify the level of species concentration in a given taxonomic group. Simpson's diversity index can take on values between 0 and 1, with 0 indicating no diversity and 1 indicating infinite diversity. The measure correlates positively with both species diversity and abundance. Therefore, the Simpson index ignores the small number of individuals belonging to rare species since it places more importance on more abundant species.

The equation used to measure it was:

$$D = \sum \left(\frac{n(n-1)}{N(N-1)} \right)$$

Where:

- n = the total number of organisms of a particular species
- N = the total number of organisms of all species

Since D measures predominance, a higher D results in less diversity (in the traditional sense). Because of this, the complement 1-D of Simpson's index is typically reported. It gives a proportionate, intuitive, and less species-richness-dependent measure of diversity.

Sediment granulometry assessment

Grain size is a key feature of sediment particle transit and deposition (Blott and Pye 2001), as it permits the

assessment of sediment nature at sampling stations (Gray and Elliot 2009). Using modified scales from Udden (1914) and Wentworth (1922), sediment was classified.

Statistical analyses

Species abundance, species' relative abundance, frequency of occurrence (FOQ), the relative frequency of occurrence, and species diversity indices are performed as univariate analyses. The primary objective of the multivariate analysis was to evaluate the variability between sampled species, families, and sampling locations. Dendrograms were used to visualize macrobenthic assemblage patterns to determine the link between sampling sites. Using SIMPER (Similarity Percentage) tests, it was determined which species contribute to observed variations between and within sites. The grain size distribution was analyzed with the GRADISTAT tool, a Microsoft Excel-based statistical package. Univariate and multivariate analyses were conducted using the Microsoft Excel tool Pac and PRIMER (Plymouth Routines In Multivariate Ecological Research) version 6, respectively. In addition, version 23 of IBM SPSS (Statistical Package for the Social Sciences) was used to test hypotheses.

RESULTS AND DISCUSSION

Polychaetes, crustaceans, mollusks, echinoderms, and sipunculids were discovered and recognized within the collected samples. Figure 2 depicts a selection of these creatures.

Macrobenthic species abundance and relative abundance

Table 1 displays the variety of species found at Ekumfi and Jubilee. There were 1113 individuals with an average density of 38 individuals/m² in the nearshore habitat and 2205 individuals with an average density of 47 individuals/m² in the deep-sea environment. The analyses yielded polychaetes, crustaceans, mollusks, and "others" as taxa. Other species consisted of foraminiferans, nematodes, nemertean, and sipunculids.

The numerical abundance of species in the nearshore habitat revealed that there were 194 polychaetes, 827 crustaceans, 35 mollusks, 14 echinoderms, and 43 other species. The respective average densities were 15, 62, 23, 28, and 57. There were 983 polychaetes, 696 crustaceans, 229 mollusks, 37 echinoderms, and 260 other species inside the deep-sea ecosystem. Their relative total densities were 36, 59, 42, 29, and 157 (Table 2).

Crustaceans > polychaetes > molluscans > others > echinoderms dominated the shallow Ekumfi seabed, whereas polychaetes > crustaceans > molluscans > others > echinoderms dominated the deep Jubilee seabed.

Macrobenthic species richness and diversity

Margalef's index (d) in the nearshore environment was 15.68, and Pielou's index (J') was 0.88. Shannon-Weiner and Simpson indices were 4.13 and 0.98, respectively, for the diversity. In the deep-sea benthos, Margalef's index (d) was found to be 24.16 while Pielou's index was 0.88. Shannon-index Weiner's diversity is 4.43, and Simpson's index is 0.98. It indicates that species richness and variety were greater in the macrobenthos of the deep sea (Table 3). The significance of the discrepancy was evaluated using the Mann-Whitney test (Table 4).

Cluster analysis

Dendrograms depicting a Bray-Curtis similarity cluster assessment between-site (Figure 3) and within-site (Figures 4 and 5) are provided. About 75% dissimilarity was found between-site. Across all of Ekumfi Aboano, the average degree of similarity was 40%. Within-site similarity for Jubilee Fields was measured at 35%.

Sediment characterization

Very fine sand, well sorted, was found in the Ekumfi sediment core, while very coarse silty fine sand, poorly sorted, was found in the Jubilee sediment core (Table 5). The average grain size of the sediments in the nearshore and offshore regions was determined to be 99.80 µm and 109.79 µm, respectively. At Ekumfi, the correlation between abundance and grain size was positive (0.82), whereas it was negative (-0.82) at Jubilee Fields (Table 6).

Species frequency of occurrence

The most common species of macrobenthic organisms at Ekumfi Aboano and Jubilee Fields are depicted in Figures 6 and 7, whereas the most common macrobenthic families are depicted in Figures 8 and 9.

Nineteen (19) out of 116 species were found to have the highest frequency of occurrence (> 20%) in the Ekumfi survey (Figure 6). Arthropods (13 species), polychaetes (2 species), mollusk (1 species), echinoderm (1 species), nemertean (1 species), and nematode (1 species) made up the majority of the 19 dominant species. Of the 188 species found in the Jubilee Fields, 14 were more common than the 50% threshold (Figure 5). Six annelids (polychaetes), six arthropods (crustaceans), one mollusk, and one nematode were among 14 species.

Similarity percentage (SIMPER)

To compare species richness between and within sites, the percentage of species contribution to the sample was calculated. Eleven (11) species accounted for 70.3% of the community structure in the Ekumfi samples, leading to an average similarity of 5.68% between them. In the Jubilee Samples, 24 species accounted for an average of 28.41% of the similarity and 70.4% of the community structure. Seventy-two species made up 70.3% of the difference in community structure between the Ekumfi and the Jubilee.

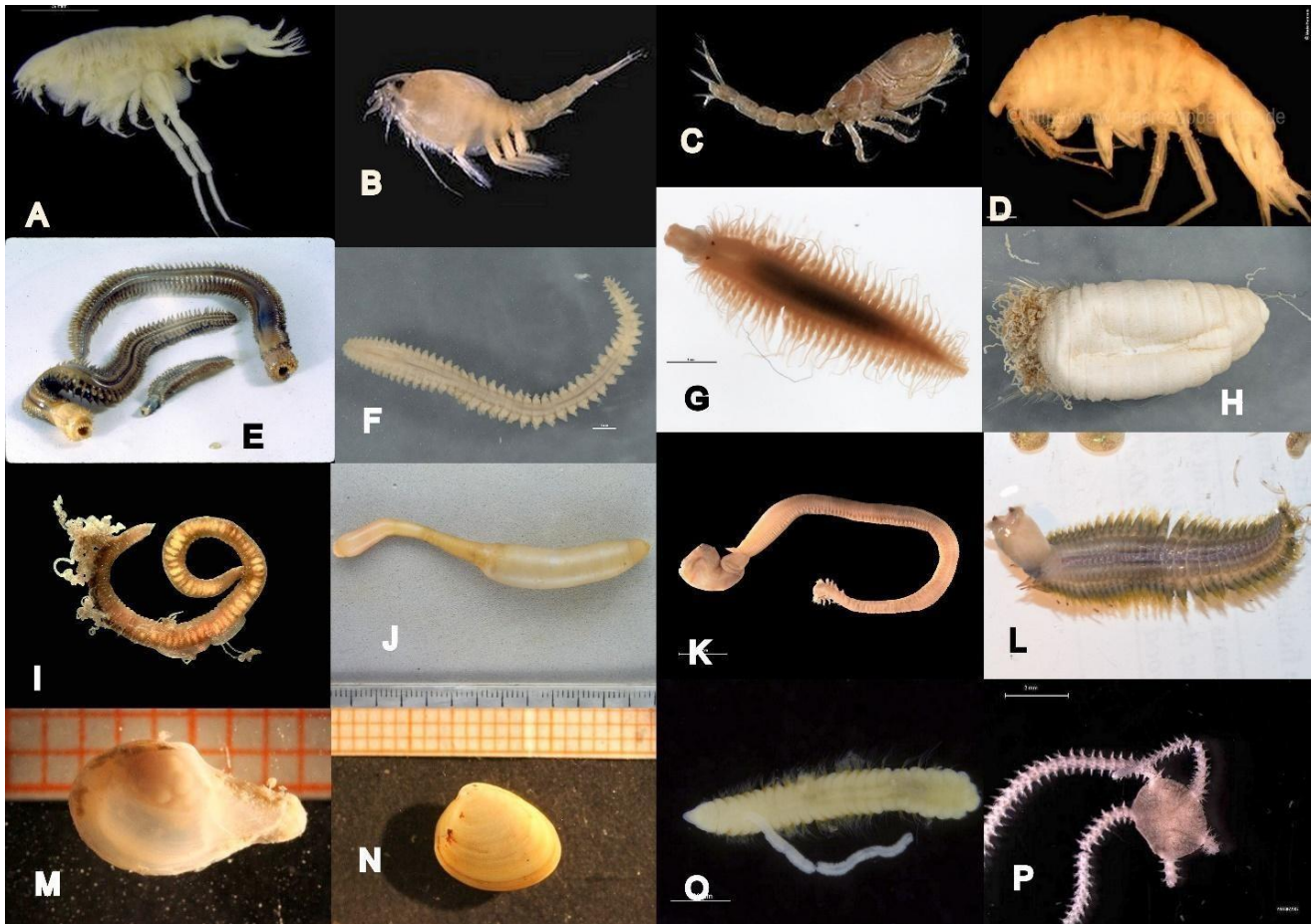


Figure 2. Photo documentation of some macrobenthic fauna found at the study sites; (A) *Harpinia* sp. [Crustacea], (B) Phyllocarida [Crustacea], (C) Diastylidae [Crustacea], (D) Oedicerotidae [Crustacea], (E) Nephyridae [Polychaeta], (F) Paralacydonidae [Polychaeta], (G) Hesionidae [Polychaeta], (I) Cirratulidae [Polychaeta], (J) Sipuncula, (K) Goniadidae [Polychaeta], (L) Polynoidae [Polychaeta], (M) Cuspidaria [Mollusca], (N) Nuculidae [Mollusca], (O) *Cossura* sp. [Polychaeta] and (P) *Amphiura* sp. [Echinodermata] (Photo credit: <https://creativecommons.org/>)

Table 1. Abundance (No. of individuals) and relative abundance (%) of major macrobenthic faunal groups were identified at the study sites

Taxa	Ekumfi Aboano			Jubilee Field		
	No. of species	Abundance (No. of individuals)	Relative abundance (%)	No. of species	Abundance (No. of individuals)	Relative abundance (%)
Polychaetes	52	194	17.43	109	983	44.58
Arthropoda	53	827	74.30	47	696	31.56
Molluscans	6	35	3.14	22	229	10.39
Echinoderms	2	14	1.26	3	37	1.68
Others	3	43	3.86	7	260	11.79
Total	116	1113	100	188	2205	100

Table 2. Densities (individuals/m²) of major macrobenthic faunal groups

Location	Major taxa					Total
	Polychaeta	Crustacea	Mollusca	Echinodermata	Others	
Ekumfi Aboano (nearshore)	15	62	23	28	57	38
Jubilee Fields (deep-sea)	36	59	42	29	157	47

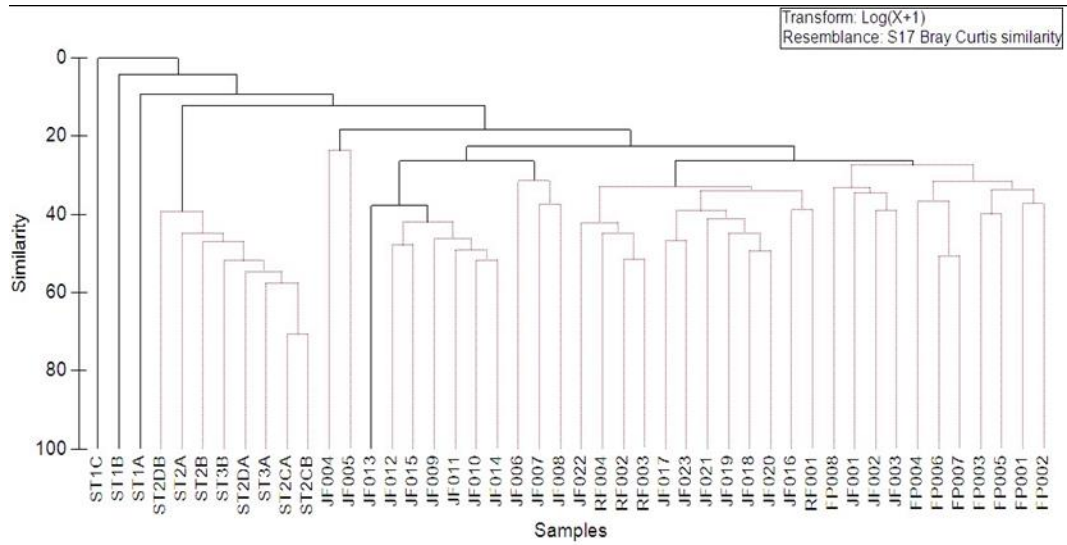


Figure 3. Significance test of the difference between sampling sites

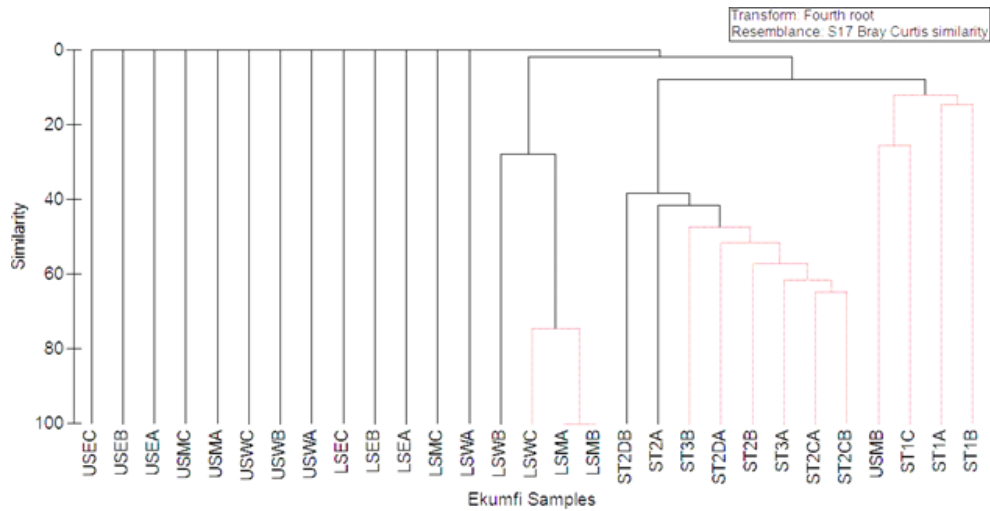


Figure 4. Bray-Curtis similarity (%) dendrogram within Ekumfi sites, Ghana

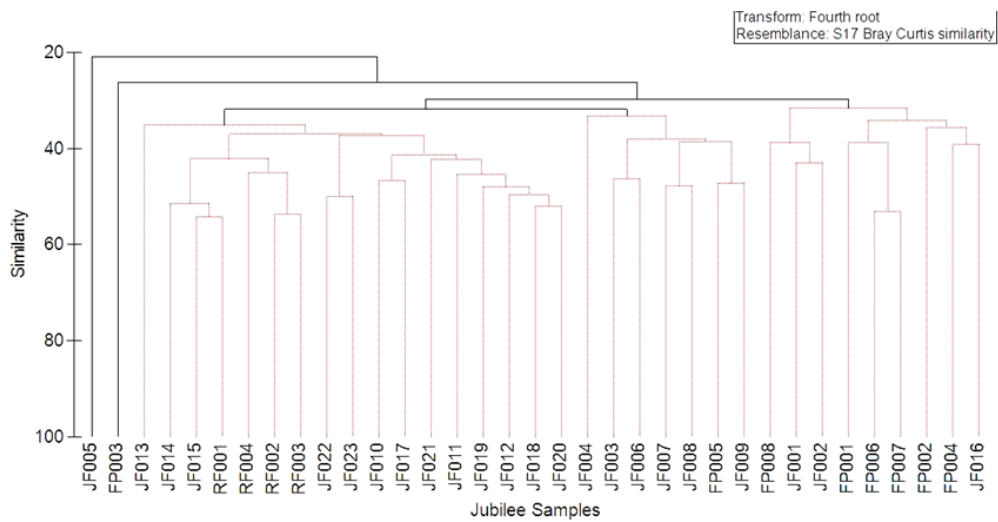


Figure 5. Bray-Curtis similarity (%) dendrogram within Jubilee sites, Ghana

Table 3. Between-site species richness and diversity indices

Diversity indices	Ekumfi Aboano	Jubilee Fields
Margalef's index (d)	15.68	24.16
Pielou's index (J')	0.88	0.85
Shannon-Weiner index (H')	4.13	4.43
Simpson's index (1-D)	0.98	0.98

Table 4. Significance test of the difference between sampling sites

α	0.05
P value	0.750

Table 5. Summary of sediment grain size results for Ekumfi Aboano and Jubilee Fields, Ghana

	Ekumfi Aboano	Jubilee Fields
Sieving Error	3.9%	2.6%
Sample Type	Bimodal, Moderately Sorted	Trimodal, Poorly Sorted
Sediment Name	Moderately Sorted Very Fine Sand	Very Coarse Silty Fine Sand

Table 6. Correlation between abundance and sediment grain size

	Abundance	Sediment grain size
Ekumfi Aboano		
Abundance	1	
Sediment grain size	0.816	1
Jubilee Fields		
Abundance	1	
Sediment grain size	-0.816	1

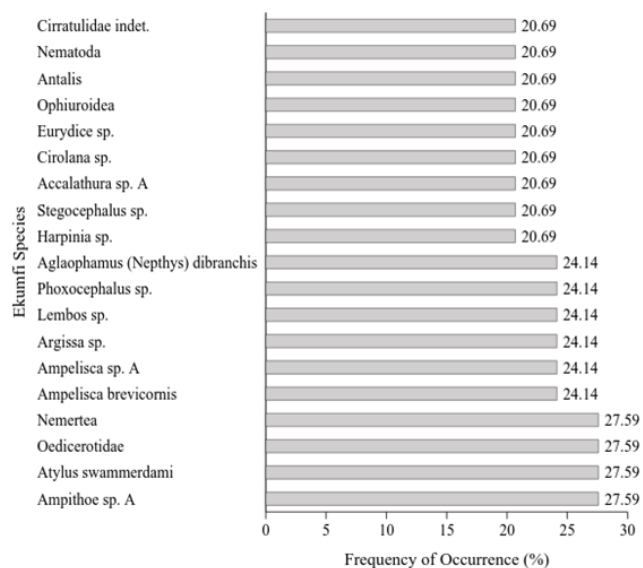


Figure 6. Frequency of occurrence for dominant (>20 %) macrobenthic species in Ekumfi Aboano, Ghana

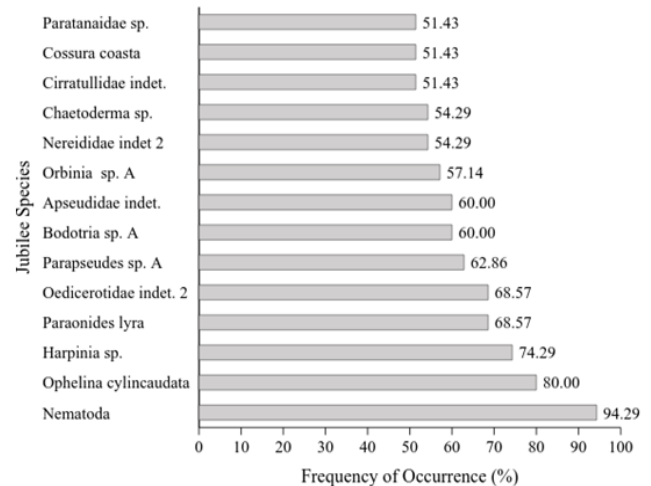


Figure 7. Frequency of Occurrence for dominant (>50 %) macrobenthic species in Jubilee Fields, Ghana

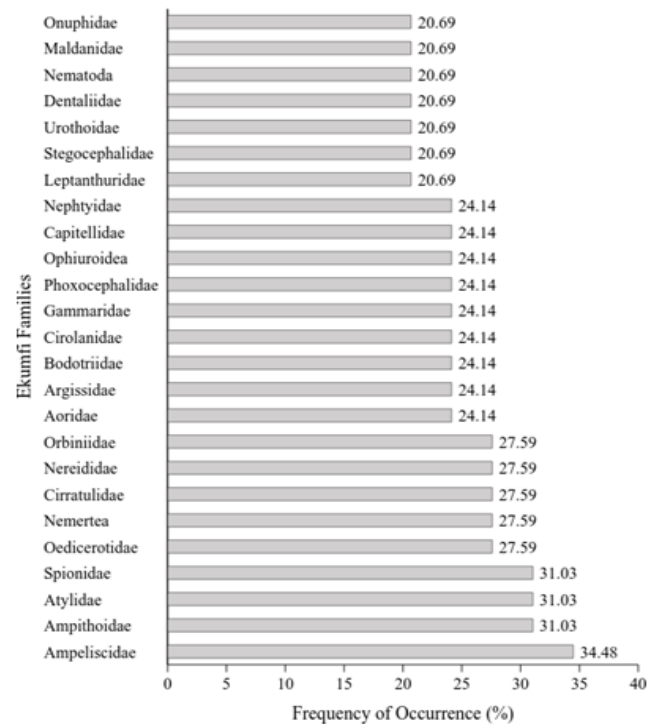


Figure 8. Frequency of Occurrence for dominant (>20 %) macrobenthic families in Ekumfi Aboano, Ghana

Discussion

According to Table 2, a healthy marine ecosystem would include 38 creatures per square meter in the Ekumfi Aboano area and 47 organisms per square meter in the Jubilee Fields area. However, it is not possible to achieve since benthic species are not evenly distributed. Species macrobenthic assemblage richness was higher in Jubilee ($H' = 24.16$; 2205 individuals) than in Ekumfi ($H' = 15.68$; 1113 individuals). It can only be explained by considering the scale and intensity of the perturbation in addition to the number of samples obtained, i.e., the relationship between species richness and sample size (Magurran 2004).

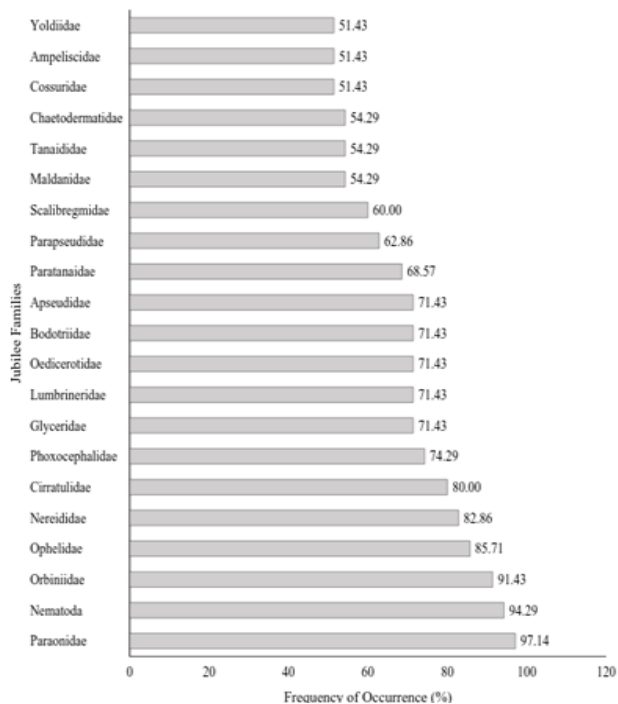


Figure 9. Frequency of occurrence for dominant (>50 %) macrobenthic families in Jubilee Fields, Ghana

The species diversity index was 0.90 in both cases. It suggests that macrobenthos patchiness, predators, underwater current, tidal, or wave movement all play a role in maintaining a somewhat even distribution of species throughout both sampling sites (Macdonald et al. 2012). The potential of an ecosystem to sustain a wide range of taxa and a robust community structure can be inferred from the species diversity present within sites (Erfemeijer et al. 2012) (Table 3).

The high numbers of nematodes indicated that both areas had abundant detritus, bacteria, and fungi, causing nematodes to be more common and abundant overall in both areas studied (Table 6). Changes in ratios measured over time can reveal whether the food chain is stable, developing, organized, or deteriorating (Krumins et al. 2013).

A substantial positive trend (0.82) was seen between abundance and grain size in the nearshore environment, while a large negative trend (-0.82) was seen in the deep-water environment. The activity of organisms (bioturbation, organic matter present, and feeding strategies), population density (number of species), diversity (types of organisms), and abundance (sizes of organisms) all have an impact on sediment composition (including sediment particle size) (Mermillod-Blondin et al. 2005; Wahl 2009). Benthic communities and sediment composition have been shown to have either no or a weak association in some research (Seiderer and Newell 1999; Arrighetti and Penchaszadeh 2010). According to the results, larger grain sizes in the average sediment contributed to fewer deep-water macrobenthos and more

nearshore ones. It is common for the sediment properties of the nearshore seabed to change as a result of inland material being transported to the coast (Logan 2007).

The cluster analysis showed that nearshore and deep-water macrobenthic assemblages were 82% different. Dissimilarities like these can be attributed to a wide range of natural and anthropogenic factors, such as the composition of the sediment, the pressure at which it is held, the temperature at which it is maintained, the availability of food and water, and the proximity of trawling and anchoring grounds. Since the composition of the sediment and the availability of food are affected by the speed of the currents, the availability of food is the determining factor in the composition of the marine (Wieking and Kroncke 2005).

The distribution and abundance of macrobenthic animals are influenced by the distribution and composition of sediments, which differ between deep-sea and nearshore locations. The composition of the macrobenthic community is often dependent on depth (Allotey 2010). Sediment in the deep sea was said to be finer than that at the near coast. Variations in hydrodynamic regimes (wind velocity and direction, current and tide motions) influence weather patterns, physicochemical or biochemical processes, and the biological activities of different species, all of which contribute to the observed variations in sediment nature (Open University 2002).

About 90% dissimilarity was found using the Bray-Curtis similarity test amongst the sampled sites in Ekumfi Aboano (nearshore). The most prevalent families (>20%) were arthropods (14 families) and polychaetes (8 families). Within Jubilee Fields (deep-sea), Bray-Curtis similarity was approximately 70% dissimilar. The dominant families that occurred most frequently (> 50%) were polychaetes (10 families) and arthropods (8 families). As Patel and Desai (2009) discovered, the nearshore environment, which consisted primarily of very fine sand, was more dominated by arthropods than polychaetes. Still, the deep-sea environment of fine silty sand had more polychaetes than arthropods.

Using the SIMPER test at the species and family level, comparisons of contributing species and families to the respective community structure were established (Tables 7-11). Within the macrobenthic community structure of the nearshore seafloor, the polychaete family Pisionidae and the crustacean family Ampeliscidae contributed 18.71%. Pisionids are aggressive burrowers with a strong preference for soft, silty substrates and are frequently seen in interstitial groups, whereas Ampeliscids are tube-dwelling organisms that inhabit fine sand and mud. Both families are cosmopolitan and can survive in shallow to deep water. In Jubilee, polychaete families (Paraonidae [8.37%], Orbiniidae [6.59%], Opheliidae [6.22%], Nereididae [5.11%], and Cirratulidae [4.88%]) and nematodes contributed the most to the community structure. It was discovered that these polychaete groups are burrowers with a strong affinity for sandy mud substrate (Day 1967; Rouse and Pleijel 2001). Similar to Gray and Elliot's (2009) observations, the collected species were global and representative of the sediment's nature.

The Ekumfi macrobenthic community structure was dominated by crustacean species (including *Ampithoe* sp. [11.07%], *Argissa* sp. [9.64%], and *Lembos* sp. [8.4%]). It is identical to Gray's (2002) observation of crustacean dominance in sandy areas, especially nearshore. Nematodes, *Ophelina* cylindricaudata, and *Harpinia* sp. contributed 21.15 % to the abundance and structure of the community. Due to their free-living or parasitic nature, nematodes outweigh the other species, particularly in an oxygen-depleted and organic-rich environment (Abbott and Murphy 2003). The average dissimilarity between Ekumfi and Jubilee was 95.52%, demonstrating the statistically significant difference ($p= 0.05$) between the macrobenthic infauna of nearshore and deep-sea habitats.

The 2015 sampling of the Jubilee Field macrobenthic assemblage structure revealed that polychaetes (44.58%) and arthropods (31.54%) comprised 76.14% of the community structure. Within the Jubilee Field, a polychaete complex including 109 species was discovered. Unexpectedly, it was determined that there is a greater likelihood of finding an arthropod (59 individuals/m²) or mollusk (42 individuals/m²) per square meter than a polychaete (36 individuals/m²). During this survey, no exotic or invasive species were identified. The sediment is comprised of very coarse, silty, fine sand that is heterogeneous and characteristic of places with a low wave or current activity, as found in deep-sea environments (Cartes et al. 2002; Gray and Elliot 2009). Therefore, the abundance of creatures in the region can be related to exploratory operations.

Ekumfi Aboano, on the other hand, had a limited diversity of taxa, as polychaetes and arthropods made up 92% of the 116 species obtained (105 species). With a density of 62 individuals per square meter, arthropods comprised more than half of the total abundance. With the strong energy in the region from waves and currents, the predominant sediment nature was discovered to be well-sorted and homogeneous in grain size, presumably impacted by terrestrial runoff from inland waters, aeolian deposition, or meteorological activities.

In conclusion, compared to nearshore seabed sediment from Ekumfi Aboano (very fine sand), the study found that polychaetes were more common in deep-seabed sediment from Jubilee Fields (fine silty sand). There is a correlation between nearshore and deep-sea depth, sediment fineness, and the diversity of macrobenthic organisms, suggesting that deeper waters are home to more diverse and abundant macrofauna. The composition of the macrobenthic community is not noticeably different between the nearshore seafloor (Ekumfi Aboano) and the offshore seafloor (Jubilee Fields). From the Jubilee Field, this research found that I polychaetes (44.58%) and crustaceans (31.56%) made up the majority of the community structure, (ii) the macrobenthic fauna were evenly distributed (0.85) and highly diverse ($H' - 4.43$; $1-D - 0.98$), and (iii) the taxa dominance order was polychaetes > crustaceans > molluscans > others > echinoderms. This study found that Ekumfi Aboano has: I a highly varied ($H' - 4.13$; $1-D - 0.98$) and evenly distributed (0.88) macrobenthic community, (ii) the majority (91.73%) of the macrobenthic

fauna abundance as polychaetes (17.43%), with crustaceans (74.30%) dominating, and (iii) the following taxonomic dominance order: crustaceans > polychaetes > molluscans > others > echinoderms.

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Carbon stock of above ground mangroves in the Lower Volta Area, Ghana

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Abstract. Henry MJ, Gordon C, Pabi O. 2021. Carbon stock of above ground mangroves in the Lower Volta Area, Ghana. *Indo Pac J Ocean Life* 5: 61-73. The mangroves and other blue carbon systems are under high pressure because of coastal development and population. The degradation of mangrove continuity leads to the loss of the carbon stocks which is stored in the mangrove ecosystem. This study used GIS-based analysis using allometric equations and Landsat images to estimate the mangrove above-ground carbon stock in the Lower Volta area in Ghana. The classified Landsat images were used to obtain the mangrove area coverage. The ASTER GDEM covering the mangrove was calibrated to obtain the above-biomass, mangrove heights, and above ground carbon stock estimated using a global allometric equation. This study identified the socio-economic factors influencing mangrove exploitation and assessed local residents' willingness to use an alternative energy source, Liquefied Petroleum Gas (LPG). The carbon stock in 2014 for the study area was estimated at 269,379.5 Mg, and the carbon stock was estimated at 50.102 Mg per hectare. The changes in carbon stock on a time series analysis revealed that the study area lost its carbon stock between 1991 and 2014 at 161,428.65 Mg. The results indicated that significant factors influencing mangroves' exploitation were the commercial supply of fuel wood, increased income, and supply of fuel wood for domestic use. The local residents were less likely to use LPG as an alternative due to price and safety considerations and preferred mangroves as an energy source. All major stakeholders were recommended to contribute towards effectively managing and protecting the mangrove resource.

Keywords: Allometric, carbon stock, coastal, Ghana, ecosystem

INTRODUCTION

Mangroves refer to tropical vegetation positioned at the interface between land and sea, found along the coast and estuaries throughout the tropics and subtropical regions that uniquely adapted to thrive in soils with high salinities (Joshi and Ghose 2003). Although mangroves account for 1% of tropical forests, it is the most carbon-rich containing an average of 1,023 Mg carbon per hectare (Spalding et al. 2010; Donato et al. 2011). With the effects of climate change more apparent, significant reductions in greenhouse emissions are urgently needed, aligning with the need to properly manage habitats that act as critical carbon sinks to reduce greenhouse gas (Smith and Gattuso 2009).

The mangroves in Ghana are mainly found along the fringes of lagoons on the western coast, bordering the Volta River's lower reaches and deltaic areas. They are best developed along a stretch on the west coast between Cote d'Ivoire and Cape Three Points (FAO 2005). Mangroves are important because they provide ecosystem services, including protection of coastlines, erosion, and floods; nursery grounds for juvenile fish, crabs, and mollusks; and supporting livelihoods by providing goods such as wood fuel, timber, and non-timber forest products (Alongi 2002). Gordon et al. (2009) estimated the value of mangrove-related harvesting and contribution to marine fisheries is well over \$ 6,000,000 annually in Ghana. This estimate

excludes others, such as coastline protection and nesting sites for migratory birds.

In Ghana, mangroves are threatened by land-based sources of pollution, hydrological and land use change, and population growth. The mangrove area in this country fell by 24%, from 181 km² to 137 km², between 1980 and 2006 (Corcoran et al. 2007). The continuous degradation increases the risk of stored carbon accumulation being released into the atmosphere and CO₂ concentration (Kauffman et al. 2014). The mangroves as efficient carbon sinks have been recognized recently and incorporated into climate change mitigation, which focuses on reducing CO₂ and other GHGs by conserving and restoring natural systems. (Nellemann et al. 2009).

Blue carbon refers to the carbon stock stored in oceans and coastal ecosystems, such as; mangroves, seagrass meadows, and tidal salt marshes. It includes the carbon stored within the soil, the living biomass below ground (roots), the living biomass above ground (leaves, branches, stems), and the non-living biomass, e.g., dead wood and leaf litter (McLeod et al. 2011). The coastal ecosystems store more carbon than terrestrial ecosystems, especially in the soil. The limited carbon storage potential in terrestrial soils is because of the supply of oxygen availability, which allows bacteria to carbon oxidation resulting in its release back into the atmosphere (Schlesinger et al. 2001). The soil is usually saturated with water, keeping oxygen concentrations very low, leading to continual vertical carbon accretion and a high overtime build-up (Chmura et al. 2003). Therefore the soils

in coastal ecosystems can store carbon for long periods (centuries to millennia) than those in terrestrial ecosystems (Chambers et al. 2001)

Mangroves have high above-ground and below-ground biomass, productivity, and high carbon sequestration rates despite their small global area (Komiyama et al. 2008; Donato et al. 2011; Mcleod et al. 2011). Approximately 2,000 Mg/ha of carbon is stored in the mangrove ecosystem, one hundredfold more than in high tropical forests. The spatial variations understanding in carbon stocks and forest biomass are important to inform global climate change models and developing policies, planning actions, and programs to mitigate their climate change effects (Nepstad et al. 2011; Grabowski and Chazdon 2012), while mangroves are highly threatened, especially with over a third of the world's mangroves lost through conversion into agriculture and aquaculture (Alongi 2002).

The aims of this study are: (i) To map out the mangrove area within the study area and determine the features of the land cover. (ii) To estimate the carbon stock and the above-ground biomass using allometric equations and determine the changes over the past 25 years. (iii) To assess the perception of change by the local community in the mangrove area. (iv) To assess the willingness to use alternative energy sources such as LPG and identify socio-economic factors that drive mangrove exploitation.

MATERIALS AND METHODS

Study area

The study area comprised sections of the Keta Municipal area and the South Tongu Districts of the Ghana Volta Region, where the highest mangroves in the savannah zone occur (Akpalu 2007). It lies within latitude 5°46'N and 5°57'N and longitude 0°41' E and 0°53' E and covers an area of about 280 km². It covered several towns and villages,

Sesieme, Anyanui, Hawui, Gamenu, Tunu, and Bomigo (Figure 1).

The vegetation within the study area includes the northern part of tall grasses interspersed with medium-sized trees and the middle with short grasses and some short trees. Mangroves and tall grasses characterize the southern part along the Volta Estuary. These areas experienced a double maximum rainfall pattern, with the major season from March to July and the minor season beginning in September through November. It has rainfall between 800-1,000 mm annually.

Mangrove vegetation continuously stretches at the southwestern end of the municipality, from Anyanui to Bomigo, which formed the basis of the selection of the area.

Data collection

Satellite imagery

Landsat Thematic Mapper (TM) imagery of the study area at a spatial resolution of 30m × 30m was obtained from the Global Land Cover Facility of the United States Geological Survey (<http://earthexplorer.usgs.gov/>). That was to determine the mangrove area, land cover features, and the above-ground carbon stocks estimation in the mangroves.

Three Landsat TM images, 1991, 2002, and 2014 of the mangroves within the study area were obtained to classify mangroves to determine the areal coverage. The selected data sets shown in Table 1 were cloud-free images acquired between January and March.

Table 1. Dates of Landsat images acquired

Year	Month	Satellite
1991	March	Landsat 4
2002	January	Landsat 7
2014	March	Landsat 8

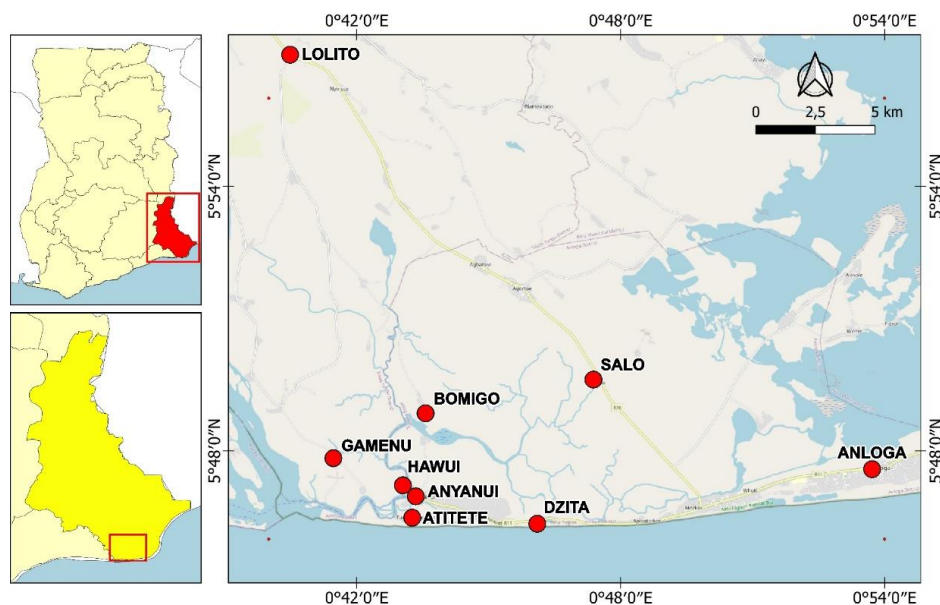


Figure 1. Map of the study area in the Volta Delta, Ghana

The Advanced Space-borne Thermal Emission and Reflectance Radiometer (ASTER) Global Digital Elevation Model (GDEM) version 2 was obtained from NASA's Land Processes Distributed Active Archive Centre. The ASTER GDEM is the earth's surface map derived from landscape observation on an optical stereo instrument, including its land cover. The data was generated at a sampling space of 30 meters. It was obtained for the mangrove heights estimation based on the assumption that mangroves are located at sea level, and elevation measurements can be calibrated for the canopy height estimation of mangroves (Simard et al. 2006)

Questionnaire administration

Fieldwork was carried out in February 2016 in two villages (Bomigo and Hawui) in the Lower Volta Area. These settlements were selected due to mangroves were harvested extensively in these villages. The study's objectives were to access the perception of the change in mangroves area, assess the willingness to use LPG as an alternative energy source, and identify socio-economic drivers of mangrove exploitation.

The total population of these two communities (Ghana Statistical Service 2012) was about 1,000. However, with an annual growth rate of 2.5 % per annum, the population was projected to be about 1,200 in 2016, and a sample size of 120 was selected.

A total of 120 questionnaires were administered by purposive sampling to residents of the two mangrove harvesting communities. Data gathered from respondents covered the following: (i) Demographics, (ii) Occupation, (iii) Benefits derived from mangroves and how these changes. (iv) Socio-economic factors that drive mangrove exploitation. (iv) Willingness to use Liquefied Petroleum Gas as an alternative energy source

Data analysis

Pre-processing and spatial sub-setting of Landsat images

Three clear, cloud-free Landsat images were selected to classify the study area: March 1991, January 2002, and March 2014. These periods also parallel to Ghana's dry season, making field sampling and ground truthing relatively easier than in the wet season. These study areas are contained within Landsat path 193 and row 56. The Landsat images were subsets using the spatial/spectral tool in ENVI 4.7. The tool obtained a region of interest with a high concentration of mangrove vegetation.

Analysis using ENVI 4.7 and ArcMap 10.1

The methods to analyze data included image classification (supervised and unsupervised), the development of land cover classes, an accuracy assessment (confusion matrix), and change detection analysis.

The loaded bands to obtain the natural/true color of the images were; bands 7, 5, and 3 for Landsat 8 and Landsat 4; bands 3, 2, and 1 for Landsat 7.

Unsupervised classification

An unsupervised classification using Iterative Self-organizing Data Analysis (ISODATA) in ENVI 4.7 was

initially conducted in the study area to determine mangroves' coverage. That was to help in the field validation and later supervised classification (Fatoyinbo et al. 2008; Fatoyinbo and Simard 2013). Furthermore, different from the K-mean method, which requires prior knowledge to estimate the number of clusters, the ISODATA could create as many classes as possible based on the data by automatically calculating class means equally distributed in the data space and then using minimum distance techniques could iteratively clustering the remaining pixels. Each iteration process recalculates means and reclassifies pixels concerning new means. Unless a standard deviation or distance threshold is specified, the pixels are then classified to the nearest class. The iteration process continues until the number of pixels in each class changes by less than the maximum number of iterations reached or the selected pixel change threshold (Tou and Gonzalez 1974)

Supervised classification

This classification method was the clusters of pixels in a dataset into classes corresponding to user-defined training areas. The training areas of different Regions of Interest (ROIs) were carefully selected for supervised classification in ENVI 4.7. The assumption used for the Maximum Likelihood supervised classification is that each band's class statistics are normally distributed and determine whether a pixel belongs to a specific class based on the highest probability (maximum likelihood).

ENVI implements maximum likelihood classification for each pixel in the image by calculating the following discriminant functions (Richards 1999)

$$g_i(x) = \ln p(\omega_i) - 1/2 \ln |\Sigma_i| - 1/2(x - m_i)^T \Sigma_i^{-1}(x - m_i) \quad (\text{Eq. 4})$$

Where: i = class

x = n -dimensional data (where n is the number of bands)

$p(\omega_i)$ = probability that class ω_i occurs in the image and is assumed the same for all classes

$|\Sigma_i|$ = determinant of the covariance matrix of the data in class ω_i Σ_i^{-1} = its inverse matrix

m_i = mean vector

The identification of mangroves during the classification was aided by data from the World Atlas Earth scan by Spalding et al. (2010) and high-resolution imagery from Google Earth.

The resulting classes were combined into a final classification with four land cover types: (i) Mangroves, (ii) other vegetation, (iii) water, and (iv) bare ground.

Confusion matrix

A confusion matrix, the error matrix, was used to assess the image classification accuracy. It does so by comparing the image classification to the ground truth information. The result of an accuracy assessment provides an overall accuracy of the map based on an average of the accuracies for each class in the map.

$$\text{Overall accuracy} = \frac{\text{Number of pixels correctly classified}}{\text{Total number of pixels}} \quad (\text{Eq.5})$$

Kappa measures the agreement or accuracy between the classification map and the reference data as indicated by the major diagonals, and the chance agreement indicates the row and column totals (Jensen 2003). The kappa coefficient is given by the formula below:

$$\text{Kappa (k)} = \frac{P_0 - P_e}{1 - P_e} \quad (\text{Eq.6})$$

Where: P_0 : the proportion of correctly classified cases, and P_e : represents the proportion of correctly classified cases expected by chance.

Change detection analysis

After each image belonging to the respective years was classified, a multi-date post-comparison and change detection algorithm was used to determine changes in the land cover in the intervals; 1991-2002 and 2002-2014. The change detection computed class or pixel change, change in the area, and percentage change for all classes

Field measurements

A survey of mangrove sites within the study area was conducted from the 10th to the 13th of February, 2014. This period was within the range of time the study's satellite images were acquired and the dry season, making the mangroves fairly accessible. The preliminary maps of mangrove areas were obtained from initial visits and classifications as bases for the field survey.

A total number of 14 sites were visited during the field survey. In addition, GPS readings of mangrove locations were taken as ground control points across the study area covering towns including Dzita, Atitete, Salo, Anyanui, and Bomigo.

At five mangrove sites, a total of 20 sample plots of 0.01 ha (10m × 10m) were assessed. Parameters included GPS readings, species, mangrove heights, and the number of trees within a sample plot. The mangrove height was determined by measuring the distance from the tree and the elevation angle using a range finder and a clinometer, respectively. The tree height was computed using obtained tree distance and angle of elevation. The above-ground mangrove biomass was estimated by the tree height measurements

Estimating the above-ground biomass of mangroves

In this study, the land cover map masked all the areas, not within the mangrove area on the GDEM. That included areas above 15 m because the tallest tree recorded from field measurements was 12 m, similar to the tallest mangrove tree observed by Ntyam (2014) at Songhor, also located in the coastal savanna zone. Therefore, an assumption of a maximum tree height of 15 m was established

The ASTER GDEM was calibrated using equation (1) from Simard et al. (2006). The assumption to the equation was applied based on low tree diversity and similar structural and zonation patterns observed globally in mangrove ecosystems (Chapman 1944, 1970; Smith 1992). In addition, this study assumed that mangroves grow at sea

level, so topography was not taken into account because the ASTER GDEM has a positive bias to land cover features such as mixed forests and woody wetlands (Meyer and ASTER-GDEM-Validation-Team 2011). However, the elevation measured by GDEM correlates with canopy height and, therefore, could be calibrated to estimate the canopy height of mangroves (Simard et al. 2006).

$$H = -2.19 \times 1.12 H_{\text{GDEM}} \quad (\text{Eq. 7})$$

The above-ground biomass was estimated using a global allometric equation (7) developed by Saenger and Snedaker (1993a,b) which was used by Fatoyinbo et al. (2008) and Fatoyinbo and Simard (2013) in estimating the biomass of mangroves in Mozambique and Africa, respectively.

$$B_H = 10.8 \times H + 35 \text{ RMSE } 43.8 \quad (\text{Eq. 8})$$

Where

B_H : above-ground biomass

H: mangrove canopy height

RMSE: root mean square error

The carbon stock was then computed from the above-ground biomass using the conversion factor of 0.5 (Tang et al. 2014), as shown below.

$$C = 0.5 \times \text{ABG} \quad (\text{Eq. 8})$$

Where: C is the carbon stock, and ABG is the above-ground biomass)

Socio-economic factors that drive mangrove exploitation and the willingness to use LPG as an alternative energy source

A multiple regression analysis to determine whether the identified socio-economic factors significantly influenced the decision to exploit mangroves was conducted using the equation below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e \quad (\text{Eq.9})$$

Where Y: a decision to exploit mangroves

β_0 : constant of regression

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: respective regression co-efficient

X_1, X_2, X_3, X_4, X_5 : respective independent variables (factors that influence mangrove exploitation)

e: error of the regression

A logistic regression using the odds ratio was used to determine the willingness of the local people to use LPG as an alternative energy source using the equation below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + e \quad (\text{Eq. 10})$$

Where Y: willingness to use LPG as an alternative energy source

$\beta_1, \beta_2, \beta_3$: respective regression coefficient

X_1, X_2, X_3 : respective independent variables of price, safety, and preference

e: error of the regression

Limitations of study

The accessibility to mangrove areas due to the lack of roads necessitating movement by boat in some instances was the major challenge during field sampling. Field plots were therefore established along the road from Salo down to Anyanui. In this study, the sizes of plots were significantly smaller than the spatial resolution of satellite images; therefore assumed that the natural height variability of the mangroves area was not fully represented and could not be used to calibrate the ASTER DEM (Simard et al. 2008)

RESULTS AND DISCUSSION

Land-use/cover features

This study identified four land cover features in the Lower Volta area: Mangroves (*Rhizophora* sp. and *Avicennia* sp.), Water, Other Vegetation, and Bare Ground. Table 2 shows the description of each land cover feature.

The proportion and distribution of land cover features by area and percentages are shown for the years 1991, 2002, and 2014 in Tables 3, 4, and 5 and Figure 2. However, there was a continuous decline in mangrove areas from 1991-2014, while bare ground and other vegetation areas increased. There was also a significant decrease in the area covered by water between 1991-2002.

1991 land cover accuracy assessment

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 85.43% with a kappa coefficient of 0.787.

Distribution of land cover features (1991)

The total subset representing the Lower Volta covered about 280 km². Out of this total, approximately 34.22% was classified as mangroves representing an area of 95.954 km². Other land cover types classified included water, mainly the Volta Lake, which covered 11.87%, representing 33.283 km², bare ground, including some settlement areas, and 38.51% representing 107.966 km², and other vegetation types covered 15.40% representing 43.185 km², which is summarised in Table 3.

2002 land cover accuracy assessment

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 90.09% with a kappa coefficient of 0.864.

Distribution of land cover features (2002)

Of the total area covered by the study area, approximately 35% were classified as mangroves, accounting for 87.700 km². Water which was mainly contributed by the Volta lake, contributed 8.50%, representing 21.190 km². The bare ground class, including some settlement areas, covered 44.91% of the study area,

representing 112.502 km². The other vegetation covered 23.51% representing 58.863 km² (Table 4).

Land cover accuracy assessment (2014)

An accuracy assessment was conducted with ground reference points and randomly generated points to produce an overall accuracy of 85.18% with a kappa coefficient of 0.7957.

Distribution summary of land cover features (2014)

Out of the total classified area, approximately 22.73% was classified as mangroves representing an area of 63.729 km². Water covered 8.41% of the area representing 23.580 km², bare ground, which included some settlement areas, covered 43.49%, representing 121.943 km², and other vegetation types covered 25.37%, representing 71.143 km² (Table 5).

Table 2. Land-use/cover features

Land cover feature	Description
Mangrove	All mangrove tree species, mainly <i>Rhizophora</i> sp and <i>Avicennia</i> sp
Water	Natural water sources, including rivers and lakes (Volta lake)
Bare Ground	Bare land areas and other areas with patches of grass
Other Vegetation	All other vegetation types apart from mangroves

Table 3. Distribution summary of land cover features (1991)

Land cover feature	Points	Percentages	Area/km ²
Mangrove	106,616	34.22%	95.954
Water	36,981	11.87%	33.282
Bare Ground	119,962	38.51%	107.965
Other Vegetation	47,983	15.40%	43.184

Table 4. Distribution summary of land cover features (2002)

Land cover feature	Points	Percentages	Area/km ²
Mangrove	97,445	35.00%	87.700
Water	23,655	8.50%	21.289
Bare ground	125,002	44.91%	112.501
Other Vegetation	56,404	23.51%	58.863

Table 5. Distribution summary of land cover features (2014)

Land cover feature	Points	Percentages	Area/km ²
Mangrove	70,810	22.73%	63.729
Water	26,200	8.41%	23.580
Bare Ground	135,492	43.49%	121.942
Other Vegetation	79,048	25.37%	71.143

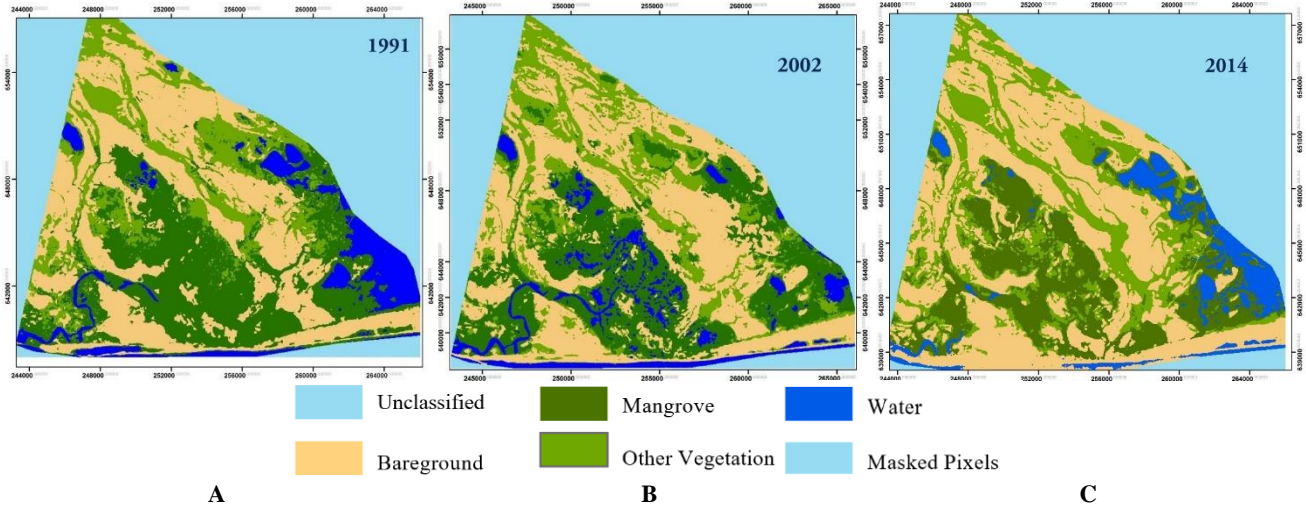


Figure 2. Map of land cover features. A. March 1991, B. January 2002, C. March 2014

Patterns of changes in land cover features from 1991 to 2002

The mangrove area in 2002 was reduced by about 8.6% compared with the area covered in 1991. The area covered by water showed a similar pattern of change, decreasing by about 36.0% compared with the area covered in 1991. Within this same period, there was an increase in the area covered by other vegetation and bare ground. The other vegetation area increased by about 36.3%, and the bare ground area cover increased by about 4.2%. The changing pattern over the 10 years showed the conversion of approximately 40% of the mangrove area into other classes; bare ground, water, and other vegetation accounting for

about 14%, 7%, and 18%, respectively. The changes in area coverage of each land cover feature from 1991-2002 are shown in Tables 6 and 7.

Table 6. Changes in area cover of land cover features (1991-2002)

Land cover feature	Area (1991) (km ²)	Area (2002) (km ²)	Change (km ²)
Mangrove	95.95	87.70	-8.25
Water	33.28	21.29	-11.99
Other Vegetation	43.18	58.86	+15.68
Bare ground	107.97	112.5	+4.54

Table 7. Changes in land cover features (1991-2002)

Land cover features (Initial 1991, Final 2002)	Bare ground	Mangrove	Water	Other vegetation	Row total	Class total
Percentages						
Mangroves	2.288	60.999	48.073	24.748	99.988	100
Water	1.134	7.368	38.222	0.634	99.996	100
Bare ground	84.095	13.996	3.38	16.525	99.985	100
Other vegetation	12.461	17.63	10.262	58.039	99.977	100
Masked pixels	0.022	0.008	0.062	0.054	0.042	100
Class total	100	100	100	100	0	0
Class changes	15.905	39.001	61.778	41.961	0	0
Image difference	4.201	-8.602	-36.035	36.307	0	0
Area (km²)						
Mangroves	2.47	58.53	16	10.69	87.69	87.7
Water	1.22	7.07	12.72	0.27	21.29	21.29
Bare ground	90.79	13.43	1.13	7.14	112.48	112.5
Other vegetation	13.45	16.92	3.42	25.06	58.85	58.86
Masked pixels	0.02	0.01	0.02	0.02	0.07	177.24
Class total	107.97	95.95	33.28	43.18	0	0
Class changes	17.17	37.42	20.56	18.12	0	0
Image difference	4.54	-8.25	-11.99	15.68	0	0

Patterns of changes in land cover features from 2002 to 2014

Tables 8 and 9 show the changes in land cover features from 2002-2014 in percentages and area. There was a 27% decline in the mangrove area in 2014 compared with the area in 2002. Conversely, in the previous period between 1991 and 2002, the area covered by water increased by about 11% in 2014. The area covered by bare ground and other vegetation showed a similar increasing pattern. The area covered by other vegetation showed the greatest increase of 20.1%, and the bare ground area increased by about 8.4%.

There were also some significant changes between classes. For example, another vegetation area has about 41% of its area being converted into other classes, including bare ground and mangroves, accounting for 24% and 11%, respectively. The mangrove area also had about 47% of its area converted into other vegetation and water; these accounted for 26% and 12%, respectively. The area covered by water had the highest area (58%) converted into other classes. About 40% was converted to mangroves and 15% into bare ground.

Patterns of changes in land cover features from 1991-2014

Figure 3 shows the changes in terms of area coverage of the land cover features over 23 years. The mangrove area reduced from 95.95 km² in 1991 to 87.7 km² in 2002. That represented a decline of 8.6%. The mangrove area continued to decline from 87.7 km² to 63.73 km² representing a 27.3% reduction. A comparison of the mangrove area from 1991 to 2014 showed a significant decline of 33.6%. There was a significant reduction in the area covered by water from 33.28 km² in 1991 to 21.29 km² in 2002. In contrast, there was a

small increase of 2.29 km² in the area covered by water from 2002 to 2014. The area coverage of the bare ground and other vegetation increased steadily from 1991 to 2014. The bare ground increased from 107.97 km² to 112.5 km² in the 1991-2002 period and then from 112.5 km² to 121.94 km² in the 2002-2014 period, representing an overall increase of 13.8%. The other vegetation area cover increased from 43.18 km² to 58.86 km² in 1991-2002 and then from 58.86 km² to 71.14 km² in 2002-2014.

Mangrove height and biomass estimation

Figure 4 represents the mangrove height ranging from 1.19 m to 14.61, averaging 6.9 m. Again, height values are represented on a grey scale, with low values graduating from dark regions to high values in lighter regions.

The above-ground biomass of mangroves represented in Figure 5 ranged from 46.9 Mg to 192.788 Mg, with an average of 109.8 Mg. The total above-ground biomass and carbon are shown below in Table 10. Again, height values are represented on a grey scale, with low values graduating from dark regions to high values in lighter regions.

Table 8. Changes in area cover of land cover features (2002-2014)

Land cover feature	Area (2002) (km ²)	Area (2014) (km ²)	Change (km ²)
Mangrove	87.70	63.73	-23.97
Water	21.29	23.58	+ 2.29
Other vegetation	58.86	71.14	+12.28
Bare ground	112.5	121.94	+9.44

Table 9. Changes in land cover features (2002-2014)

Land cover features (Initial 2002, Final 2014)	Bare ground	Mangrove	Water	Other vegetation	Row total	Class total
Percentages						
Mangroves	1.592	53.238	40.279	11.334	99.999	100
Water	0.485	12.233	41.907	5.721	99.927	100
Bare ground	86.062	8.740	15.642	23.937	99.970	100
Other vegetation	11.853	25.772	2.16	58.986	99.966	100
Masked pixels	0.008	0.016	0.013	0.021	0.022	100
Class total	100	100	100	100	0	0
Class changes	13.938	46.762	58.093	41.014	0	0
Image difference	8.392	-27.333	10.759	20.861	0	0
Area (km²)						
Mangroves	1.79	46.69	8.58	6.67	63.73	63.73
Water	0.55	10.73	8.92	3.37	23.56	23.58
Bare ground	96.82	7.67	3.33	14.09	121.91	121.94
Other vegetation	13.34	22.6	0.46	34.72	71.12	71.14
Masked pixels	0.01	0.01	0	0.01	0.04	177.2
Class total	112.5	87.7	21.29	58.86	0	0
Class changes	15.68	41.01	12.37	24.14	0	0
Image difference	9.44	-23.97	2.29	12.28	0	0

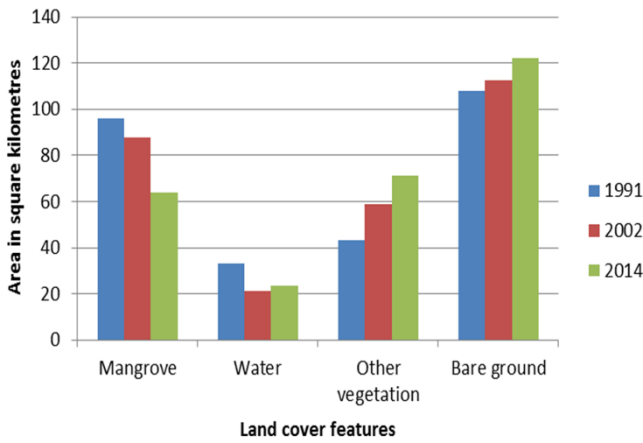


Figure 3. Changes in land cover features from 1991-2014

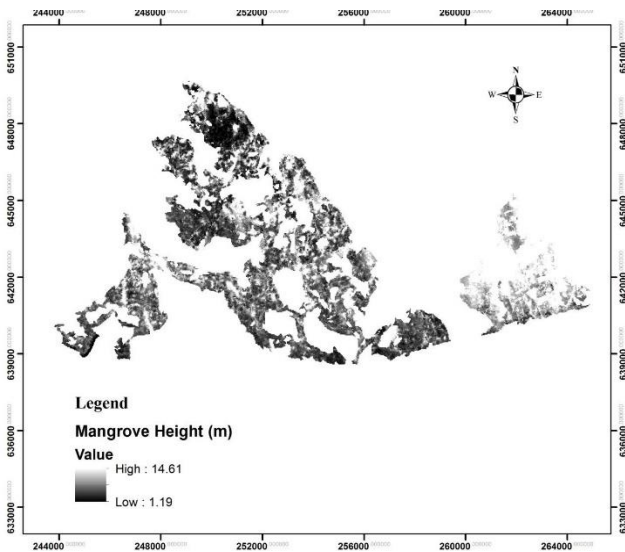


Figure 4. Map of mangrove heights

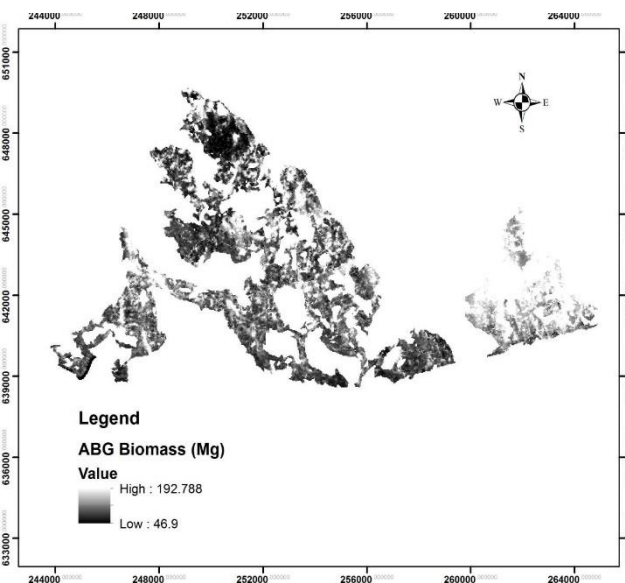


Figure 5. Map showing the above-ground biomass of mangroves (2014)

Table 10. Above-ground biomass and carbon stock of mangroves (2014)

Area (km ²)	Total biomass (mg)	Biomass per hectare (mg/ha)
53.766	538,759.00	100.204
Area (km ²)	Carbon (mg)	Carbon per hectare (mg/ha)
53.766	269,379.50	50.102

Table 11. Changes in Above-ground biomass and carbon from 1991-2014

Year	1991	2002	2014	Change (1991-2014)
Mangrove Area (km ²)	95.95	87.70	63.73	-32.22
Biomass (mg)	961,457.38	878,789.08	638,600.09	-322,857.29
Carbon (mg)	480,728.69	439,394.54	319,300.05	-161,428.65

Table 12. Potentially lost CO₂ from 1991-2014

Carbon stock lost (mg)	Potentially lost CO ₂ (mg)
161,428.65	602,352.15

Table 13. Average changes in carbon stocks and average rate of change

Period	Change in carbon (mg)	Rate of change per year (mg/yr)
1991-2002	-413,34.15	-3,757.65
2002-2014	-120,094.49	-10,007.87
Average	-807,14.32	-6,882.76

Perception of change

There was a consensus on the general decline of mangroves in the Lower Volta area. However, opinions were divided regarding the mangrove area in the two communities. In Bomigo, about 77% of respondents reported that the mangrove area in their community had increased. Of these respondents, 44% were male, and 56% were female. Regarding occupation, about 5% of those who observed an increase in mangrove coverage were mangrove harvesters, fishermen, and people who engaged in both fishing and mangrove harvesting, accounting for 65% and 30%, respectively. Excessive mangrove planting attributed about 77% of those who reported an increase in mangrove area coverage. The remaining had no idea the cause of the increase in mangroves, attributed to 23%. On the other hand, about 17% of respondents in Bomingo reported a decrease in the mangrove area. Of this, 60% were male, and 40% were female. Regarding occupation, 40% were mangrove harvesters, and 60% engaged in mangrove harvesting and fishing (Figure 6).

In Hawui, about 79% of respondents reported a reduction in mangrove coverage. Of these, about 67% were male, and 33% were female. Regarding occupation, 67% were in mangrove harvesting, and 33% were fishing. About 93% of respondents who observed a reduction in mangrove areas

attributed them to harvesting mangrove resources. The remaining 7% attributed the reduction in mangroves to changes in the Volta River hydrology. Of the 21% of respondents who reported an increase in the mangrove area, about 64% were male, and about 36% were female. Regarding occupation, about 45% were mangrove harvesters, 27% were engaged in fishing, and 28% were fishing and mangrove harvesting (Figure 7).

Social survey results

Socio-economic factors that drive mangrove exploitation

The major factors in the study area that influenced the respondent's decision to exploit mangrove resources were identified as: (i) Increased income, (ii) wood for construction, (iii) Medicinal purpose, (iv) commercial supply of wood fuel, (v) Supply of wood fuel for domestic use.

A multiple regression analysis was conducted to establish whether these factors influenced the decision to exploit mangroves. The results showed that these factors significantly influence the decision to exploit mangroves at a 95% confidence interval ($p = 0.035$).

An individual significance test was conducted using a t-test statistic to determine the significance of each factor influencing the decision to exploit mangroves. The results revealed that the following factors were significant; commercial supply of fuel wood, increased income, and wood fuel for domestic use, as shown in Table 14 below with a $p < 0.05$. On the other hand, the decision to exploit

mangroves did not significantly influence by medicinal purposes and the lack of alternative energy sources.

The R^2 obtained from the regression output was 0.65. That means about 65% of the total variation with benefits derived from mangrove harvesting is attributed to the identified factors shown in Table 14, which indicates that about 35% of the variation is not identified.

In magnitude, increased income has the highest outcome with a coefficient of 0.838. That was followed by the commercial supply of wood fuel with a coefficient of 0.525, supply of wood for domestic use with 0.430, wood for construction with 0.240, lack of alternative energy source with 0.197, and medicinal purpose with 0.142, respectively.

The respondents' demographic characteristics were also analyzed to determine whether they influenced the decision to exploit the mangrove resource. The analysis showed that the demographic characteristics, i.e., marital status, number of children, sex, age, and education level, did not significantly influence the decision to exploit the mangrove resource ($p > 0.05$), as shown in Table 15.

The willingness to use LPG as an alternative was conducted to test energy sources with a binary logistic regression. The results showed that respondents are about 0.445 times less likely to use LPG due to the product's price. It also showed that the local people are 1.497 times more likely to use mangroves due to preference than LPG. Finally, due to safety, it was also shown that people were about 0.743 times less likely to use LPG as alternative energy. These results are shown below in Table 16.

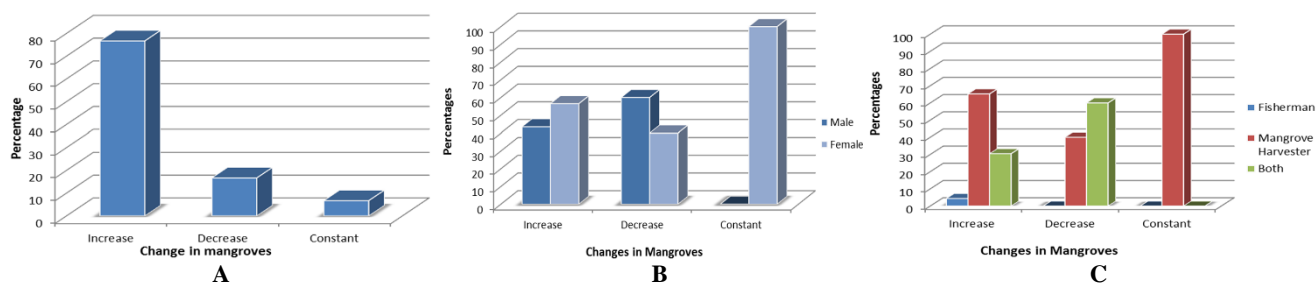


Figure 6. Perception of change in mangroves of Bomingo. A. All, B. Gender base of increase, C. occupation base.

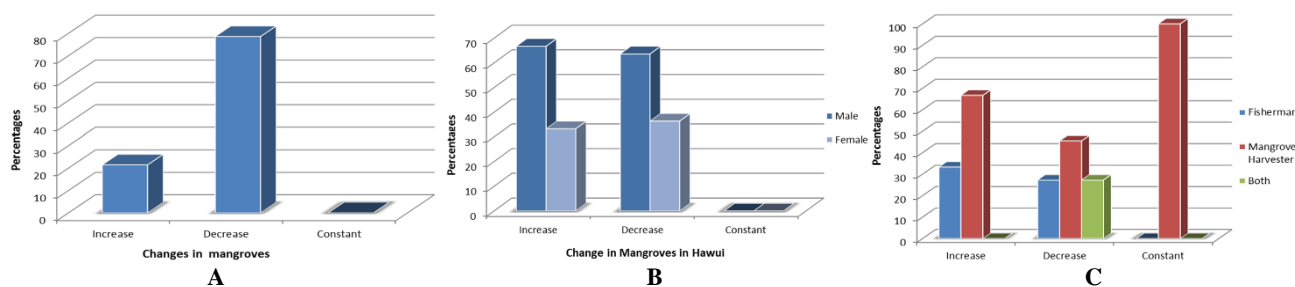


Figure 7. Perception of change in mangroves of Hawui. A. All, B. Gender base of increase, C. occupation base

Table 14. Significance of socio-economic factors in influencing mangrove exploitation

Variable	Co-efficient	Standard error	p-value	Confidence interval
Increased income	0.838	0.304	0.001*	0.425-0.920
Commercial supply of fuel wood	0.525	0.341	0.002*	0.16-1.213
Supply of wood fuel (domestic)	0.430	0.242	0.023*	0.059-0.524
Wood for construction	0.240	0.330	0.125	0.150-0.320
Medicinal purpose	0.142	0.208	0.063	0.105-0.221
Lack of alternative energy sources	0.197	0.202	0.03*	0.212-0.605

Note: *significant at $P \leq 0.05$

Table 15. Significance of demographic characteristics in influencing mangrove exploitation

Variable	Co-efficient	Standard error	p-value	Confidence interval
Age	-0.800	0.158	0.616	-0.067-4.703
Marital Status	0.255	0.255	0.323	-0.804-0.123
Sex	-0.340	0.229	0.146	-0.400-0.240
Educational level	-0.074	0.131	0.575	-0.339-0.191
Number of children	0.060	0.082	0.466	-0.105-0.226

Table 16. Willingness to use LPG as an alternative energy source

Variable	Co-efficient	Standard error	Odds ratio	p-value	Confidence interval
Price	-0.809	0.907	0.445	0.030*	0.75-2.633
Preference	0.404	0.980	1.497	0.001*	0.219-10.221
Safety	0.298	0.966	0.743	0.758	0.112-4.932

Note: *significant at $p \leq 0.05$

Discussion

Image classification accuracy

The image classification's lowest overall accuracy was 85.18% in 2014, and the highest was 90.09% for the 2002 classification. The highest kappa coefficient was 0.864 for the 2002 and 0.796 for the 2014 classifications. According to Rahman et al. (2004), kappa values greater than 80% represent a strong agreement between the classification map and ground reference points. Therefore, the classification map generated from this study strongly agrees with the ground information.

Change detection

The decrease in mangrove vegetation between 1991 and 2002 could be attributed to the exploitation of the mangroves by the local people. Tsikata et al. (1997) reported that the damming of the Volta River at Akosombo and Kpong resulted in the decline of economic opportunities such as marine and inland fishing. Furthermore, the dam's construction resulted in changes in the hydrology and salinity of the water. In addition to declined soil fertility, climatic conditions changes, and population pressure rendered the exploitation of the mangrove resource a major economic activity.

The conversion of 18% and 14% of mangroves to other vegetation and bare ground may reflect the intensity of mangrove exploitation. A degraded mangrove area may be classified as other vegetation or bare ground, depending on the degree of exploitation. The loss of mangrove area is consistent with the increase in area covered by other

vegetation (16%) and bare ground (5%). The results also showed a significant decrease in the water amount between 1991 and 2002. This change could be attributed to the differences in the dates of acquisition of Landsat images. The 1991 Landsat image was acquired in March, which marks the beginning of the rainy season, while the 2002 Landsat image was acquired in January, a dry month throughout the country (Ghana Meteorological Agency 2016).

Between 2002 and 2014, the mangrove vegetation area fell by 27%, which could be attributed to an increase in the intensity of mangrove exploitation. While using mangroves as fuel wood has been a traditional practice for the local people (Aheto et al. 2016), following the increased population with an associated increase in demand for both domestic use (Ghana Statistical Service 2008) and commercial markets (Arthurton et al. 2006) may contribute to such significant decrease in mangrove area. The mangrove area loss is consistent with the observed conversion of the mangrove vegetation into other classes of about 47%, mainly other vegetation, which accounted for 26%. Although there was a general increase in the area covered by water which could be attributed to rainfall starting in March, about 58% of the previous cover had been converted into other classes. Furthermore, a significant portion of the area covered by water is shown to have been converted into mangroves by (40%), which could be a classification error due to the inability to discriminate between mangroves and mudflats that occur within the

mangroves. The mudflats may occur due to the drying up of the water body.

Figure 7 provides a snapshot of changes between 1991 and 2014. According to Arthurton et al. (2006), Ghana Statistical Service (2008), and Aheto et al. (2016), the observable 33% decline in mangrove areas between 1991 and 2014 could be attributed to the progressive increase in mangrove exploitation. The decline in the mangrove area was consistent with the increase in the area covered by bare ground and other vegetation. The increase of other vegetation in the area could be attributed to the inclusion of degraded mangrove areas as part of the other vegetation class. The increased human settlements due to the increased human population and increase in the bare ground could be attributed to mangrove areas that have been totally degraded.

Estimating mangrove height, biomass, and carbon stock

The ASTER DEM was calibrated with equation (7) derived by (Simard et al. 2006). Calibrated ASTER DEM height estimates were compared with field estimates; this showed a positive correlation with a standard error of 2.3 m was close to the ASTER DEM error reported for flat areas by Tachikawa et al. (2011). The ASTER DEM was therefore considered well calibrated.

The above-ground biomass for 2014 was estimated by applying equation (3) developed by Saenger and Snedaker (1993a,b). This equation was used by Fatoyinbo et al. (2008) and Tang et al. (2014) to estimate mangroves' above-ground biomass, which applies to mangrove forest trees with heights up to 40 m. The mangrove area was reduced from 63.73 km² to 53.77 km² due to the masking of heights above 15 m. As a result, the total above-ground biomass for the mangrove area was estimated to be 5.38759×10^5 Mg. The above-ground mangrove biomass was 100.204 Mg/ha, similar to the mean above-ground living biomass of 94.49 ± 78 Mg/ha reported by Aheto et al. (2011). That result is also consistent with the mean above-ground biomass estimated by Fatoyinbo and Simard (2013) of 97 Mg/ha. These findings, according to Aheto et al. (2011), are indicative of low structural development of mangroves compared with other areas like French Guiana, where Komiyama et al. (2008) estimated the above-ground biomass to be 169.1 Mg/ha for *Avicennia* sp., and 315.5 Mg/ha for *Rhizophora* sp. trees respectively.

The stand biomass estimation indicates the allocation of carbon in plant tissues which is important for sequestration or carbon accounting (Kairo et al. 2008). The total above-ground carbon stock estimated for the study area was 2.693795×10^5 Mg. The carbon stock was found to be 50.102 Mg/ha, which was within the range of values reported by Adame et al. (2013), Tang et al. (2014), and Rahman et al. (2015). The estimated carbon stock recorded, 50.10 Mg/ha, is within the range of 1.5-88 Mg/ha reported by Adame et al. (2013) and 45.24 -152.57 Mg/ha reported by Rahman et al. (2015). The carbon stock per hectare estimated from this study is similar to the mean above-ground carbon of Ghana's mangrove (56.57 Mg/ha) reported by Tang et al. (2014). Higher values of above-ground carbon (75.4-206 Mg/ha) were reported by Stringer et al. (2015). These differences in the above-ground carbon stocks

estimation could be attributed to including downed debris, leaf litter, and standing dead.

An examination of mangrove carbon stock changes revealed that the study area had lost about 161,428.65 Mg of its carbon stock because of the loss of mangroves between 1991 and 2014. Pendleton et al. (2012) expressed carbon stock in terms of potential CO₂ emissions by multiplying carbon stock by a factor of 3.67 (molecular weight ratio of CO₂ to C), which gives a value of 602,352.15 Mg of CO₂ that may have been lost. However, this figure is conservative, as many studies have shown that most ecosystem carbon is stored within the sediment. An analysis of the changes in carbon stock revealed an average rate of 6,882.76 Mg of carbon is being lost yearly (Tables 11, 12, and 13).

Perception of change

The general consensus of a decline in mangroves in the Lower Volta agrees with the loss of mangroves in Ghana reported in the literature (Spalding et al. 2010; Mensah, J. 2013; Aheto et al. 2016). The commercial harvesting of mangroves as a livelihood alternative could be attributed to this mangrove loss. In addition, the livelihoods related to fishing and farming were lost due to a reduction in riverine flow into the Keta lagoon caused by the damming of the Volta River, resorted respondents to an alternative livelihood.

Most of the respondents (77%) in Bomigo reported an increase in the mangrove, attributed to excessive planting, which was reported that mangroves were formerly planted to meet its demand as wood fuel for smoking fish. However, there had been a fall in demand for mangroves for wood fuel because of a progressive reduction in fish catch in Bomigo to be smoked. The extensive growth of mangroves also worsened fishing canoes from accessing fishing areas. In addition, the abundance of mangroves in the area has attracted residents from neighboring villages, such as Hawui and Tunu, who engage in mangrove harvesting.

In Hawui, about 79% of the respondents reported a reduction in the mangrove area, which was attributed to the intensive harvesting of mangroves. The current economic hardships and sole dependence on mangroves for domestic energy make the mangrove resource an integral component of the local economy, and mangrove harvesting is an alternative livelihood option. That has led to a total depletion of the mangrove resource in Hawui, resulting in residents moving to Bomigo to harvest mangroves.

Socio-economic factors that drive mangrove exploitation

Several factors significantly influenced the decision to exploit mangroves: increased income and commercial supply of fuelwood and wood fuel for domestic use. That follows Tsikata et al. 1997; Aheto et al. 2016 reported an attributed to the fact that the mangrove resource is viewed as an economic resource. Each of these factors has direct economic benefits. The sole dependence on fuel wood for cooking energy and the mangrove market's existence at Anyanui contribute to the significance of these factors. The 'medicinal purposes' was not a significant factor influencing the decision to exploit mangroves due to the availability of

modern healthcare facilities. Further analysis also revealed that the respondents' demographic characteristics did not influence the decision to exploit mangroves. That could be attributed to the limited economic opportunities making mangrove exploitation the accessible means to sustain their livelihood.

Willingness to use LPG as an alternative energy source

Respondents were less likely to use LPG due to price and the additional cost of LPG being more expensive due to buying a cylinder safety considerations (Bukari 2012); it could also expose users to severe burns and injuries in case of gas accidents. The results also indicated that the respondents were more likely to use mangroves as fuel wood over LPG due to preference, which follows Tsikata et al. (1997), who attributed mangroves as fuel wood to their high caloric value and the attractive gold color they impart onto fish when used in fish smoking.

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Economic impacts of climate change on livestock and crop returns in the coastal region of Kenya

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Abstract. Wachira PW, Ndunda E, Sitati N. 2021. *Economic impacts of climate change on livestock and crop returns in the coastal region of Kenya. Indo Pac J Ocean Life 5: 74-82.* The objectives were to assess which impact climate change has on crop net revenue, to evaluate the impact of climate change on livestock net revenue, and to estimate the impact of climate change on combined net revenue. The study was conducted in all six counties in coastal area of Kenya, i.e.: Kwale, Lamu, Tana River, Mombasa, Kilifi, and Taita Taveta. A sum of 631 respondents was interviewed to obtain the cross-sectional survey data. The secondary data on precipitation, temperature, and evaporation for 40 years was obtained from Kenya Meteorological Department. The data was analyzed using the Ricardian model; the linear and quadratic effects of climate change on crops, livestock net revenue, and the combination were calculated. The study shows that climate change significantly ($p < 0.05$) affects net revenues from livestock, crops, and a combination of livestock and crops. Other socio-economic variables that were found to also significantly ($p < 0.05$) affect net revenue from crops, livestock, and a combination of crops and livestock were access to media, credit services access, farmer-to-farmer extension services, size of land owned, climate change awareness, education level, age, and gender of the household head. The results show a non-linear relationship between climate variables and net revenues from crops, livestock, and agriculture. This study concludes that a unit increase in precipitation increases crop revenues; at the same time, a unit increase in mean annual temperature significantly reduces crop and total farm income. The marginal effect of increasing a unit in precipitation is a reduction of livestock net revenue. An increase in livestock production revenue from a unit temperature increase (linear) can be attributed to the livestock breeds in the coastal region inherent to dry weather. However, results show that increasing quadratic temperature would reduce net livestock revenue. This study recommends enhancing awareness of climate change, crop, livestock, and combined agriculture adaptation strategies. Also important is access to credit facilities that help farmers greatly to acquire the necessary inputs for crop production in time. Further, training groups of farmers would be appropriate in the study area since the trained farmers preferably transfer the learned technologies to others through farmer-to-farmer extension services. Media access should be enhanced whereby information on appropriate livestock and crop production technologies may be communicated to farmers.

Keywords: Climate change, crop, economic, livestock

INTRODUCTION

Agriculture is the backbone of Kenya's economy, which contributes 27% and 24% indirectly and directly, respectively. In addition, this sector accounts for 65% of all informal employment in rural areas. However, Kenya faces notable challenges as far as food security is concerned, mainly resulting from overdependence on rain-fed agriculture (Government of Kenya 2013; Wawira and Thenya 2017).

The number of people who rose to approximately 3.8 million in 2009/2010 from 650,000 in 2007 who required food assistance (Government of Kenya 2013). Nowadays, approximately 18 million people are starving without immediate assistance from the state (Ngwiri 2016). Agricultural areas, which are pastoral and marginal, are highly vulnerable to impacts arising from climate change. Livelihood opportunities and the resilience ability of communities have been eroded, as a result giving rise to undesirable coping strategies.

This background expresses the need to assess and estimate the impacts on agriculture from climate change incorporating crops and livestock production. The results

will broaden and extend the understanding of Kenya's agricultural productivity and climate change. That will give rise to informed levels of decision-making, thus significantly reducing poverty and promoting sustainability in development. As far as vision 2030 in Kenya is concerned, the agricultural sector has been identified as could deliver 10% of the entire annual budget under the economic pillar. However, there is an urgent need to transform the smallholder sector to innovate, thus operating optimally for improved production (Government of Kenya 2010; Abraham and Pingali 2020; Fan and Rue 2020).

Kenya's agriculture is mainly fed through rain and thus depends fully on rainfall in almost the country. Only 1.7 percent of the total agricultural land is under irrigation (Agricultural Sector Development Strategy 2009). However, fluctuating agricultural productivity is a major concern considering Kenya's fast-growing population. In addition, marginal and pastoral agricultural areas are susceptible to the effects of changing climatic patterns. Nevertheless, agriculture remains the sole food source in Kenya, thus a notable basis of the national economy. Moreover, the food policy should serve humanity by the advancement of human goals, thus eradicating poverty and

hunger. Even though emerging forces, including climate change, recently challenged these goals.

A common consensus among environmental and agricultural economists is that climate change seriously threatens sustainable agriculture. The United Nations Development Programme (UNDP) estimates that one of the hardest hit continents by changes in climatic patterns in Africa, as it faces severe effects in comparison to other parts globally. Because the African economy is climate-dependent in most sectors, the capability to adjust and subsist to changing climate is highly limited (Ayinde et al. 2011; Dell et al. 2012; Iheoma 2014; Abidoyea and Odusola 2015; Fant et al. 2016; Apollo and Mbah 2021). For instance, small-scale farms account for 75% of all agricultural production and 70% of livestock production, and the entire marketed crop (Agricultural Sector Development Strategy 2009).

Poverty has been a hard hit in the Kenyan coastal region for many decades. Land tenure, yearly drought and floods, and undeveloped agricultural markets as major challenges alongside increasing poverty levels to non-performing agriculture in the country (Agricultural Sector Development Support Programme 2009). It is clear that climate change may interrupt the progress already made regarding eradicating hunger globally. That is based on the fact that the stability of the entire food production system may be risked by changes in climate owing to short-term supply variability (Wheeler and Braun 2013). However, fewer studies have been done on agriculture to explain the results of variations in climate, especially in the coastal region. Therefore, this study aims to investigate climate change's impacts by analyzing trends in rainfall patterns

and temperature variations over time in livestock and crop production.

The objective of this study was to assess the economic impacts of climate change on agriculture in Kenya's coastal region. Specific objectives were used to achieve this: to assess which impact climate change has on crop net revenue, to evaluate the impact of climate change on livestock net revenue, and to estimate the impact of climate change on combined net revenue.

MATERIALS AND METHODS

Study area

Location: Coastal region of Kenya, formerly the coastal province, comprises six counties, namely Tana River, Lamu, Kilifi, Kwale, Taita Taveta, and Mombasa County (Figure 1, Table 1). Taita Taveta covers an area of 17,083 Km², its capital town is Voi. Area coverage of Kwale County is 8,270 Km² and its capital town is Ukunda. Mombasa County lies between longitudes 39°34' and 39°46' and latitudes 3°56' and 4°10' south of the equator. The county has the smallest area in the region and covers an area of 229.7 km². It is headquartered in Mombasa city. Kilifi County has an area of 12,245 km² with 109 km of ocean line stretch. It is headquartered in Kilifi town. Lamu County is located in the northern part of the Kenyan coastal region. It lies 1° 40' and 2° 30' South and longitude 40° 15' and 40° 38' East. The county covers an area of 6,273 km² and a beach coastline of 130 km. The sixth county is Tana River, covering an area of 38,437 km².

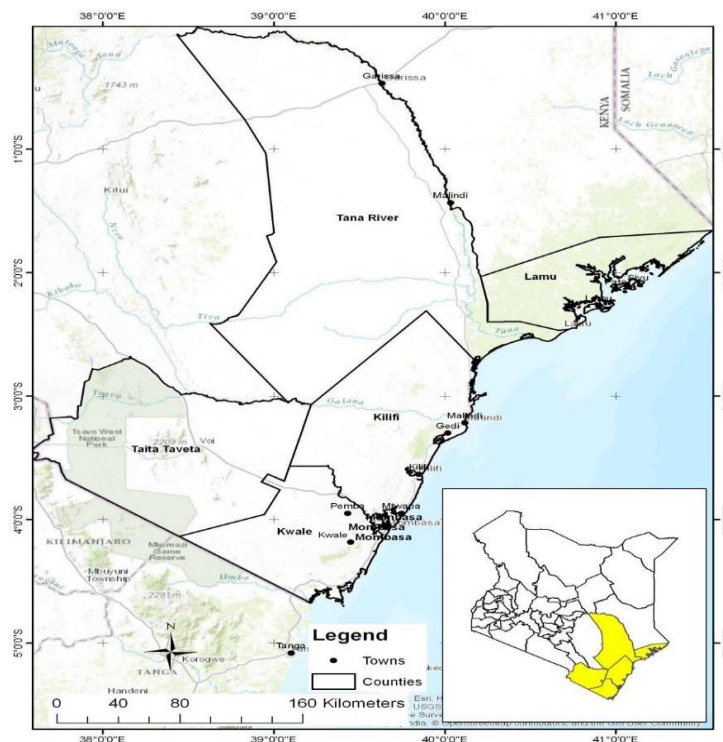


Figure 1. Map showing the study area in Coastal region of Kenya

Table 1. Coastal region population summary

County	Population (Census 2009)	% Total	The population of households practicing mixed farming	Sample size
Kilifi	1,109,735	33.37	93	92
Kwale	649,931	19.54	117	116
Lamu	101,539	3.06	137	135
Mombasa	939,370	28.24	67	67
Tana River	240,075	7.22	92	91
Taita Taveta	284,657	8.56	141	139
Totals	3,325,307	100		640

Drainage: The region has both perennial and seasonal rivers. Sabaki and Tana Rivers are the main perennial rivers. Tana River, 850 km in length, with 95,000 km² in the catchment area, enters the ocean halfway of Malindi in Kilifi County and Lamu County near Kipini. Sabaki River, 650 km long, discharges two million tons of sediments and 2,000 million³ of fresh water into the Indian Ocean on the northern side of Malindi via the Sabaki estuary. Other seasonal and semi-perennial rivers in the coastal region include Ramisi, Tsalu, Nzovuni, Voi, Kombeni, Uмба, and Mwachema (FAO 2015).

Population: In 2009 census, Kilifi County clearly leads in size among the six counties, with 33.37% of the population within the region. It is important to consider that, within the six counties, one of the Mijikenda people, Giriama, forms 57% of the total population living in Kilifi County. Mombasa County is a metropolitan area with the entire Mijikenda group equally represented. On the contrary, another subgroup within Mijikenda, Digo, constitutes 49% of the total population in Kwale County. Other tribes, such as Luhya, Kisii, Kamba, and Arabs, are also present within the six counties.

Social economic: The household source income, income level, and employment status in the coastal region are well documented. The main sources of income are self-employment in businesses at 39%, followed by agriculture at the household level at 15%, and finally, the public sectors employments. Tana River County has the highest number of households that depend on livestock and agriculture, which clearly indicates its population is mainly nomadic pastoralists.

Study design

This study used a dedicated survey research design. Cross-sectional data on farmland on actual observations within the different Counties of farm performance in areas where agriculture is practiced. The target group was farmers who practiced mixed farming.

Sample size and sampling procedure

Random and proportional sampling was employed in selecting households during this study. Proportional sampling reduces bias and ensures that particular parts of the population are not over-represented. A random selection method was done to identify the households. A total of 640 households sample size (Table 2) was derived based on the formula (Israel 2009) indicated below:

$$n = \frac{N}{1 + N(e)^2}$$

Where: a 95% confidence level and P = 0.05 in the sample size are used to assume for the equation, N is the population size, and e is the precision level that is 0.01. Based on the above figure, the response rate was 98.4%, with 631 questionnaires.

The household list was obtained from Nyumba Kumi village older adults at the location level through local National Administration (NA) officers (Chiefs). Ten questionnaires were administered in each of the six counties. Moreover, the questionnaire was pretested before to get a better actual data collection exercise, which helped to perfect the tool for quality and relevant data collection. Then the questionnaires were administered with the assistance of trained enumerators. Section C of the questionnaire was an in-depth interview with the respondents.

Data collection methods

Primary data

Primary data for this study was achieved by administering semi-structured questionnaires to household heads. Enumerators were trained in the administration of the questionnaires before data collection. That was to minimize mistakes, standardize the data collection procedure and ensure data quality. The questionnaires contained information on socioeconomics and adaptation to climate change, which captured 2015 production data incomes as the output. In addition, enumerators interviewed farmers practicing mixed farming as earlier identified that practicing agriculture within the counties in every tenth household.

Table 2. Study sample size summary

County	Population of households practicing mixed farming	Sample size
Tana River	92	91
Mombasa	67	67
Taita Taveta	141	139
Kilifi	93	92
Kwale	117	116
Lamu	137	135
Total		640

Secondary sources of data

Secondary data used for the study were obtained from Kenya Meteorological Department (KMD) and Kenya Agricultural Research and Livestock Organization (KARLO) Mtwapa. Other major sources of information included Government of Kenya publications, coastal counties websites, dissertations, peer-reviewed journals, Institutional websites, and textbooks. Climate data employed for the study covered 40 years (1972-2012). Secondary data collected included average temperature, precipitation, and evaporation every month within the 40 periods analyzed by this study.

Data analysis techniques

Theory and model

The Ricardian model is a linear regression model relating to cross-sectional data. The net revenue was a function of three regressors; The climate variables covering temperature and precipitation, characteristics of soil covering fertility and erosivity, and social and economic variables, including education level, age, gender, and distance to the market and land ownership. In addition, the annual mean average of the quadratic and linear terms of climatic variables (temperature, precipitation, and evaporation) were considered for 40 years. Therefore, the study analyzed three modified Ricardian models for livestock net revenue, crop net revenue, and combined net revenue of the entire farm. The Ricardian-modified models were analyzed using STATA 2014 software, which was used to calculate livestock net revenue, net crop revenue, and the combined farm revenue for livestock and crops as dependent variables. It is worth considering that climate change affects all variables across the three modified Ricardian models (Gebreegziabher et al. 2013). The results obtained were shown in graphs and table format.

The study used the Ricardian model to measure welfare change. According to Mendelsohn et al. (1994), this research employed Ricardian analysis to determine the impacts of climate change on Kenyan coastal region agriculture, generally mixed farming. This study tried to analyze the effect of climate change on crop farming, livestock farming, and the combined agriculture of crops and livestock. The principle captured in the equation indicates that the land net productivity is equivalent to their total farmland net revenue, as follows;

$$V_{rt} = P_t Q_{rt} \beta_{rt} Z_t - M_t X_{rt} e^{-\delta t} dt \quad [\text{eq.1}]$$

Where: P_t is the market price at location t of every crop, Q_{rt} is a crop at farm r output at location t , β_{rt} is a vector of inputs at farm r for each crop (other than land), Z_t is an exogenous vector variable at location t , M_t is a vector of input prices at location t , δ is the interest rate, and t is period. Also, note that the δt term is for discounting. The farmer wants to select X to raise net revenues for crop net given market prices and farm characteristics. Therefore, the Land value V_{rt} can only be expressed as a function of exogenous variables by solving equation (1) above. Those site-specific exogenous environmental factors include climate variables (temperature (T) and precipitation (P)),

socio-economic variables (H), soil variables (S), and geographical variables (G). An assumption was made to capture returns from livestock production: the farmer maximizes net revenue by selecting which livestock to buy and the inputs to apply.

$$\text{Max } (\beta = P_{qx} Q_x(G_L, \infty, L, \mu, C, \Omega, \phi)) - P_f \infty - P_w L - P_M \mu \quad [\text{eq.2}]$$

Where: β is the revenue obtained from livestock (animal) x , GL is grazing land, P_{qx} is the market price of animal x , Q_x is a production function for animal x , ∞ is feeds, L is a labor inputs vectors, μ is a vector of capital such as milking cans, C is a vector of climate variables, Ω is available water, ϕ is a vector of soil characteristics of grazing land vector, PF a vector of prices for each type of feed, PW is prices vector for every variety of labor, and PM capital (rental price). When a farmer rears the species (animal) x and the number of animals maximizing benefits, then the representative problem affecting the farmer's condition to maximizing profits can be specified as:

$$\beta^* = \beta(P_q, C, W, \phi, PF, PW, PM) \quad [\text{eq.3}]$$

Equation (3) is the Ricardian equivalent of livestock production. Finally, Seo and Mendelsohn (2006) tell how profits vary across all the exogenous variables a farmer faces.

Empirical model and data

Empirical model

This study uses Log Linear Ricardian analysis, Massetti and Mendelsohn (2011), as land values are log-normally distributed. As earlier mentioned, the Ricardian model uses actual observations of farm performance (Mendelsohn et al. 1994). The analysis comes from several explanatory variables from geography, climate, and social-economic variables that directly affect farm revenue. The Ricardian technique's main aim is to assess agricultural land changes regarding net revenue across climate gradients (Wood and Mendelsohn 2014).

This study also used a quadratic model of climate indicating the non-linear relationship between climate, net crop, and livestock, including the following empirical model:

$$VL = R_0 + R_1 \delta + R_2 \delta^2 + R_3 \infty + R_4 \beta + \mu \quad [\text{eq.4}]$$

Where VL is the net revenue per hectare, δ the climate variables vector, δ^2 squire vector of climate variables, ∞ set of soil variables, β set of social-economic variables, μ is the error term, R 's are requiring estimation parameters, and R_0 is the constant term, and the rest are coefficients. Then, δ^2 and δ captures linear and quadratic terms for precipitation and temperature, respectively. Moreover, when the quadratic term is negative, the function has a hill shape; when the quadratic term is positive, the net revenue function is U-shaped (Mendelsohn et al. 1994).

The equation below describes the marginal impact of climate variables on the value of land per hectare (direct crop revenue);

$$E \{dV/d\delta_i\} = E \{R1_i + 2R2_i * \delta_i\} = R1_i + 2R2_i * E(\delta_i) \text{ [eq.5]}$$

The equation mentioned above established the net economic welfare change. The environmental changes bring about changes in welfare from x to y , which consequently causes changes in the farm inputs from β_a to β_b . Impacts of non-marginal changes in climate on land per hectare value in specific farms were expressed as the comparison between the approximated value of land with the new climate variables (precipitation (P) and temperature (T)) T1P1 and the approximated land value at the current climate variables TOP0.

$$\Delta W = W(\beta_b) - W(\beta_a) \text{ [eq.6]}$$

Where: ΔW represents welfare change, $W(\beta_b)$ is the welfare after the change, and $W(\beta_a)$ is welfare before the change.

$$\Delta W = \sum_{i=1}^n (PLb_{Qbi} - PLa_{Qai}) \text{ [eq.7]}$$

$$PLb_{Qbi} = Pi_{Qi} - Ci(\beta_i, Mi, Zi) \text{ [eq.8]}$$

Where: PLb_{Qbi} are at β_b and PLa_{Qai} are at β_a .

The data analysis

In this study, to obtain dependent variables, a cross-sectional survey of 640 households farms was carried out in the coastal region of Kenya that included livestock net revenue, net crop revenue, and net revenue from the whole farm as indicators of potential effects of climate change and variability in climate on household level farm production.

As independent variables, samples were used from different counties to capture the temperature, precipitation, and evaporation variability within Kenya's coastal region. The systematic sampling method selected 640 household samples supporting livestock and crop farming. Specifically, Kwale, Tana River, and partly Taita Taveta largely support livestock rearing on a large scale, while Kilifi, Lamu, and partly Mombasa and Taita Taveta counties largely support crop production. The main crops grown were maize, bananas, peas, beans, green grams, mangoes, cashew nuts, and coconuts. The main data captured in this study were the farms' production in terms of climate, net revenue, and social demographic aspects. In addition, net revenues were obtained for livestock and crop production data, which were obtained from respective district records.

Mean precipitation, temperature, and evaporation data for 40 periods (1972-2012) were obtained from Kenya Meteorological Department (KMD), and the soil characteristics were obtained from KARI regional offices, respectively. Net revenue, in this study, was obtained as overall revenue minus costs/expenses entailing outlay in cash. The Ricardian model on the analysis of land values or net revenue per hectare for crop agriculture (Gebreegziabher et al. 2013). The crops' net revenue was calculated as total returns less the cost of seeds, all chemical inputs, manure, and market costs. The livestock

revenues were calculated as the total returns less the cost of feeds, veterinary services, and medicine. The significant challenge in measuring the amount of land used for livestock by farmers is the reliability of public, open, and communal land. Moreover, there was also the challenge of quantifying own household labor; thus, it was not factored as part of the cost. Therefore, the study needs to use the Ricardian model to analyze data.

RESULTS AND DISCUSSION

Data presentation

Descriptive statistics of variables used in the regression models

Table 3 shows the summary statistics of variables used for regression analysis for both secondary and primary data from the 631 respondents and climate data. According to the results, the annual minimum crops net revenue was Kshs.-36,000, while the maximum return per hectare was Kshs. 560,800. In Livestock production, the minimum net revenue was Kshs. -32,000; conversely, the maximum annual returns were Kshs. 977,500, with the combined agriculture minimum annual net revenue was Kshs. -36,000 and a maximum of Kshs. 973,000. In the studied area, the mean total revenue was Kshs. 99,168, contributed largely by livestock production at 53% (Kshs. 52,754) and crop production at 47% (Kshs. 46,414).

The maximum and minimum precipitation of the area was 95.0 and 38.9 mm, respectively. Mean precipitation during the 40 periods was found to be 76.59 mm. The minimum temperature was 29.88°C, and the maximum was 30.90°C. The mean temperature and evaporation were 30.62°C and 6.38 mm, respectively.

Adaptation to precipitation and temperature was 52%, and farmer-to-farmer information sharing was 46%. About 62% of the interviewed respondents stated that they had access to climate information, while 81% had access to media. However, only 20% of those who responded could access credit services. Most farmers in the study area used cattle to cultivate, and most were hired. The use of hired labor was 76% attributed to the preference for using cattle for cultivation.

The Ricardian model was used in this study, as described in the methodology chapter, to assess the effect of climate change on agriculture in Kenya's coastal region. The dependent variables in the regression models are; net livestock income, net crop income, and combined net income. According to the Student t-test for the significance of every estimated coefficient, climate variables were significant parameters ($p < 0.05$) to determine the net incomes from livestock, crops, and the net combined income. This study used three models of the Fisher-Snedecor tests (Snedecor and Cochran 1989), which were validated since their regressions were all significant ($p < 0.05$). The coefficients of determination livestock, crop, and combined models were 48%, 37%, and 42%, respectively.

Table 3. Descriptive statistics of variables used in the regression models

Variable	Mean	Std.dev.	Min	Max
Crops Net Revenue (KSHS)	46414.55	59464.04	-36000	560,800
Livestock Net Revenue (KSHS)	52753.69	81769.79	-32000	977,500
Combined Net Revenue (KSHS)	99168.24	104117.7	-36000	973,000
Precipitation (mm)	76.59	20.20	38.9	95
Temperature (°C)	30.62	0.43	29.88	30.96
Evaporation (mm)	6.38	0.59	5.82	7.19
Market Distance (Km)	8.33	5.40	2	22
Adaptation (0/1)	0.52	0.49	0	1
Farmers to farmer information (0/1)	0.46	0.49	0	1
Climate change awareness (0/1)	0.32	0.48	0	1
Access media (0/1)	0.81	0.38	0	1
Access to Credit services (0/1)	0.20	0.40	0	1
Hired labor use (0/1)	0.76	0.42	0	1
Land owned (acres)	1.05	3.55	0	16
Climate change awareness (0/1)	0.68	0.46	0	1
Employment status (0/1)	0.19	0.38	0	1
Soil erosion severity (0/1)	0.11	0.31	0	1
Soil fertility status (0/1)	0.36	0.48	0	1
Education level of household head (years)	6.14	0.80	1	11
Age of household head (years)	40.99	17.15	0	77
Gender of household head (0/1)	0.70	0.56	0	1

Crop net revenue analysis on Ricardian regression

The results from the Ricardian regression model based on net crop revenue showed that both the linear and the squared terms of climate change significantly ($p < 0.05$) affect the net crop revenue in the coastal region (Table 4), thus change in climate has a non-linear impact on overall crop revenue in the study area (Mendelsohn et al. 1994; Kurukulasuriya et al. 2006). According to linear terms, an increase in precipitation raises net crop income. However, the increase in both temperature and evaporation lowered crop income in the study area. That depicted that prolonged high temperatures are detrimental to crop productivity, indicating that global warming is probable to pose a damaging impact on agricultural activities unless government and farmers enhance measures to adapt to counter the expected impacts of changes in climate (Kurukulasuriya et al. 2006)

Other factors that were found to significantly ($p < 0.05$) influence overall revenue from the crops are distance to market, severity of erosion, employment status of the household head, availability of climate change information from media outlets, access to credit services, extension services for farmer-to-farmer, land size owned, adaptation to changes in climate, as well as the use of hired labor in the farm. The inverse relationship between distance to the market and the net revenue from crop production may be attributed to costs incurred in transporting inputs to the farms and outputs to the market. Awareness of climate change was found to raise net crop income significantly, which is attributable to the ability of the farmer to seek varieties of crops that can yield optimally in various climatic conditions.

A positive effect of adaptation to changes in climate on net income from crop farming could be attributed to the

production of resilient crops and hence able to yield well under harsh climate conditions. In addition, access to credit facilities can enable farmers to acquire farm inputs and hence increase farm productivity. The coefficient of erosion severity in the farms was as anticipated. An increase in erosion lowers the ability of the farm to support optimal crop yields, lowering revenue from crops. The increased revenue from hired labor may be explained by timely farm operations such as planting, weeding, harvesting, and postharvest processes.

Ricardian regression analysis for net livestock revenue

Results from the model for livestock production (Table 5) showed that climate change significantly ($p < 0.05$) affects net revenue for both the linear and quadratic terms. It implied that climate change has effects that are non-linear on net livestock revenue in the coastal region of Kenya. The linear term of precipitation significantly positively affected net revenue from livestock production. Similarly, the coefficient of the linear term of temperature was positive.

In addition to the climate change factors, several socio-economic variables were also found to influence the net revenue from livestock production significantly. Similar to the net crop revenue model, distance to the market significantly affected livestock net revenue. That may be readily explained by the costs incurred as farms transport livestock production inputs to the farms. Additional costs may be incurred when farmers transport their livestock to the market. Consequently, these costs lower the net revenue earned from livestock production.

Table 4. Ricardian regression estimates for crops' net revenue

Variable	Coeff.	Std. Err.	t-test
Precipitation	981.53***	174.40	5.63
Precipitations_ SQ	6.62***	1.13	5.84
Temperature	-51272.92***	6084.46	-8.43
Temperature_ SQ	840.94***	99.12	8.48
Evaporation	-19809.23***	4383.86	-4.52
Evaporation_ SQ	-79.87	85.67	-0.93
Distance market	-8487.11***	1414.97	-6.00
Erosion severity	-16042.57***	5977.35	-2.68
Employment status	11642.41***	4074.02	2.86
Access to media	16035.65***	5321.58	3.01
Credit services access	20708.27***	4716.24	4.39
Farmer-to-farmer extension services	11079.11***	5058.67	2.19
Size of land owned	3428.97***	651.10	5.27
Climate change awareness	9244.50***	3868.37	2.39
Adaptation to climate change	22393.21***	3740.88	5.99
Hired labor use	10001.50***	4461.34	2.24
Education level of household head	4308.09	2366.97	1.82
Age of household head	36.53	111.14	0.33
Gender of household head	-5194.55	3811.60	1.36
Soil fertility	1024.12	2154.51	0.48
Constant	646372.90***	255509.00	2.53
F (20, 610)	20.58		
Prob > F	0.00		
R-SQ	0.37		
Root MSE	61078		
N	631		

Note: *** $p < 0.05$

Table 5. Ricardian regression estimates for livestock net revenue

Variable	Coeff.	Std. Err.	t-test
Precipitation	2089.73***	1090.01	2.11
Precipitations_ SQ	49.56	37.74	1.31
Temperature	229.10***	110.21	2.08
Temperature_ SQ	-531.42***	130.81	-4.06
Evaporation	-1052.91***	482.00	-2.18
Evaporation_ SQ	-75.27***	33.17	-2.27
Distance market	-3244.01***	914.97	-3.55
Erosion severity	-3982.57	3166.21	-1.26
Employment status	2842.41	2918.22	0.97
Access to media	1595.15***	729.81	2.19
Credit services access	4281.27***	1716.24	2.49
Farmer-to-farmer extension services	-1066.13	2188.02	-0.49
Size of land owned	2009.51***	998.01	2.01
Climate change awareness	2818.20***	1301.09	2.17
Adaptation to climate change	12921.34***	5192.99	2.49
Hired labor use	-10011.50	5193.17	-1.93
Education level of household head	6302.99	4116.92	1.53
Age of household head	909.19***	409.37	2.22
Gender of household head	4701.37	2704.99	1.74
Soil fertility	978.86	701.21	1.40
Constant	337624.50	270515.50	1.25
F (20, 610)	15.53		
Prob > F	0.00		
R-SQ	0.38		
Root MSE	60542		
N	631		

Note: *** p < 0.05

Access to media turned out positive and significant, suggesting that providing information through local media outlets to farmers can influence their decisions greatly. Change in climate awareness had a notable and positive outcome on net livestock revenue, which implied that farmers who know the existing climatic conditions are likely to choose breeds of livestock that can suit their areas well. Adaptation to climate change had the expected positively significant coefficient. Livestock farmers who have adapted to climate change have realized increased net revenue. The results showed that the household head's age had a positive and significant coefficient, which may be partly attributable to experience gained in livestock production that can help make appropriate decisions and thus increase the net revenue (Gebreegziabher et al. 2013).

Ricardian regression analysis for net combined (crop & livestock) revenue

The regression model results based on net crop and livestock revenue (whole farm) showed that both the linear and the squared terms of climate change have a significant ($p < 0.05$) consequence on the combined net revenue in the coastal region (Table 6). Therefore, there was a non-linear impact of change in climate on net combined revenue in the study area. Furthermore, the linear term for precipitation had a significant and positive coefficient, whereas the coefficients for temperature and evaporation were negative.

Results of the model show the distance to the market negatively affected the total farm net revenue. That

compared well with the findings from the two separate models (crop and livestock), whereby costs incurred in transporting farm inputs and outputs can lower the enterprise's profitability. On the other hand, the farmer-to-farmer extension was a significantly positive determinant of the combined net revenue, which explained the importance of using farmers to reach out to others to disseminate farming technologies. Also, a farmer's land size significantly affects the combined net revenue. That is partly due to the requirement of a large parcel of land to practice mixed farming.

The level of education of a household head had a significant as well as a positive coefficient. Education contributed to a farmer understanding complex aspects of climate change easily compared to illiterate farmers. The gender variable had a negatively significant coefficient. A female-headed household in the study area increased combined net revenue significantly, which is attributable to women's role in providing farm labor in Kenya's coastal region. Farmers' awareness of climate change was established to significantly influence the combined net revenue. That compares well with the results from earlier regression models where crop and livestock net revenues were considered in isolation. Similar results were also observed for the farmers who had adapted to the change in the climate.

The coefficient of adaptation to changes in climate was found to be positive and significant. That underscores the relevance of appropriate adaptation strategies in order to realize an increase in combined net revenue.

Table 6. Ricardian regression estimates for combined net revenue

Variable	Coeff.	Std. Err.	t-test
Precipitation	-481.53***	174.40	-2.76
Precipitations_ SQ	31.11***	4.06	7.66
Temperature	-329.26***	101.96	-3.23
Temperature_ SQ	1929.49***	364.40	5.30
Evaporation	-19809.23***	4383.86	-4.52
Evaporation_ SQ	-7700.24***	1912.34	-4.03
Distance market	-2143.27***	819.97	-2.61
Erosion severity	-921.30	3109.41	-0.30
Employment status	1108.41	7114.21	0.16
Access to media	2172.33***	818.53	2.65
Credit services access	10019.23***	3702.45	2.71
Farmer-to-farmer extension services	21179.71***	8793.10	2.41
Size of land owned	1008.29***	379.44	2.66
Climate change awareness	1819.37***	717.11	2.37
Adaptation to climate change	10401.92***	4393.41	2.37
Hired labor use	1770.18	3809.53	0.46
Education level of household head	3804.67***	1873.15	2.03
Age of household head	109.03	86.33	1.26
Gender of household head	-7099.01***	3299.00	-2.15
Soil fertility	602.93	499.07	1.21
Constant	1488413.00***	541470.10	2.75
F (20, 610)	5.85		
Prob > F	0.00		
R-SQ	0.42		
Root MSE	1.00E+05		
N	631		

Note: *** p < 0.05

Climate variables and their marginal effects

Table 7 indicates the marginal effects of the climate variables (precipitation, temperature, and evaporation) on agriculture. According to the results, the analysis of marginal impact showed that a 1mm increase in annual precipitation would increase to Kshs. 374.02 and 201.31 from net crop and total net farm revenue, respectively. However, the marginal impact of precipitation on livestock net revenue was significantly negative. A unit increase in annual mean precipitation reduced livestock net income by Kshs 119.04.

The marginal impacts of temperature on the overall revenues showed that an annual rise of 1°C in temperature would have a significantly positive effect on livestock net revenue but a negative impact on farm net income and crop net revenue. According to the results, an annual net gain of Kshs 229.65 is expected from livestock agriculture when the annual temperature increases by 1°C. However, net losses of Kshs 4,893.35 and Kshs 374.88 resulted from a 1°C increase in temperature. These results compare with the ones obtained in similar studies by other researchers (e.g., Seo and Mendelsohn 2006; Gebreegziabher et al. 2013).

In analysis, the marginal result of evaporation on the crop, livestock, and farm net revenues showed that an increase in mean annual evaporation by 1mm significantly reduces net crop revenue by Kshs 10,312.92. However, the marginal impacts of evaporation on livestock and farms were insignificant.

Overview of adaptation to climate change in the coastal region of Kenya

Previous studies on adaptation to climate change show that it significantly reduces the susceptibility to expected imminent effects of climate change (Kabubo-Mariara and Karanja 2006). These studies show that the potential of adaptation strategies in lessening the extreme effects of global warming is huge. The adaptations addressed in this study were on livestock and crop production. In this study, the considered climate change adaptations in the coastal region of Kenya included: improved livestock and crop varieties, optimal water management approaches, increased use of organic fertilizer, conservation tillage farming, and adoption of agro-forestry techniques.

Figure 2 showed that there is awareness among farmers of the variability of climate and have started to adapt to varying precipitation and temperature. According to the figure, 78% of farmers adapt by focusing on improved varieties, diversifying crops, and breeding selection and enhancement through artificial insemination. Over 73% of farmers practice water management by harvesting runoff into small water pans for watering both crops and animals, especially after the rains. In soil management, over 60% of the farmers managed water and soil practices of conservations like terraces. The use of organic fertilizer was found at 58%. As indicated, practicing agro-forestry techniques and conservation tillage was relatively above average across the region.

Table 7. Climate variables' marginal effects

Climate Variables	Crop	Livestock	Agriculture (total)
Precipitation	374.02***	-119.04***	201.31***
Temperature	-4893.37***	229.65***	-374.88***
Evaporation	-10312.92***	-391.11	-1127.56

Note: *** p < 0.05

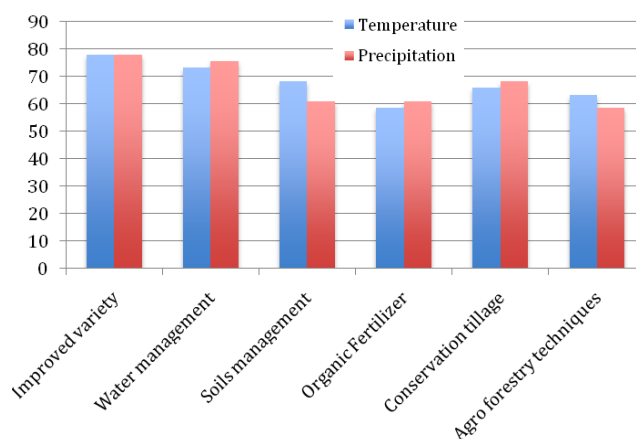


Figure 2. Adaptation to climate change in the coastal region of Kenya

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Litter assessment at the Sakumono and La Pleasure coastal areas, Ghana

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Abstract. Adjei O, Lampsey AM. 2021. Litter assessment at the Sakumono and La Pleasure coastal areas, Ghana. *Indo Pac J Ocean Life* 5: 83-91. Ghana has a difficult time managing waste, especially in the cities. The situation is even made worse in coastal urban areas by population growth. When the rains fall and wash the solid wastes downstream, most waste produced and lost inland ends up in the coastal and marine environment. In addition, revelers who use the areas for entertainment and tourism also contribute to the waste created. The Sakumono and La Pleasure Beaches in the Greater Accra Region served as the sites for this study. This study's primary goal was to assess how much waste was on the beaches at the two locations. The study made use of a transect measuring 1,000 m². A total of 2,697 litter items were collected from the two beaches. During the survey, 50.07 kg from both sites comprised the entire weight of the litter collected. Comparatively, the amount of waste collected from La Pleasure was 18.28 kg, which accounted for 36.51% of the total amount of litter surveyed. The amount of trash collected from Sakumono Beach was 31.79 kg, representing 63.49% of the total litter surveyed. Plants were discovered to be the most prevalent material by weight and number. Plastics accounted for 72.56% of the total composition for both beaches, or 1,975 items, and 65.53% of the total composition, or 32.81 kg, respectively. In comparison to La Pleasure Beach, Sakumono Beach was found to be more littered. An alpha value of 0.05 (a p-value = 0.02) indicated this was significant. Ongoing monitoring, intensive education, and sensible policy initiatives are still essential to address the beach litter problem along Ghana's coasts.

Keywords: Coastal, plastic, urban areas, waste management

INTRODUCTION

Large inland lakes and other areas that serve as an interface or transition between land and water are considered coastal areas (Masalu 2000). Coastal regions house more than 60% of the world's population despite making up only 10% of the planet's land area (Lakshmi and Rajagopalan, 2000). The coastal area and its resources are under great pressure due to the growing populations in coastal areas. Many of these activities produce large amounts of waste and litter in coastal areas. Beach debris is an issue worldwide (Derraik 2002; Gregory and Andrady 2003; Ivar do Sul and Costa 2007; Lie et al. 2018). According to the UNEP (2009), marine debris or marine litter is any durable, manufactured, or processed solid object dumped, disposed of, or left outside in the Great Lakes. They also include items created or used by people and intentionally or unintentionally lost to the ocean, including those carried to the ocean by rivers, drainage systems, sewage systems, or even the wind (Galgani et al. 2010).

The NOAA (2007) states that common household items, commercial goods, lost or abandoned fishing gear, and industrial products qualify as marine debris or litter. Introducing significant amounts of litter into the marine environment could also result from natural disasters like floods, landslides, hurricanes, and tidal waves (Thompson et al. 2005). Marine debris can be found on all kinds of

beaches. They can be found on both remote and popular recreational beaches worldwide (Jambeck et al. 2001; Sheavly 2007). Despite regional, national, and international efforts, there are signs that the marine litter issue is only getting worse (UNEP 2016). According to Sheavly (2007), UNEP (2009), NOAA (2010), and World Ocean Review (2010), marine debris is not just a problem for the environment, but it is also bad for business and aesthetics.

Depending on where it enters the water, marine litter can be classified as either ocean-based or land-based (NOAA 2007a; Sheavly 2007; UNEP 2016). According to Thompson et al. (2009), the main ocean-based sources include fishing, shipping, offshore mining and extraction, legal and illicit dumping at sea, abandoned, lost, or discarded fishing gear, and natural catastrophic events. Some significant terrestrial or land-based sources include industrial discharges, waste from dumps, fishing activities, tourism, discharge, and storm-related natural events (Allsopp et al. 2006; Mouat et al. 2010). According to estimates, land-based sources account for about 80% of marine debris pollution worldwide, with ocean-based sources accounting for the remaining 20% (CMC 2000; World Ocean Review 2010). As a result of their inability to be linked to a single or unique source, other items are categorized as general source items (Jambeck et al. 2015). Other elements, such as ocean current patterns, tides, climate, and proximity to urban areas, landfills, industrial and recreational areas, shipping lanes, and commercial

fishing grounds, affect the kind and quantity of marine debris found in open ocean areas or gathered along beaches and the ocean (UNEP 2016). Beach litter that accumulates along scenic shorelines and waterways detracts from those beaches' aesthetic appeal and satisfaction and harms tourism (Rockefeller 2003). Marine debris is unsightly and dangerous to other marine organisms and equipment. Discarded fishing equipment, ropes, and plastic bags can get caught around boat propellers and cause damage or get sucked into the boat's engines (UNEP 2009). Medical waste and other used medical equipment left around carelessly on beaches can carry diseases, even as broken glasses and other sharp objects pose obvious risks for beachgoers who may be barefooted (NOAA 2010). Beach debris can also destroy an organism's habitat by affecting water quality and physically harming delicate ecosystems. The effects and impacts of marine litter also extend to seagrass beds, coral reefs, and the benthic species that inhabit them. According to NOAA (2010), marine biodiversity may also suffer from marine litter. Numerous species unintentionally consume the waste after mistaking it for food. Discarded fishing nets, gear, lines, and other types of litter can entangle marine organisms, causing harm or even death (Sheavly 2007).

About 550 km of Ghana's coastline, which faces the Gulf of Guinea, is a very productive and long fishing line (EPA 2012). The country's abundant natural resources, which have a significant economic benefit, represent its productive nature (Amlalo 2007). According to Nunoo and Quayson (2003), plastics make up the majority of litter, a trend supported by several international studies (UNEP 1990; Topping et al. 1994; Hoagland and Kite-Powell 1997; CMC 2000; UNEP 2009).

This study's main objective is to evaluate the amount of litter on the beaches at Sakumono and La Pleasure. The

specific objectives are (i) Identifying the sources of litter at Sakumono and La Pleasure Beaches is the first of the specific goals. (ii) Analyze the amount and composition of the beach debris at Sakumono and La Pleasure Beaches. (iii) Assess the spatial variation in the amount of trash at Sakumono and La Pleasure Beaches.

MATERIALS AND METHODS

Study area

Two beaches in Ghana, Sakumono Beach, and La Pleasure Beach, were chosen for this study (Figure 1). About 12 kilometers separate the two beaches. Apart from these two beaches fulfilling the criteria for beach monitoring mentioned earlier (Opfer et al. 2012), they were chosen because La Pleasure Beach is a managed beach and Sakumono is a free and open beach. Therefore, an area of about 550 meters separates the two beaches.

People from the Sakumono township use the Tema Metropolis' Sakumono Beach as a place to land their catch of fish. Small-scale, artisanal farming and fishing are the main livelihoods of the Sakumono people. Sakumono Beach is close to the Sakumono II Lagoon, a Ramsar site, because of the wide variety of bird species it supports (Nunoo and Quayson, 2003). The sandy Sakumono Beach, guarded by a sea defense structure, is a popular destination for tourists from near and far. The Regional Maritime University is located on the beach's right side, and the Tema Port is on its left. Sakumono Beach is a low-lying stretch of sand with a slight incline in Accra's semi-arid coastal region. The beach has fine to coarse sand grains and receives an 800 mm average of rain annually over two rainy seasons.

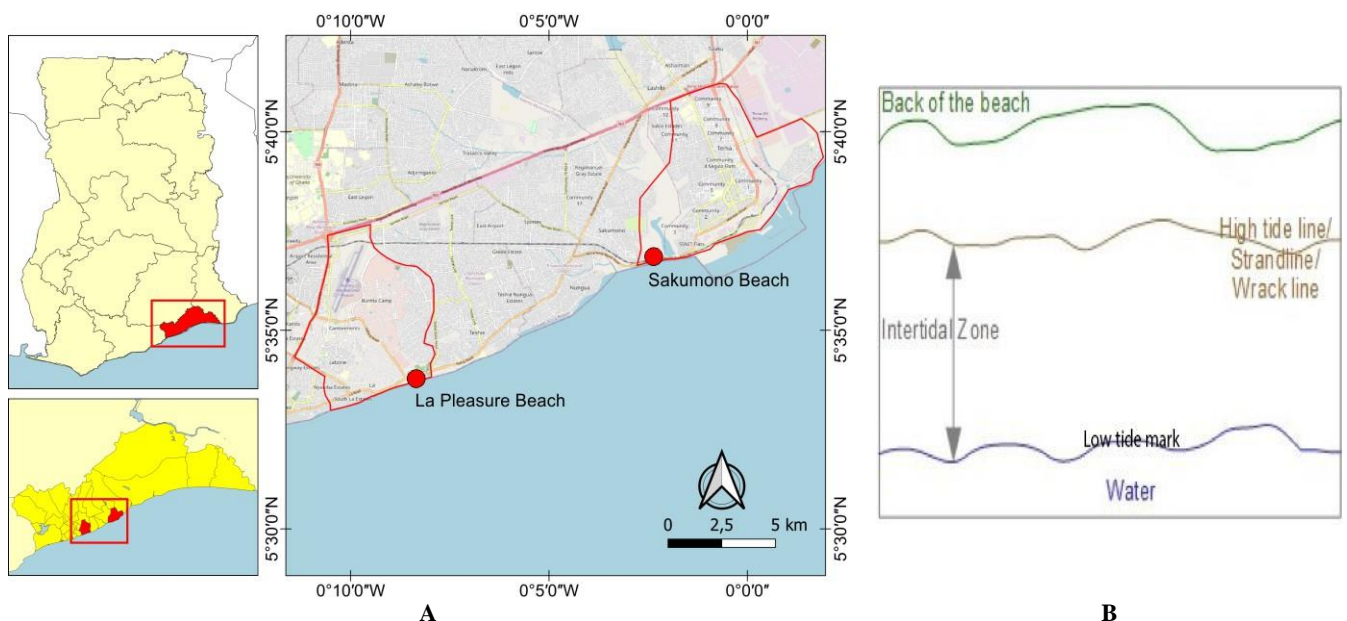


Figure 1. Map of Ghana showing study sites at Sakumono Beach and La Pleasure Beach. B. Diagram showing water level for sampling

In the La Dade-Kotopon Metropolis, the La Pleasure Beach is also situated at La Pleasure, off the Accra-Teshie/Nungua Road. The beach is one of Accra's busiest beaches and receives both domestic and international visitors every day of the week (Tsagbey et al. 2009). La Pleasure Beach is a sandy beach with fine to coarse sand grains; just like Sakumono Beach, La Pleasure Beach has a moderate slope.

The Greater Accra area includes both beaches. However, the Greater Accra region is the smallest, with a total land area of 3,245 km² and a population of 4,010,054, or 16.3% of Ghana's population (GSS, 2014). The coastline of the Greater Accra area, which stretches from Kokrobite in the west to Ada in the east, is about 225 km long.

As Sakumono is an open-access beach with unrestricted entry, these two beaches were chosen for the survey. Therefore, entering Sakumono beach is free, and there are no restrictions on what revelers can bring onto the beach. Contrarily, entry to La Pleasure Beach is more expensive and has more restrictions.

Data collection and analysis

A week before the survey began, a preliminary survey was conducted at the two beaches to pick the stations and get a sense of the beaches. During the preliminary survey, the two beaches were divided into five surveying transects measuring 100 x 10 m (1,000 m²). The Garmin Etrex 10 GPS was used to georeference the points. The coordinates were recorded and added to the GPS as entry points every 100 meters. This was done to act as a sampling frame for random selection during each visit. Furthermore, to correspond with the two beaches surveyed, the 100 x 10 m transects were designated La1-La5 and Sak1-Sak5. The edge of the transect was made to start at the low tide mark and follow the shoreline. The preliminary survey was also used to clean the beaches of any debris that had already accumulated there.

From January to April 2019, on the same day (Thursday), the beaches were surveyed twice a month at low tide, typically between 0 m and 0 m tidal levels. A 1,000 m² transect at each beach was randomly chosen for surveying during each survey event. Every transect had an equal chance of being chosen because pieces of paper with the codes for the different transects were folded. The transect's entire litter was gathered into trash bags with labels and taken outside for sorting and weighing. Hands were protected by latex gloves while selecting the litter. Any litter sticking out of the sand was carefully removed; if it was torn in the removal process, it was disregarded. That was done to ensure no litter within transect was missed and to avoid those that were deeply buried. Also, to prevent the phenomenon where a portion of the litter is buried and might not be accounted

Laboratory analysis

The litter was divided into distinguishable groups in the laboratory after sorting and arranging it. The litter was air-dried before being counted and electronically weighed to the nearest kilogram. This was done to obtain the litter's actual weight and remove as much sand and water as

possible. Each bag was weighed before the contents were sorted and categorized following the Master List of categories in the guidance document (TGML/JRC) (Galgani et al. 2013b). The basic material types are as follows, with a total of thirty-nine (39) subcategories: (i) plastic, (ii) metal, (iii) rubber, (iv) glass/ceramics, (v) natural products, and (vi) miscellaneous. The litter was further categorized as either ocean-based or land-based based on the classification by Barr (2000).

Data analysis

The checklists were converted to an electronic format (Excel 2019, Microsoft) to calculate statistical parameters and weight percentages and to register the count of all items across all beaches. Then to perform a t-test and Analysis of Variance (ANOVA) on the data were to examine if there were any significant differences between the two beaches' litter.

RESULTS AND DISCUSSION

Results

A total of 2,697 items were gathered from the Sakumono and La Beaches throughout the study (Table 1). The combined weight of the litter from both sites during the survey was 50.07 kg (Table 2). While 18.28 kg of litter was collected from La Pleasure, it comprised 36.51% of the total amount of litter surveyed. The weight of litter collected from Sakumono Beach was 31.79 kg, which accounts for 63.49% of the total weight of the litter surveyed.

Sakumono had an average of 209 litter per week, with a mean weight of 3.97 kg and an average litter size of 2.86 kg. The average number of litter per week at La Pleasure Beach was 129, the average weight per week was 2.28 kg, and the average weight per week was 0.92 kg (Table 3).

Plastics were found to be the most abundant in number and weight. For both beaches, plastics comprised 65.53% (Figure 2) by weight at 32.81 kg and 72.56% (Figure 3) composition by number or quantity at 1,975 items.

At the various beaches, this trend of composition remained constant. Plastics were the most prevalent material at Sakumono in terms of weight (Figure 4) and number (Figure 5), each at 67%. Plastics were found to be the most prevalent type of litter at La Pleasure Beach, both in terms of weight and quantity (Figures 6 and 7).

By numbers, water sachets were the most abundant in terms of plastics (Figure 8). By numbers, the water sachets made up 22% of the plastics collected from both beaches (Figure 10). Although water sachets were abundant in numbers, toys weighed far more than them (Figure 9). Toys made up about 39% of the total weight of plastics (Figure 11). Regarding numbers, toys were the least, at only 13 (Figure 8). Twenty-five (25) of the thirty-five (35) litter types collected during the survey were identified as land-based marine litter, with only three (3) litter types identified as ocean-based (Table 4).

Table 1. List of litter items and numbers for both beaches

Item	Number	% Number
Plastics		
Bottles	282	10.4560623
Cutlery	67	2.48424175
Cigarette lighters	19	0.70448647
Cigarette butts	205	7.60103819
Styrofoam	160	5.93251761
Cups	20	0.7415647
Water sachet	424	15.7211717
Bags	320	11.8650352
Caps/lids	125	4.63477938
Toys	13	0.48201706
Synthetic rope	65	2.41008528
Fishing net	14	0.51909529
Strapping bands	17	0.63033
Crates/containers	23	0.85279941
Diapers	34	1.26065999
Sanitary towel/tampon	32	1.18650352
Straws	137	5.07971821
Metals		
Cans	87	3.22580645
Other pieces of metals	23	0.85279941
Crown corks	198	7.34149055
Rubber		
Balloons	46	1.70559881
Slippers	31	1.14942529
Condoms	56	2.07638116
Gloves	2	0.07415647
Tires	4	0.14831294
Pieces of foam	30	1.11234705
Glass/ceramics		
Bottle	34	1.26065999
Pieces	32	1.18650352
Natural products		
Processed wood	14	0.51909529
Rope	15	0.55617353
Paper/cardboard	32	1.18650352
Juice carton	94	3.4853541
Miscellaneous		
Clothing/rags	27	1.00111235
Shoes	12	0.44493882
Bags	3	0.11123471
Total	2697	100

Table 2. List of litter items and weights for both beaches

Item	Weight (kg)	% Weight
Plastics		
Bottles	2.45	4.89981385
Cutlery	0.24	0.48171317
Cigarette lighters	0.00	0.00796864
Cigarette butts	0.05	0.09007158
Styrofoam	0.85	1.69358529
Cups	0.12	0.2396583
Water sachet	4.03	8.04453011
Bags	1.28	2.55635515
Caps/lids	0.03	0.04992881
Toys	12.70	25.3658334
Synthetic rope	4.49	8.97021027
Fishing net	3.18	6.35533856
Strapping bands	0.02	0.03734675
Crates/containers	0.28	0.55121408
Diapers	2.34	4.66494872
Sanitary towel/tampon	0.74	1.46990421
Straws	0.03	0.05472198
Metals		
Cans	2.18	4.3438066
Other pieces of metals	1.24	2.48046336
Crown corks	0.26	0.51406704
Rubber		
Balloons	0.01	0.0183738
Slippers	0.19	0.37147036
Condoms	0.02	0.04473622
Gloves	0.00	0.00119829
Tires	4.30	8.58775558
Pieces of foam	0.18	0.35948744
Glass/ceramics		
Bottle	2.04	4.07419102
Pieces	1.60	3.19544394
Natural products		
Processed wood	0.00	0
Rope	0.00	0
Paper/cardboard	0.12	0.23646285
Juice carton	1.30	2.59070617
Miscellaneous		
Clothing/rags	1.03	2.04907842
Shoes	0.23	0.46493709
Bags	2.57	5.13467897
Total	50.07	100

Table 3. Mean weekly weights and number of litter for both beaches

Beach	Mean weekly weight (kg)	Mean weekly number
Sakumono	3.97 ± 2.86	209 ± 92.66
La Pleasure	2.28 ± 0.92	129 ± 30.63

Table 4. Sources of litter items (Barr 2000)

Sources	Types
Land-Based	Plastic Bottles, Straws (plastic), Plastic bags, caps/lids, Glass bottles, Water sachets, Balloons, Metal cans, Cigarette packaging/ wrappers, Crown corks, Styrofoam packs, plastic cutlery, cigarettes butts, shoes, Clothing/textile, condoms, diapers, Toys, Plastic cups, rubber slippers, Bags, sanitary towels/tampons, Newspaper/Magazine pieces, juice cartons.
Ocean/Waterway-Based	Fishing net, Rope, Strapping bands.
General	Nails, Cardboard, Glass, Metal, Plastic containers, Styrofoam, Pieces of foam, and Car tires.

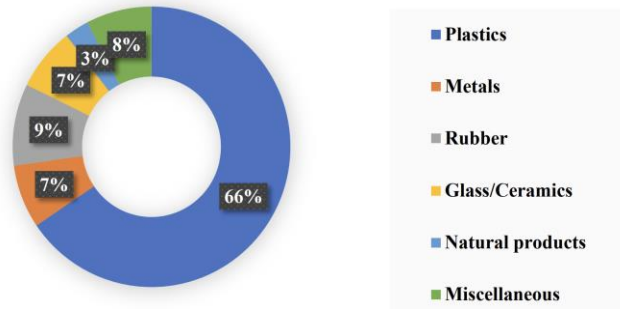


Figure 2. Composition of total litter by weight at both beaches

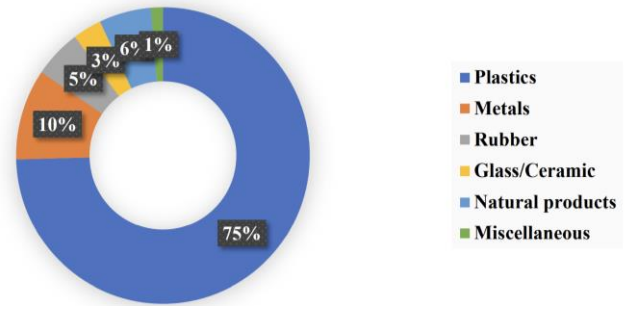


Figure 5. Composition by number of litter at Sakumono

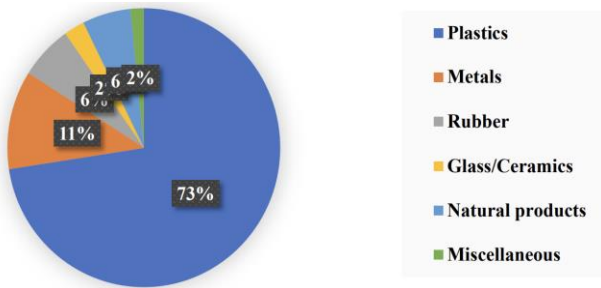


Figure 3. Composition of total litter by number at both beaches

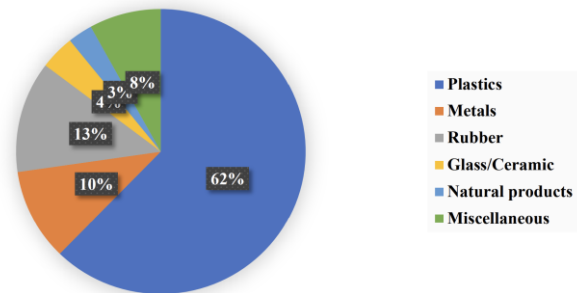


Figure 6. Composition by weight of litter at La, Ghana

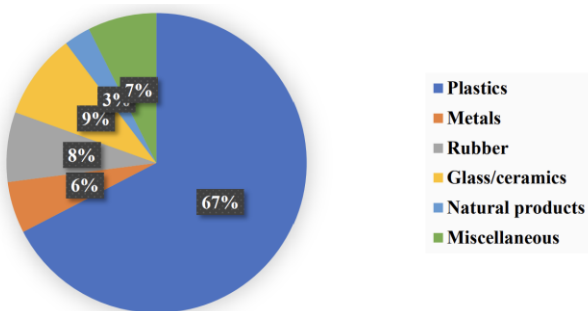


Figure 4. Composition by weight of litter at Sakumono, Ghana

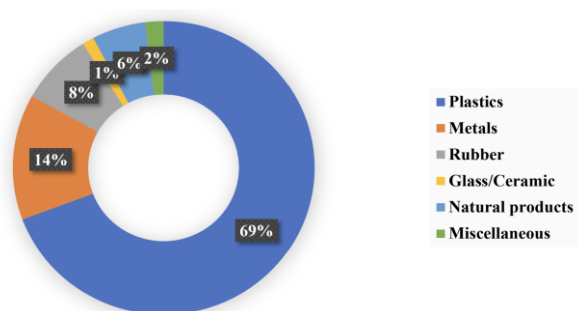


Figure 7. Composition by number of litter at La, Ghana

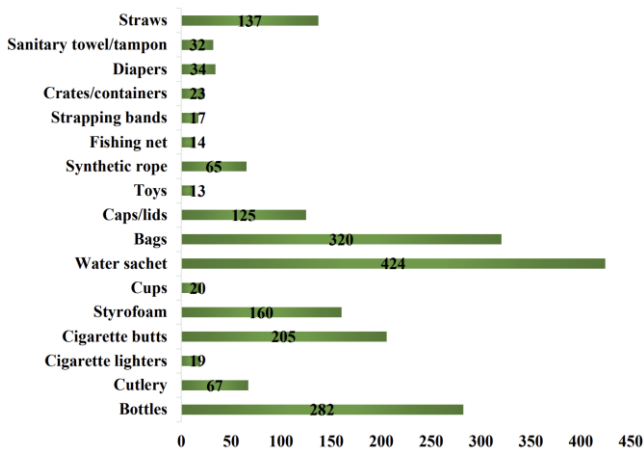


Figure 8. The abundance of the most dominant litter type (Plastics)

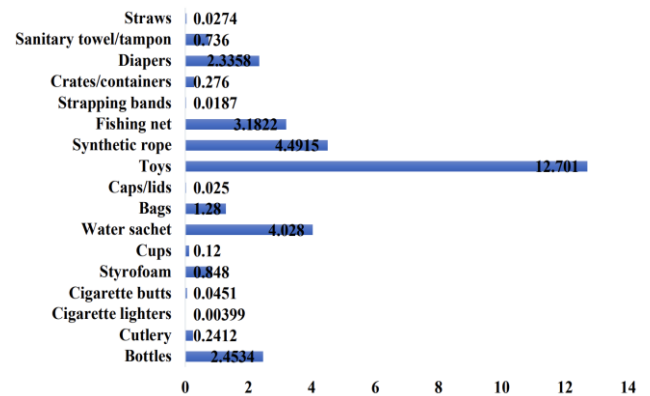


Figure 9. Weights of most dominant litter types

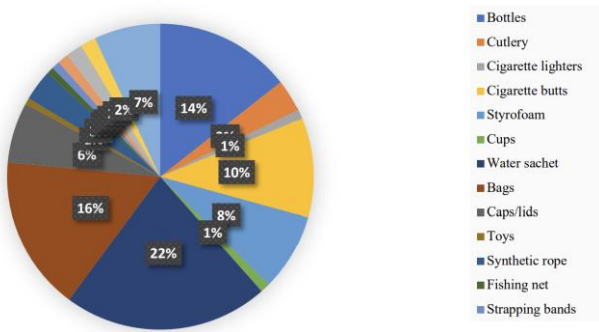


Figure 10. Percentage by number of plastics at both beaches

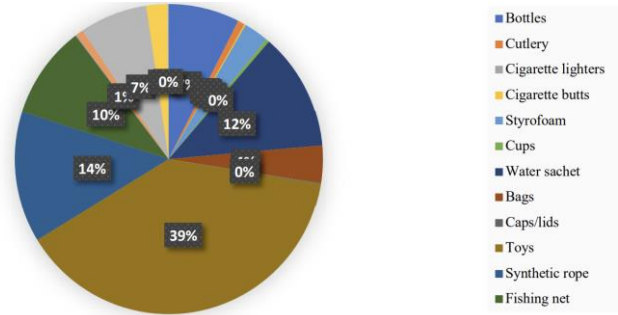


Figure 11. Percentage by weight of plastics from both beaches

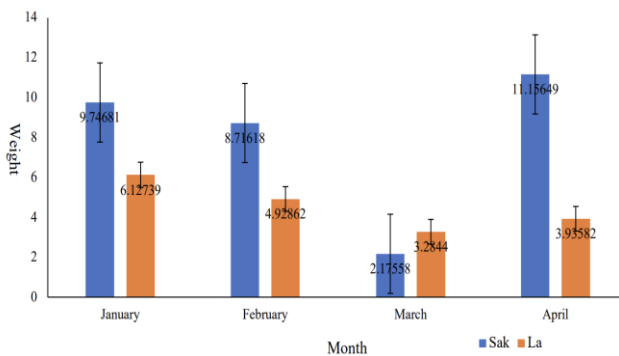


Figure 12. Monthly variation by weight

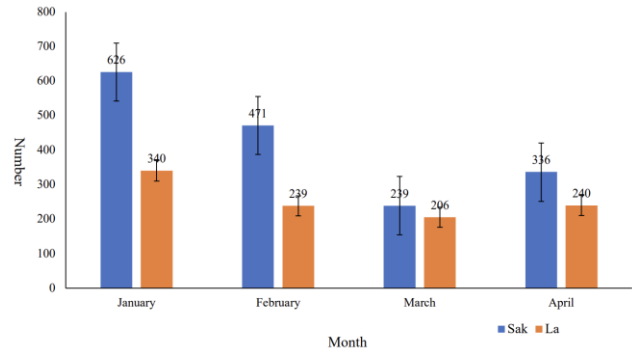


Figure 13. Monthly variation by number

Table 5. ANOVA Table for spatial variation in the amount of litter at Sakumono and La Pleasure Beaches, Ghana

Source of variation	SS	df	MS	F	P-value	F crit
Between Groups	52326.125	1	52326.125	9.0298544	0.02385469	5.98737761
Within Groups	34768.75	6	5794.79167			
Total	87094.875	7				

The weight and quantity of trash at the two beaches decreased over the survey's four months (Figures 12 and 13). However, this pattern changed in the fourth month, which was April. Over the previous month, there was an overall increase. However, Sakumono Beach recorded the highest weight in April (Figure 12). The survey as a whole gave this the highest weight. A total of 11.16 kg of litter was gathered at Sakumono Beach in April, accounting for about 22% of the total litter gathered throughout the survey (Figure 12). The litter with the smallest weight was found in March. This occurred at Sakumono Beach (Figure 13).

The density of trash at Sakumono and La Pleasure Beaches was 0.418 items/m² and 0.256 items/m², with monthly averages of 418 and 256 items, respectively. There was a p-value of 0.02 when using an ANOVA with a 95% confidence level (Table 5).

Discussion

Types and quantities of marine litter

A total of 2,697 pieces of marine debris totaling 50.0713 kg were gathered for this study. This number was lower than Van Dyck et al. (2016), 18.241 and 297.59 kg

total. The sheer volume of beaches surveyed might explain this disparity. Four beaches were surveyed for that particular study (Sakumono, Mensah Guinea, La Pleasure, and Korle Gonno). The beaches at Sakumono and La Pleasure were the only two to receive surveys for this study. The length of the study may have also contributed to the variation in litter amounts. In contrast to Van Dyck et al. (2016), who conducted their study over sixteen weeks, the current study took place over eight weeks. The methodology employed may also supporting for the weight difference. Moreover, to determine the current study's actual weight as accurately as possible, the litter was air-dried and removed as much sand as possible. Unfortunately, the study did not go into detail about this. Both the current study and the one were carried out within 1,000 m² transects, but in the current study, each survey was carried out by randomly selecting a transect, ensuring that every portion of the entire shoreline had an equal chance of being surveyed.

During the sampling, various litter items were discovered and gathered from the beaches, with drinking water sachets being the most prevalent. People's faith in the

water from their home faucets appears to have declined over time. The fact that people are generally aware of how polluted the water bodies that supply the water that flows through our faucets may be the cause. Given the perception that sachet water is purer than water from the faucets, trust has been placed in it. However, not every home has running water, so people turn to sachet water for any needs. This increase in demand for sachet water has also resulted in the emergence of numerous sachet water manufacturing factories and, as a result, an increase in the number of water sachets, particularly in urban areas. Then came plastic bottles, then plastic bags, and drinking water sachets. This pattern resembles the most typical things gathered during numerous shorelines and/or underwater clean-up operations. The International Coastal Clean-up report (International Ocean Conservancy 2009) lists some items as plastic bags, plastic beverage bottles, food wrappers/containers, cigarettes, or cigarette filters.

In this study, it was discovered that plastics were the most prevalent and plentiful kind of litter. This result is comparable to other surveys conducted on beaches in South Africa (STAP 2011b) and a few other carefully chosen European beaches (OSPAR 2007). The percentages of plastics found at the Sakumono and La Pleasure Beaches (66% by weight and 73% by number) also favorably contrast with those found by Van Dyck et al. (2016). This supports the claim that, globally, plastics account for 60 to 80% of all marine litter collected (Derraik 2002; STAP (2011a). The nature of anthropogenic wastes has changed significantly over the last 30 to 40 years due to the introduction of plastics and synthetic materials in recent decades (Sheavly 2005).

Plastics, in general, are strong materials that resist natural biodegradation. As a result, when plastic enters the marine environment, it does not readily and easily degrade; rather, it is only torn into pieces by abrasion against rocks and other hard surfaces as well as by wave action (Allsopp et al. 2006). Since plastics are light and float when they enter the marine environment, they can travel great distances on currents and are dispersed widely throughout the oceans (Derraik 2002; Sheavly 2005). The litter weights, which were recorded, reflect the lightness of the plastic products. Water sachets were the most numerous but among the lightest items in terms of weight due to their thickness.

Ghanaian beaches are still littered with plastic waste. That demonstrates the pervasive use of plastics in daily tasks like product packaging and the eventual improper disposal of these plastic items. According to reports, cigarette butts are one of the primary sources of marine debris on beaches in Brazil, Spain, and the US (Slavin 2011). The current study revealed a comparable pattern. Cigarette butts were the fourth most abundant item after plastic bottles, water sachets, and bags, which clearly indicated this. That suggests the beaches receive a lot of recreational traffic and are popular smoking spots. That further indicates how many people who visit the beaches are a smoker.

Sources of litter identified

According to this study, 25 of the 35 litter items gathered during the survey were land-based (Table 4). That is consistent with the claim made in the literature that roughly 80% of the types of litter found on beaches come from land-based sources (GESAMP 1991; NOAA 2007a,b; Sheavly 2007; World Ocean Review 2010; USEPA 2012). This also fits with research done on the Hawaiian Islands and the West Coast of the United States of America (Sheavly 2007). The beach's location, ease of access, popularity as a tourist destination, and human behavior are all possible explanations for the high amount of land-based litter observed. A contributing factor to the large amounts of land-based litter may be the beach's proximity to inland inflow. That might cause inland waste to flow to the beach through rivers and lagoons. Again, based on the findings of Gregory and Ryan (1997), ocean-based litter accounted for the least amount of litter in origin, supporting the least amount of ocean-based litter recorded for this study. This area has few significant shipping routes because Tema is home to the only significant port, which may account for the low levels of ocean-based litter.

The spatial and temporal abundance of marine litter

By weight and count, Sakumono Beach typically had the most litter, followed by La Pleasure Beach. This pattern may be explained by the open nature of Sakumono Beach, primarily frequented by locals who are either tourists or partygoers and everyone who does not have to pay for entry. Additionally, there are no restrictions on what revelers can bring onto the beach; anything is allowed. Additionally, Sakumono Beach has only rudimentary waste management. Contrarily, entry to the managed La Pleasure Beach is controlled. Nearly every week, tourists from other countries visit this beach. Regarding waste management, La Pleasure Beach is also run better. The beach vendors clean their respective sections, but the establishment's management oversees general cleaning.

The amount of litter surveyed at both beaches yielded a p-value of 0.02 at an alpha value of 0.05. That suggests the amounts of trash found at the two beaches are noticeably different. According to the analysis, Sakumono Beach was more polluted than La Pleasure Beach. The statistical analysis backs up the observation and demonstrates how La Pleasure Beach has been managed. This contrasts favorably with the survey conducted by Van Dyck et al. (2016); Sakumono Beach had more trash than La Pleasure Beach.

Sakumono recorded a higher amount of litter by count but a lower amount by weight in March. This phenomenon may be explained by the fact that this month has less litter than the others. In the first week of March, for instance, more condoms and crown corks were counted than in any other week of the month. On 7 March, the day following the 6 March holiday, a survey for that week was also conducted. Due to the celebratory activities, particularly during the first week, more trash was anticipated to accumulate at the two beaches in March. But that wasn't the case. The following month saw more of a rise. That may result from human activity leaving trash on the beach and the effect of currents moving the trash from other

locations to the beach. Every day, the tides rise and fall, moving the objects carried by the currents off the shore onto the shore as they do so. At Sakumono, the litter weight was highest in April and lowest in March.

Over the eight weeks, there was generally a decline in the litter trend, which may have been due to frequent beach clean-ups. However, Sakumono Beach, and the first month had the highest litter levels. This observation may be explained by the fact that celebrations and festivities continued from December (the Christmas season) through January (the New Year's celebrations).

In conclusion, plastics were the most prevalent litter at both beaches, especially drinking water sachets, followed by plastic bottles and bags. This shows the widespread use of plastics in everyday activities like packaging goods and the eventual improper disposal of these plastic items. On the other hand, in terms of quantity, most of the litter examined was made of plastic. Marine litter from land-based sources was the most prevalent during the survey, which is also suggestive of the fact that the majority of the litter generated is from activities in inland and coastal areas. From January to March, the litter collection showed a general decline over the weeks and then a sharp uptick in April. However, according to this survey, Sakumono Beach was dirtier than La Pleasure Beach. From this study, it can be inferred that La Pleasure Beach is less polluted than Sakumono Beach, with 18.28 kg of weight and 1,025 litter items compared to Sakumono Beach's 31.80 kg of weight and 1,672 litter items. That may be because La Pleasure Beach is managed and efforts are made to lessen litter on the beach.

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