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Chromodoris magnifica photo by Yuneysa Garcia

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Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

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Abstract:

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Proceeding:

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New records of nudibranchs and a sacoglossan (Gastropoda: Heterobranchia) from Sempu Strait, Indonesia

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Abstract. *Andrimida A. 2022. New records of nudibranchs and a sacoglossan (Gastropoda: Heterobranchia) from Sempu Strait, Indonesia. Indo Pac J Ocean Life 6: 1-9.* This study reports the additional records of fourteen heterobranch sea slug species from Sempu Strait, East Java, Indonesia, in which thirteen species belong to the Nudibranchia order, and one species belongs to the Sacoglossa order. These species belong to seven families: Plakobranchidae (1 species), Polyceridae (1 species), Discodorididae (2 species), Chromodorididae (7 species), Flabellinidae (1 species), Eubranchidae (1 species), and Facelinidae (1 species). All of these species are recorded for the first time from the Sempu Strait. There are two species that only could be identified to its genus, which are *Chromodoris* sp. and *Eubranchus* sp. This study also found additional record of *Plocamopherus imperialis* Angas, 1864 on the tropical waters, where this species formerly believed only exclusively distributed along the subtropical waters of Eastern Australia and Northern New Zealand. Combined with the previous study on Sempu Strait, to date, 59 species of heterobranch sea slug have been reported and recorded in this area. Species identification was conducted by carefully examining the morphological features of each specimen encountered during the surveys.

Keywords: Distribution, nudibranch, sacoglossan, sea slug

INTRODUCTION

Nudibranchs is one of the most colorful tropical reef dwellers that is very attractive for divers and underwater photographers alike (Jensen 2013). This group of animals belongs to the gastropod class under the Mollusca phylum (Burn 2015). Nudibranchs and their related molluscs are also classified under the opisthobranchs group which include the Order Cephalaspidea P. Fischer, 1883; Sacoglossa Ihering, 1876; Anaspidea Fischer, 1883; Nudibranchia Cuvier, 1817; Pleurobranchomorpha Pelseneer, 1906; and Umbraculida Odhner, 1939 (Nimbs and Smith 2017). While the term Ophistobranchia is widely used to address this certain group of shell-less gastropods, recent studies group them into the Heterobranchia subclass (Haszprunar 1985) as there is any precise distinction between the opisthobranchs and the pulmonates (Burn 2015). The epicenter of heterobranch sea slug diversity is located around the Indo-Pacific area, which holds around 3,000 species of heterobranch sea slug, where the highest diversity is concentrated on the Western Pacific, which borders Indonesia, Philippines, and Papua New Guinea (Gosliner et al. 2019). In Indonesia alone, the overall heterobranch sea slug's species number is still uncertain, and might indicate that it holds a higher diversity than the areas adjacent to it (Gosliner et al. 2019). This case might be caused by the surveys that haven't been evenly distributed on every part of Indonesian Waters. Recent studies about heterobranch sea slug's diversity are still heavily concentrated on the Eastern Part of Indonesia, mainly the Sulawesi, Maluku, and Ambon (Kaligis et al. 2018; Yonow and Jensen 2018; Kristiana et al. 2019; Ompi et al. 2019a,b; Undap et al. 2019).

Sempu Strait, East Java, Indonesia is a narrow strait, on which it only extends for less than 350 m at its narrowest points. This strait separates the Java mainland from Sempu Island. The island itself has area around 877 hectares and has been proclaimed as a "Nature Monument" since the Dutch Colonial Period through the *Besluit van den Gouverneur Generaal van Nederlandsch Indie van* 15 *Maart* 1928, No. 46 (Stsbl. 69) (Appelman 1940). The underwater around Sempu Island is known to hold a diverse marine ecosystem, from mangroves and seagrass meadow, to the coral reef (Luthfi et al. 2016; Semedi and Luthfi 2019). These diverse ecosystems provide the necessity for the heterobranch sea slug to thrive, which they are known to consume algae, sponges, coral polyps, bryozoans, and hydroids that are found in abundance when sustained by such diverse ecosystem (Purba et al. 2013). Small islands often could hold their own unique diversity of flora and fauna. However, small islands are also facing increased anthropogenic threats that risk the diversity on the surrounding area (Nimbs et al. 2020). This factor, combined with the short life of most heterobranch sea slugs which usually live less than 12 months, might affect the existence of this group of animals which is already regarded as spatio-temporary rare (Nimbs and Smith 2017).

Previous study on heterobranch sea slug's inventory on Sempu Strait found 45 species overall, on which 35 species of them belong to the Nudibranchia order, 6 species belong to the Aplysiida order, 2 species belong to the Cephalaspidea order, and 2 species belong to the

Sacoglossa order (Andrimida 2021). This study is a continuation of the survey before, in which the aim of this study is to describe additional heterobranch sea slug species found from a further survey conducted from August 2019 to December 2021. Thus, with the annexation of the previous study, this study purposes to provide documentation on the diversity of the heterobranch sea slug taxa at Sempu Strait.

MATERIALS AND METHODS

Study area

Sempu Strait, East Java, Indonesia is a 3,5 km long body of water that separates the Sempu Island Nature Reserve from Java mainland. The gap of this strait is less than 400 meters at its narrowest point. The underwater topography of this trait is dominated by patched fringing reefs on both sides of the strait. The shores are usually steep at 0 - 10 meters depth, where the deeper part of the strait is dominated by sand and silt or rocky walls. Among the nine dive sites surveyed during this study, only four dive sites come up with new records for this area (Figure 1). Those sites are Tiga Warna (8°26'22.17"S, 112°40'39.95"E), Rumah Apung (8°26'14.32"S, 112°40'47.95"E), Teluk Semut (8°26'20.6961"S, 112°40'55.9232"E), and Stumbut (8°26'34.23"S, 112°40'45.13"E).

Survey method

Surveys were conducted using SCUBA at nine dive sites on Sempu Strait between August 2019 and December 2021. This survey was conducted as a continuation of previous study on heterobranch sea slug inventory. Roving diver survey methods were conducted over the reef areas, as well as the soft-bottomed and rocky habitats adjacent to them. Roving diver technique is proven to be successful in surveying cryptic marine fauna that has unusual occurrence and usually shows up in a little number (Munro 2005; Mantiri et al. 2021). This survey method is also proven to be successful as my previous studies on Sempu Strait (Andrimida and Hermawan 2019; Andrimida 2021) also used this method. Thus, this survey method has been consistently conducted in order to search and discover the potential of new heterobranch sea slug species records in this area.

Most of these surveys are conducted during daytime, with accidental and sporadic nighttime surveys also done during the time period. The data collection is conducted by carefully documenting each species using underwater camera that capable of shooting in macro. Each specimen encountered is examined closely and photographed for identification purposes. Detailed photographs of the specimen were identified based on their external morphology compared to relevant literature (Colin and Arneson 1995; Yonow 2008; Burn 2015; Gosliner et al. 2019). Every heterobranch sea slug identified during this study has its taxon validity verified with the World Register of Marine Species.

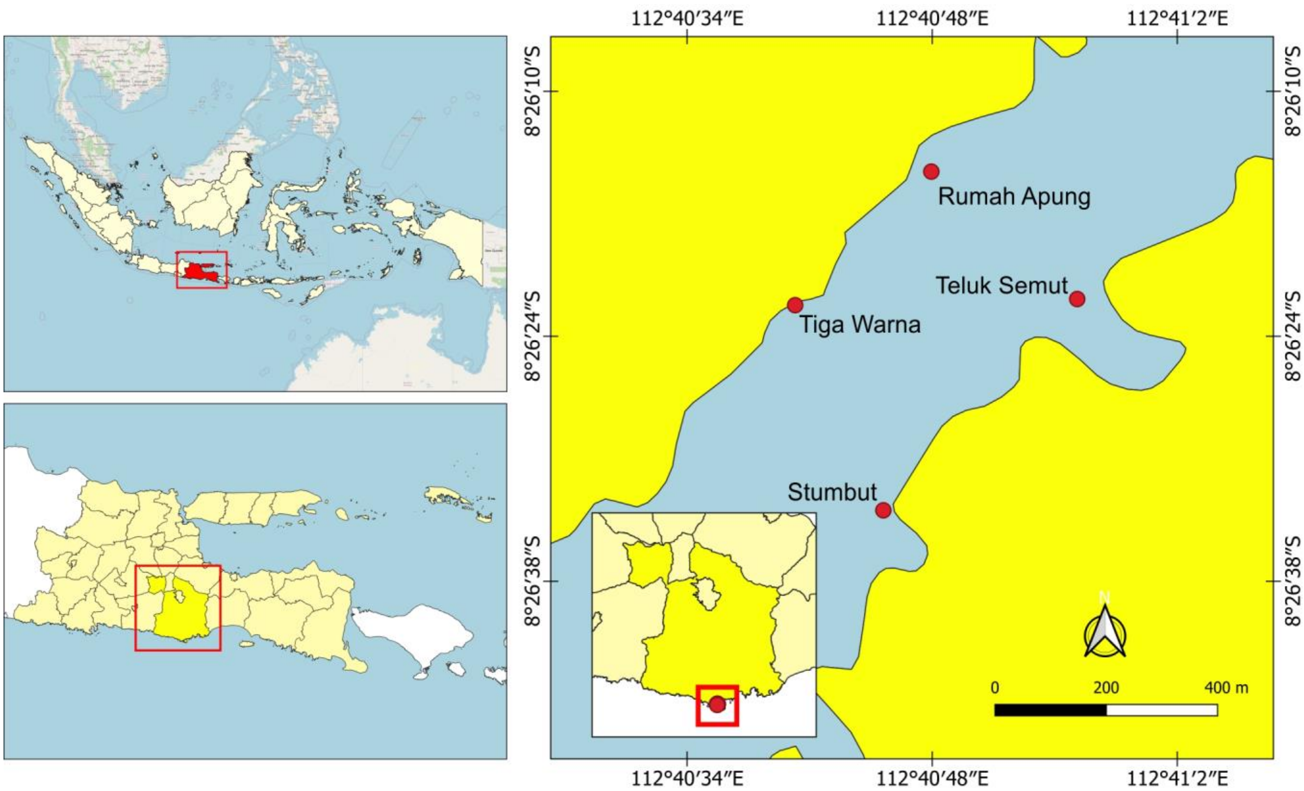

Figure 1. Location of Sempu Strait, East Java, Indonesia indicating the survey sites from this study where sites with new record(s) highlighted with black dots, while the sites that surveyed without any new record marked with white dots

RESULTS AND DISCUSSION

A total of fourteen species were recorded and identified in this study, in which all of them are new records in this area. These fourteen species consist of one sacoglossan sea slug species and thirteen nudibranch species. These species belong to seven families, which are Plakobranchidae (1 species), Polyceridae (1 species), Discodorididae (2 species), Chromodorididae (7 species), Flabellinidae (1 species), Eubranchidae (1 species), and Facelinidae (1 species). Hence, combined with all of the previous studies (Andrimida 2021), there are 59 species of heterobranch sea slug have been recorded from Sempu Strait, which consists of 48 nudibranchs species, 6 aplysiids sea hares, 2 cephalaspids, and 3 sacoglossan sea slugs species. Each species that has been identified in this study is presented here along with the diagnostic features, general geographic distribution with its recent distribution on Indonesian Waters if available. In addition, the photograph of the specimens found on this survey is also provided.

Species accounts
Class Gastropoda Cuvier, 1795
Subclass Heterobranchia Burmeister, 1837
Superorder Sacoglossa von Ihering, 1876
Family Plakobranchidae J. E. Gray, 1840
Genus *Thuridilla* Bergh, 1872
***Thuridilla gracilis* Risbec, 1928**
Photographic record

Figure 2.A. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, one individual was photographed crawling on open rocky substrates at 5 meters depth. Size approximately less than 2 cm.

Description

Long and slender-bodied sacoglossan. While moving, the notum is covered by the fold of parapodia. The mantle is greenish-black with white longitudinal lines and occasional speckles on its side. Parapodial margin on the dorsal side of the body bordered with thin orange stripe. Such orange band is also present on the tip of each rhinophore and the tip of the tail. When alerted, it opens the parapodia and shows its bluish back.

Remarks and distribution

The morphological description and coloration of the specimen stated above are in agreement with the description of this species by Yonow (2012), Gosliner et al. (2019), and Undap et al. (2019). This species is commonly seen in shallow waters, crawling in open spaces or under coral rubbles (Gosliner et al. 2019). Widely distributed in the Indian and Western Pacific Ocean (Gosliner et al. 2019), also reported as far as Lizard Island Australia and Okinawa, Japan (Furfaro et al. 2014). Indonesia: Lembeh Strait (Ompi et al. 2019a,b), Sangihe Islands (Undap et al. 2019) Bangka Archipelago (Papu et al. 2020), Bunaken (Fisch et al. 2017).

Order Nudibranchia Cuvier, 1817
Family Polyceridae Alder & Hancock, 1845
Genus *Plocamopherus* Rüppell & Leuckart, 1831
***Plocamopherus imperialis* Angas, 1864**
Photographic record

Figure 2.B. Rumah Apung, Sempu Strait, East Java, Indonesia, September 2021, one individual was photographed among green algae near the surface at low tide. Size approximately 8 cm.

Description

The body is covered with red mosaic, bordered with fine lighter red or orange lines. The anterior part of the head is flattened and bordered with small papillae. A series of paired papillae were also found down the upper edge of the mantle. Some of these papillae have a large bulb that flashes when disturbed. The tail is elongated with acute tip, but could be compressed into a paddle-like shape.

Remarks and distribution

Nudibranchs from the Genus *Plocamopherus* are known to be able to flatten their tail into a paddle-like shape, where it could use its tail for short locomotion (Morley and Hayward 2015). Inhabit intertidal rocky shores (Nimbs and Smith 2017; Gosliner et al. 2019). Known only from Eastern Australia and Northern New Zealand (Gosliner et al. 2019). Recorded in Northern Territory, Queensland, New South Wales, Victoria, Tasmania, Lord Howe's Island (Nimbs and Smith 2017) and Christmas Islands (Tan and Low 2014). It is also recorded in Numazu, Shizuoka, Japan (GBIF 2021) where it may represent a distinct species (Gosliner et al. 2019). Possibly first record from Java's Southern Sea and Indonesia.

Family Discodorididae Bergh, 1891
Genus *Halgerda* Bergh, 1880
***Halgerda elegans* Bergh, 1905**
Photographic record

Figure 2.C. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, one individual was photographed among algae and sponge-covered rock at 5 meters depth. Size approximately less than 0.8 cm.

Description

Body rigid and firm, almost oval-shaped. The body profile is high, with a series of interconnected ridges arranged on a reticulated pattern. It has no tubercles at the meeting point of the ridges. Body is whitish-translucent colored, while the ridges are orange-yellow. Around the edge of the mantle, there is a series of evenly-spaced and short black lines. Such lines are also present on the base of each rhinophore, while the rhinophores are white with black on their tip.

Remarks and distribution

This species has a similar appearance with *Halgerda albocristata* Gosliner & Fahey, 1998 where both has notum translucent and covered with yellow color and radiating black lines on the edge of the mantle (Gosliner and Fahey 1998). The difference between the species could be observed by examining the tip of the rhinophore, where *H. albocristata* has white-tipped rhinophore, as well as radiating white line along its notum (Gosliner et al. 2019). Inhabit open reefs and rocky substrates (Gosliner and Fahey 1998; Gosliner et al. 2019). Widely distributed on the Western Pacific Ocean (Gosliner et al. 2019). Initially described from Pulau Gunung Api in Banda, Indonesia (Bergh 1905), later also recorded from Papua New Guinea and Okinawa (Gosliner and Fahey 1998).

***Halgerda wasinensis* Eliot, 1904**

Photographic record

Figure 2.D. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, two individuals photographed crawling on open dead coral rubble substrates at 5 meters depth. Size approximately 5 cm.

Description

Body rigid and elongated oval-shaped. The body profile is high, with a complex network of sharp-angled ridges. The ridges near the center of the notum are more prominent than the ridges on the edge of the mantle. There are tubercles on each meeting point of the ridges. Body is bright-yellow, while the ridges are darker. The underside and the edge of the mantle are whitish and translucent. The mantle, foot, and underside of the body are covered with black spots. The tip of the rhinophores and gills are black.

Remarks and distribution

Typical *H. wasinensis* has its notum covered with black or brownish color rather than yellow (Rudman 1978). But, some specimens found in some parts Indian Ocean show that this species has a number of color variations, including the one with almost entirely white notum and the one with yellow notum and black spots, just like the specimen found on Sempu Strait (Rudman 2000). Known to be distributed on the Indian Ocean (Gosliner et al. 2019). Mainly from the East Coast of Africa (Eliot 1904), but is also reported from Christmas Islands (Tan and Low 2014) Marshall Islands (Johnson and Boucher 1983).

Family Chromodorididae Bergh, 1891

Genus *Chromodoris* Alder & Hancock, 1855

***Chromodoris magnifica* Quoy & Gaimard, 1832**

Photographic record

Figure 2.E. Tiga Warna, Sempu Strait, East Java, Indonesia, May 2021, one individual photographed crawling on open dead coral rubble substrates at 10 meters depth. Size approximately 6 cm.

Description

The mantle is elongated oval with broad mantle overlap. The body is white with a series of longitudinal black bands in the center of the notum, with shade of bluish-white between these bands. There is a broad orange sub-marginal band near the edge of the mantle, as well as the edge of the foot. The rhinophores and gills are orange.

Remarks and distribution

This species bears a close resemblance to *Chromodoris africana* Eliot, 1904, where both have white-colored notum with black elongated and orange bands on the mantel's edge. But the difference between the two is that *C. magnifica* has a thin, white band on the outer edge of the orange band, which is absent in *C. africana* (Gosliner et al. 2019). Commonly found on outer reef walls or rocky slopes (Md. Salleh et al. 2000; Gosliner et al. 2019). Distributed on the Western Pacific Ocean (Gosliner et al. 2019). Indonesia: Ambon (Fransen and Goud 1999), Bangka (Papu et al. 2020), Bunaken (Fisch et al. 2017), Lembeh (Ompi et al. 2019a,b) Situbondo (Aunurohim and Raraswati 2010).

***Chromodoris* sp. 1**

Photographic record

Figure 2.F. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, one individual photographed on top of algae-covered massive coral at 5 meters depth. Size approximately 0.5 cm.

Description

This could be the juvenile stage from one of the blue-colored *Chromodoris* nudibranch, although the exact species is still to be defined as the specimen found still having a pale coloration and a rather incomplete marking. The mantle is oval with broad mantle overlap, the edge of the mantle is also moderately undulated. The body is pale violet-blue, with three large white spots on the center of the notum. The rhinophores and gills are translucent white, with a deep-orange tip on its rhinophores and each of its gill's branches.

Remarks and distribution

The closest resemblances based on its characteristics above are *Chromodoris lochi* or *Chromodoris dianae*, where both don't have any orange band on the edge of the mantle (Rudman 1982; Gosliner and Behrens 1998). However, in its current form, with still underdeveloped marking and coloration, further examination is needed to give the exact species identification of this specimen. *Chromodoris* nudibranch mainly has a widespread distribution in the Indo-Pacific (Gosliner et al. 2019)

Genus *Mexichromis* Bertsch, 1977

***Mexichromis aurora* R. F. Johnson & Gosliner, 1998**

Photographic record

Figure 2.G. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, a pair of this nudibranch photographed on top of sponge-covered coral rubble at 10 meters depth. Size approximately 2 cm.

Description

The body shape is rounded-oval with broad mantle overlap. The background color of the mantle is pinkish purple, where it becomes darker towards the edge of the mantle and the tip of the foot. There are three wide parallel creamy white lines on the center of its mantle, each outlined with a thin white line. The light pink area of the mantle is covered with dark purple spots with occasional smaller white spots. The rhinophores and the gills have a dark orange base and tip, with white bar in between.

Remarks and distribution

The notum and foot are covered with light pink color and darken into maroon towards the edge with three wide whitish-yellow bands (Johnson and Gosliner 1998). Inhabit deeper parts of the reef, from 10 to 58 meters (Johnson and Gosliner 1998; Gosliner et al. 2019). The distribution of *M. aurora* is limited to the Western Pacific Ocean (Gosliner et al. 2019). In Indonesia, known to be recorded from Bangka (Papu et al. 2020) and Lembeh (Johnson and Gosliner 1998).

Genus *Verconia* Pruvot-Fol, 1931
***Verconia simplex* Pease, 1871**

Photographic record

Figure 2.H. Tiga Warna, Sempu Strait, East Java, Indonesia, September 2020, a pair of individuals photographed on open dead coral rubble substrates at 7 meters depth. Size approximately less than 1.5 cm.

Description

The body shape is elongate-oval, with a narrow mantle overlap. Foot is elongated, has a sharp-angled tip, and extends beyond the mantle edge. The mantle is pink with white band on the edge, although it could vary from white to pink. The underside of the body is white. On the border of the mantle, sometimes edged with broken bright red or orange bands. Gill and rhinophore tipped with orange.

Remarks and distribution

Although the original description (as *Chromodoris simplex*, Pease 1871) stated that this nudibranch has pink body-color (Pease 1871), there are variations that show white body-color (Rudman 1995; Gosliner et al. 2019) as well as pale pink (Yonow 2018). These color variations might be attributed as self-defense mechanisms to fend off predators or camouflage purposes (Rudman 1991). Widespread in Indo-Pacific (Gosliner et al. 2019). Indonesia: Bangka (Papu et al. 2020), Sangihe Islands (Undap et al. 2019), also possibly Bunaken (Eisenbarth et al. 2018).

Genus *Hypselodoris* Simpson, 1855
***Hypselodoris decorata* Risbec, 1928**

Photographic record

Figure 2.I. Teluk Semut, Sempu Strait, East Java, Indonesia, June 2021, one individual was photographed inside the crevice of algae-covered rock at 12 meters depth. Size approximately 2.5 cm.

Description

The body color is cream-yellow on the center of the notum and orange on the side to the edge of the mantle. There are thin parallel white lines along its mantle, with purple and opaque white spots between the lines. The rhinophores are cream-white, with three rhinoporal red rings. The outside of the gills is red, while the inside is white.

Remarks and distribution

This species bears a close resemblance to *Hypselodoris maculosa* described in a previous publication in Sempu Strait (Andrimida 2021). The difference is *H. maculosa* has only two rhinoporal red rings rather than three as in *H. decorata* (Gosliner et al. 2019). Abundant in shallow reefs (Gosliner et al. 2019). Distributed on Western Pacific Ocean (Gosliner et al. 2019) Indonesia: Bangka (Papu et al. 2020), Bunaken (Eisenbarth et al. 2018).

***Hypselodoris confetti* Gosliner & R. Johnson, 2018**

Photographic record

Figure 2.J. Stumbut, Sempu Strait, East Java, Indonesia, October 2019, two separate individuals photographed, both crawling on top of algae-covered rubble at 12 and 15 meters depth. Size approximately 4 cm.

Description

The body color is whitish to blue-gray, ornamented with numerous large yellow spots and smaller dark blue to black spots scattered on the surface of the notum. The side, underside, and foot also have the color and the pattern as the notum. Gill pocket is slightly elevated, with the gills colors are blue basally, with red line along the inner and outer edge of the gill branch, while the tip is red to orange. The outside middle portion of the gills is decorated with three to five yellow spots. The base of rhinophores is dark blue to purple, while the upper half is bright red.

Remarks and distribution

This is the first nudibranch on this paper that resembles *Hypselodoris infucata* and *H. kanga* from previous publications (Andrimida 2021) and the recently discovered *H. roo* (Epstein et al. 2018). Distributed on Western Pacific (Gosliner et al. 2019), Papua New Guinea, Philippines, Thailand, probably Hong Kong and Indonesia (Epstein et al. 2018; Mehrotra et al. 2021)

***Hypselodoris roo* Gosliner & R. Johnson, 2018**

Photographic record

Figure 2.K. Tiga Warna, Sempu Strait, East Java, Indonesia, September 2020, one individual photographed, hanging under the crevice of algae-covered rock at 8 meters depth. Size approximately 1 cm.

Description

The body color is whitish to pale blue-gray with numerous small to large yellow spots, as well as smaller dark blue to black spots scattered irregularly on the surface of the notum. The side and underside of the body, as well as the foot also have the color and the pattern as the notum. Gills are white, with red lines along the inner and outer edge of the gill branch, while the tip is red to orange. The outside center of the gills is decorated with a single opaque white spot. Rhinopore red with white spot at the back end of the rhinophore.

Remarks and distribution

This is the second nudibranch on this paper that resembles *H. infucata* and *H. kanga* from previous publications, also with *H. confetti* (previous species). Each of these species of *Hypselodoris* could be differentiated from each other by carefully examining the pattern and the color of their gills (Epstein et al. 2018; Gosliner et al. 2019). Distributed in the Western Pacific (Gosliner et al. 2019), notably Indonesia and Philippines (Epstein et al. 2018).

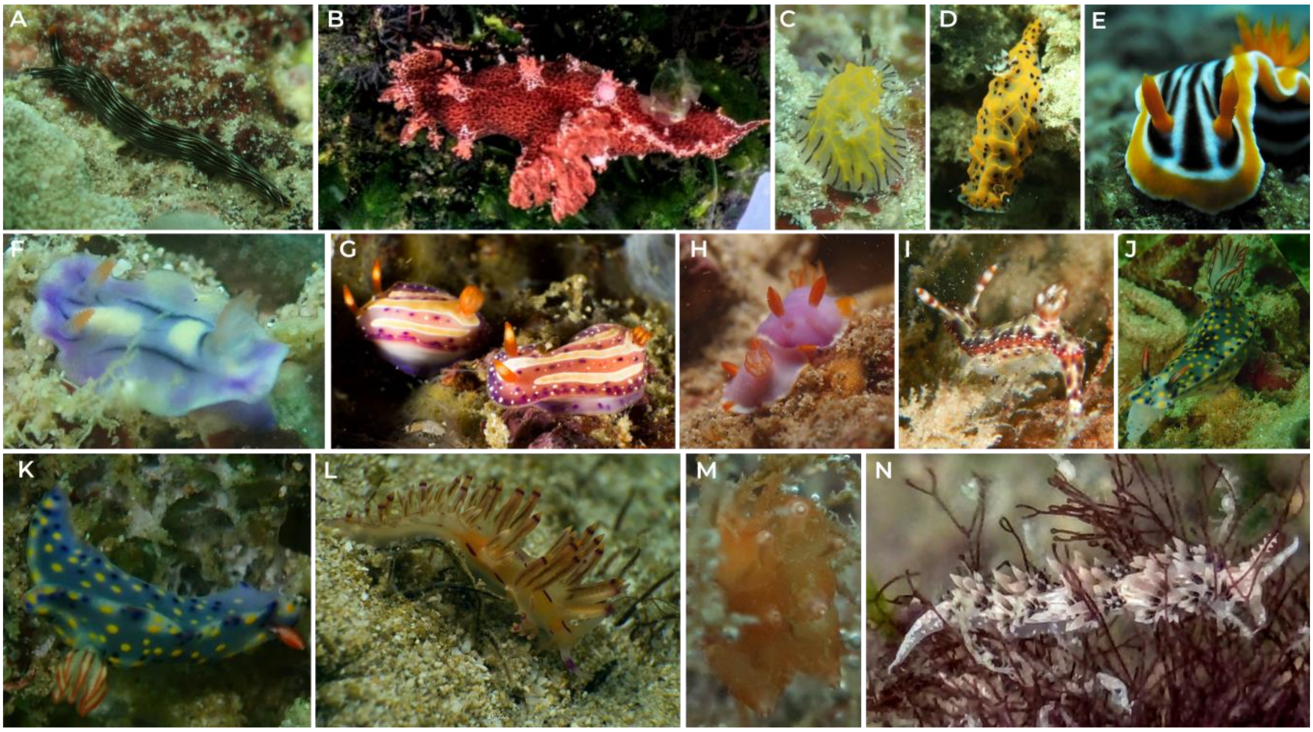

Figure 2. Heterobranchia from Sempu Strait, East Java, Indonesia. A. *Thuridilla gracilis*, B. *Plocamopherus imperialis*, C. *Halgerda elegans*, D. *Halgerda wasinensis*, E. *Chromodoris magnifica*, F. *Chromodoris* sp., G. *Mexichromis aurora*, H. *Verconia simplex*, I. *Hypselodoris decorata*, J. *Hypselodoris confetti*, K. *Hypselodoris roo*, L. *Coryphellina lotos*, M. *Eubranchus* sp., N. *Phidiana bouraillii*. Photograph by Anthon Andrimida (A, C-D, F, J-K, M) Rudi Hermawan (B & N), Browy E. Untoro (E & H), Djihadi Nopoto (G & L), I Nyoman Januarsa (I)

Family Flabellinidae Bergh, 1889
***Coryphellina* O'Donoghue, 1929**
***Coryphellina lotos* Korshunova et al. 2017**
Photographic record

Figure 2.L. Tiga Warna, Sempu Strait, East Java, Indonesia, September 2020, one individual photographed, crawling on an open sandy substrate at 10 m depth. Size approximately less than 2 cm.

Description

Body slender and narrow, with the posterior end forming an acute point. Rhinopores are papillate and shorter than oral tentacles. It has rows of fusiform cerata with pointed tip and visible digestive gland. Background color light violet, with a series of interrupted dark violet lines in the center of notum and on each side of the notum. Oral tentacle lilac with translucent tips, while the subapical part of the rhinophore and cerata reddish with white translucent tips. The visible digestive glands are brown.

Remarks and distribution

This species is identical to *Coryphellina rubrolineata* O'Donoghue, 1929 where *C. lotos* has a series of interrupted purple lines on the center of its notum rather than a long uninterrupted line in *C. rubrolineata*. *Coryphellina lotos* also has purple subapical ring with the tip of cera has an identical color with the background coloration, rather than red-violet cera with yellow tip as in *C. rubrolineata*. Inhabit shallow to deep reef (Gosliner et al. 2019). Distributed on the Western Pacific (Gosliner et al. 2019), no recent scientific record from Indonesia, but reported from Bali and Ambon based on some macrophotography online forum.

Family Eubranchidae Odhner, 1934
Genus *Eubranchus* Forbes, 1838
***Eubranchus* sp. 1**
Photographic record

Figure 2.M. Rumah Apung, Sempu Strait, East Java, Indonesia, August 2020, one individual photographed among hydroids that cover the net of Rumah Apung near the surface. Size approximately 0.5 cm.

Description

Body covered with inflated cerata, each with an acute tip. Background color is deep orange and slightly transparent. Under the bright daylight, the brown digestive glands could be easily observed. Also, there are white subapical rings on each cerata, while the apices are white.

Remarks and distribution

The difference between this specimen and *Eubranchus mandapamensis* Rao, 1968 reported from Sempu Strait before (Andrimida 2021), is this specimen has smooth rhinophore rather than annulated rhinophore While some nudibranch from the *Eubranchus* Genus has a widespread distribution in Indo-Pacific, such as *E. mandapamensis*, The undescribed species that has smooth rhinophore (stated as *Eubranchus* sp. 2 in Gosliner et al. (2019) has a limited distribution in Indonesia.

Family Facelinidae Bergh, 1889
Genus *Phidiana* Gray, 1850
***Phidiana bourailli* Risbec, 1928**
Photographic record

Figure 2.N. Rumah Apung, Sempu Strait, East Java, Indonesia, August 2020, one individual photographed among hydroids and algae that covers the net of Rumah Apung near the surface. Size approximately less than 2 cm.

Description

Body profile is high and elongated, with the posterior edge of the body narrow and sharp. The tentacles are long and blunt on their tip. Rhinopores are shorter than the oral tentacles and annulated. The cerata are short, no more than the half-length of the rhinophore. Background color is translucent white, with white speckles scattered on the head and along the notum. Body decorated with occasional orange broken stripes, usually found between the rhinophores and ceratal clusters, as well as on the side of the body. The tentacles are translucent with white band covering almost half of the tentacles. Cerata is also translucent, but covered with dense brownish-black spots, covering roughly half of the cerata.

Remarks and distribution

Some nudibranchs from the Genus *Phidiana* have a nearly identical body shape, where the coloration could be the key to differentiate with one another. This species could be identified by examining the genital pore aperture and cerata cluster (Rudman 1980). Indian and Western Pacific Ocean (Gosliner et al. 2019) and reported from Australia's South East Coast (Nimbs et al. 2015).

Discussion

This research is a continuation of the preliminary heterobranch sea slug's survey in this area prior to August 2019. With fourteen additional species found during this research, combined with the publication before, thus a total of 59 heterobranch sea slug has been recorded in Sempu Strait. The most remarkable addition to the heterobranch sea slug species checklist at Sempu Strait might be the *P. imperialis,* which this species was formerly believed to have distributed on the subtropical waters of Eastern Australia and New Zealand (Gosliner et al. 2019). Recent records from Christmas Island (Tan and Low 2014), which is located about 800 km southwest of Sempu Strait might indicate that this species might also enter the tropic waters.

Among the fourteen species recorded in this study, there are two specimens of nudibranch that only could be identified to its genus level. The first specimen, *Chromodoris* sp. was found on its juvenile stage, thus the markings on its notum were not fully developed. The examination of the general morphology concluded that this specimen indeed belongs to the Chromodorid nudibranch. The determination of the species remains unclear as there is no other blue-colored *Chromodoris* encountered in this area. The second specimen, *Eubranchus* sp. has identical morphological with *E. mandapamensis* described in the previous study. Except, this specimen has rather translucent orange-covered body with smooth rhinophore, whereas the *E. mandapamensis* has more yellowish color with purple subapical ring on its cerata and also has annulated rhinophore. Both species encountered similar substrates, on which both are found clinging on hydroid on shallow waters at Rumah Apung.

In general, the number of heterobranch sea slug species found on Sempu Strait is relatively higher than in another location in the Western Part of Indonesia, while still dwarfed by the heterobranch sea slug species number found in the Eastern Part of Indonesia. The local conditions on each location, such as the availability of prey and predators as well as natural and human disturbance, and the variety of habitats has been thought to be the main driving factors on the difference of heterobranch sea slug's species number (Ompi et al. 2019a,b; Mantiri et al. 2021). This reason could also indicate the contrast difference between the species abundance among the sites on Sempu Strait as observed by previous studies in this area (Andrimida and Hermawan 2019).

Table 1. Higher taxa of heterobranch sea slug in Sempu Strait, East Java compared to other areas in Indonesia

Sites	Expedition year	Order					Source
		Cephalaspidea + Runcinida	Aplysiida	Sacoglossa	Nudibranchia + Pleurobranchida	Total	
Sempu Strait	2018 - 2021	2	6	3	48	59	This study and [1]
Bangka Arch.	2017 - 2018	5	2	15	128	150	[2]
Ambon	2018	11	6	12	109	138	[3]
Bunaken NP	2003 & 2015	26	4	15	80	135	[4]
Lembeh	2001 - 2010	2	2	6	75	85	[2]
Pasir Putih	2008	1	1	2	27	31	[5]
Tulamben	2020	0	0	5	26	31	[6]
Sangihe	2016	0	0	3	20	23	[7]
Paiton	2011	0	1	0	15	16	[5]
Humboldt Bay, Jayapura	2021	0	0	0	14	14	[8]
Malalayang	2021	0	0	0	11	11	[9]
Jepara	2020	0	0	0	6	6	[10]

Note: [1] Andrimida 2021, [2] Papu et al. 2020, [3] Yonow and Jensen 2018, [4] Kaligis et al. 2018, [5] Muzaki and Dian 2011, [6] Marchel and Yuda 2021, [7] Undap et al. 2019, [8] Paulangan et al. 2021, [9] Mantiri et al. 2021, [10] Sabdono et al. 2021

In conclusion, this study reveals fourteen additional heterobranch sea slug species found on Sempu Strait, on which thirteen species belong to the Nudibranchia order, while only one species belong to the Sacoglossa order. These species belong to seven families, which are Plakobranchidae (1 species), Polyceridae (1 species), Discodorididae (2 species), Chromodorididae (7 species), Flabellinidae (1 species), Eubranchidae (1 species), and Facelinidae (1 species). Among the species found, there are two nudibranchs that could be identified to its genus level, which are *Chromodoris* sp. and *Eubranchus* sp. While most of the sea slugs recorded have widespread distribution in Indo-Pacific, but one remarkable addition is *P. imperialis*, where various sources stated that this nudibranch is distributed on the Subtropical waters of Australia and New Zealand. This finding might indicate that this species also enters warmer tropical waters. The result of this research combined with the preliminary study of heterobranch sea slug in this area reveals that Sempu Strait has a relatively higher heterobranch species number than another location in Western Indonesia, even though further study is needed to give comprehensive information about the diversity of this certain taxon on Sempu Strait, as well as other areas adjacent to it.

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Distribution and types of microplastics on the coast of Aipiri and Andai Beaches, Manokwari District, Indonesia

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Abstract. *Embulaba O, Kolibongso D, Tapilatu RF, Saleh F, Bawole R. 2022. Distribution and types of microplastics on the coast of Aipiri and Andai Beaches, Manokwari District, Indonesia. Indo Pac J Ocean Life 6: 10-16.* Plastic waste enters the marine environment in various sizes, from micrometers to millimeters. The composition and occurrence of microplastics were investigated on the Manokwari coast (Manokwari District, Indonesia) from two different beaches in terms of intensity of exploitation and exposure to various activities such as urbanization, ports, tourism, and morphological characteristics of the coast. The average abundance of microplastics was between 0.001 to 0.041 items/gram of dry sediment. Fragments and fibers are the two types of microplastics found to dominate. On the other hand, there was no substantial difference in the abundance of microplastics found on unexposed beaches with other beaches. Our results show that coastal morphology with gentle slopes with high tide limits tends to have a 'better' potential for accumulating microplastics on the beach. However, the accumulation of microplastic types is also primarily determined by the characteristics possessed by microplastics. Therefore, it causes spatial and temporal variability in the composition of microplastics found on the coast.

Keywords: Abundance, beach, Manokwari, microplastic

INTRODUCTION

The territory of Indonesia, which is two-thirds of its part in the form of the sea, has abundant natural resources, both living and non-biological. In addition, the relief of Indonesia, which is very rich in islands, makes Indonesia have a long coastline exceeding 99,000 km. Unfortunately, in some places, both the sea and the coast, the conditions are abysmal due to pollution from land. The impact of this contamination occurs globally and locally caused by humans. Pollution contamination occurs both in the form of liquid and solid wastes. Examples of solid waste are plastic, metal, paper, glass, and paper waste (Abu-Hilal and Al-Najjar 2004; Leite et al. 2014) which pollute beaches, shallow waters, and the high seas, with an estimated 7,000 to 35,000 tonnes (Cózar et al. 2014) in the form of macro and microplastic scraps (Cole et al. 2011; Lima et al. 2014).

Indonesia is the second-largest country globally, estimated to contribute to the amount of waste that enters the sea (Jambeck et al. 2015). The composition of the macro marine waste (> 2.5 cm) in 18 districts/cities in Indonesia is dominated by plastic waste at 31.44%, while others are in the form of wood, glass and ceramics, rubber, cloth, plastic foam, metal, paper and cardboard, and other materials (KLHK 2017). Meanwhile, the composition of meso marine waste (0.5-2.5 cm) is dominated by wood at 35.06%, and other waste in the form of plastic, glass and ceramics, metal, plastic foam, cloth, rubber, paper and cardstock, and other materials.

The potential effects of marine chemical waste tend to increase as the size of plastic particles (microplastics) decreases. In contrast, the physical effects increase as the size of macro waste increases (UNEP 2011). In addition, macrowaste has a material impact, such as covering the sediment surface and preventing the growth of mangrove seeds (Smith 2012). The threat of waste in the marine environment is crucial because it has the risk of impacting humans (Halden 2010; Cole et al. 2011; Farrell and Nelson 2013; Tapilatu and Kolibongso 2021) due to the interaction between the sea and humans (Fleming et al. 2014) as well as through transfer mechanisms from food sources such as fish, especially plankton feeders such as Manta Rays (Thovyan et al. 2020) and mollusks, where the number increased from 1985 to 1995 (Willoughby et al. 1997).

Indonesia has committed to reducing 70% of marine waste by 2025 based on Presidential Regulation No. 83 of 2018. One of the supports for this policy is determining the level of marine waste pollution, especially those deposited on the beach. However, microplastics' spatial variability, composition, and deposition in coastal sediments are still subject to tidal influence.

MATERIALS AND METHODS

Research sites

Manokwari District is the capital city of West Papua Province and is located in the north of Bird's Head section of the island of Papua, Indonesia. This research was carried out in two locations: Andai and Aipiri Beach (Figure 1) in March 2020, with data collection carried out in two (2) different observation periods. Data collection for period I was carried out on 7-8 March 2020, and period II was carried out on 22-23 March 2020. These two beaches differ in the intensity of exploitation and exposure to various anthropogenic activities, such as proximity to city centers, ports, fishing ports, and tourist areas selected for this research.

Data collection

Microplastic survey method

At the beach, the determination of transects, which could reach 100 m, was done purposively by considering the length of the beach. The making of the transect line was based on the Coastal Waste Monitoring Guidelines (KLHK 2019), which divided the transect line into five sections (quadrants A, B, C, D, E) with a length of 20 meters each. In each quadrant, a 5 x 5 m sub quadrant was placed. In each sub quadrant, 25 plots with a size of 1x1 m were placed (Figure 2).

Marine waste samples taken in this study were in the form of microplastic-sized waste (in the substrate). Prior to sampling, a number was drawn for the boxes to be collected. From 25 numbers, five numbers were selected. The box was in the 5 x 5 meter quadrant. In each of five previously selected boxes, a 1 x 1 meter quadrant was placed, then a 1 kg substrate sample was taken at 3-5 cm depth, then the substrate was put into the sample container and coded. The separation of microplastic particles (0.045-5mm) was separated from the substrate in several stages: drying, volume reduction, density separation, filtering, and visual sorting.

Drying was carried out in an oven at 105ºC for 72 hours. First, reducing the volume of dry sediment was done by filtration (size 5 mm) (Hidalgo-Ruz et al. 2012). Next, the density separation step was carried out by mixing dry sediment samples (500 grams) with saturated NaCl solution (3L), then the mixture was stirred for 2 minutes (Claessens et al. 2011). The plastics that float are polystyrene, polyethylene, and polypropylene. Finally, the filtering step was carried out by filtering the supernatant (45 μm size). Microplastic particles were visually sorted using a monocular microscope and grouped into four types, namely film, fiber, fragment, and foam (Hidalgo-Ruz et al. 2012).

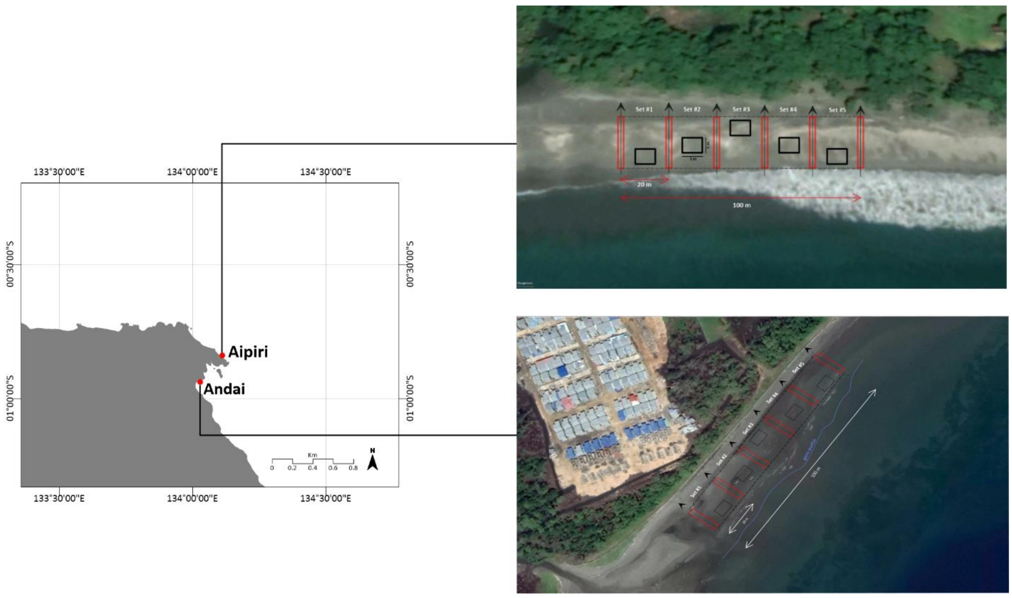


Figure 1. Research location map in Andai and Aipiri of Manokwari District, West Papua Province, Indonesia

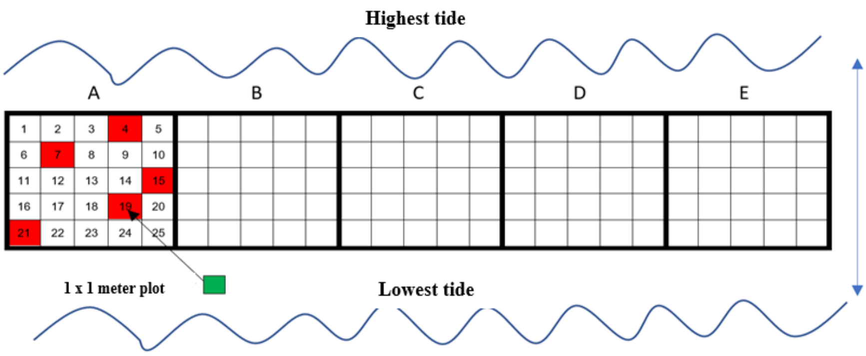


Figure 2. Schematic of transect and sub transect sampling

Oceanographic parameters

Water current data were taken in situ and from the Copernicus Marine Environment Monitoring Service (CMEMS) (http://resources.marine.copernicus.eu) with a resolution of 1/12º or 0.083x0.083 km. The database in the physics analysis model in CMEMS used NEMO Model version 3.1. The measurement of the slope of the coastal slope was carried out using a waterpass hose and a scaling pole (Kalay et al. 2018). The measure was started from the shoreline (highest tide area) to the lowest tide area at 10 m from the observation point (r-axis).

Data analysis

Data on the abundance of microplastics were analyzed statistically. The Kruskal-Wallis test was used to examine non-parametric significant differences, including the quantity and composition of microplastics between the two locations and observation points. If the test results were significantly different, it was continued with the Mann-Whitney Test to identify significant differences between the two groups (Claessens et al. 2011).

RESULTS AND DISCUSSION

Types and abundance of microplastics

There were four types of microplastics on the Manokwari beach: fragments, foam, fiber, and film (Tables 1 and 2). Microplastic fragments, fibers, foams, and films were all found on the Andai coast. Meanwhile, the types of fragments, fiber, and foam were found only on the coast of Aipiri. The abundance of fragment types was the most dominant microplastic found compared to other types, with a range of 0.004-0.052 items/gram of dry sediment (Table 1). The lowest abundance was found for foam with 0.002-0.006 items/gram of dry sediment. The fragments were abundant on the Andai coast, with an average abundance of 0.041 items/gram of dry sediment. Meanwhile, fiber was found with the highest abundance on the Aipiri coast, with an average of 0.008 items/gram of dry sediment (Table 2). The differences in the types of microplastics found were caused by several factors, such as the type of substrate and water conditions.

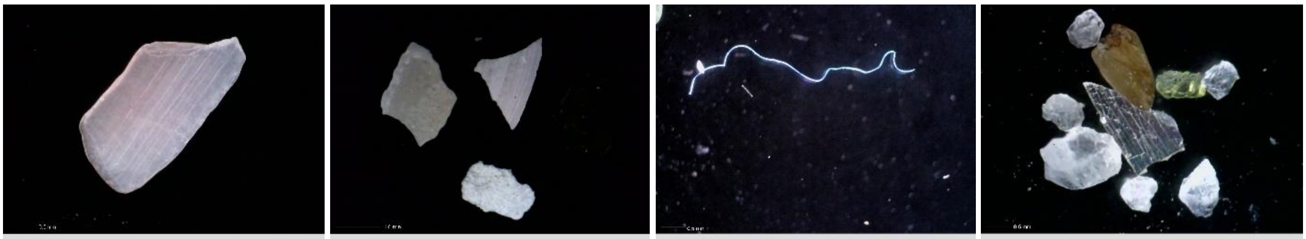
The highest abundance was found for microplastic fragments with a percentage of 22.2% to 83.9%. Meanwhile, the lowest percentage was found for foam types, from 4.8 to 33.3%. The highest mean abundance for fragments (77.7%) was on the Andai coast. Meanwhile, on the coast of Aipiri, it is fiber (44.4%) (Table 2). The fragments had a morphology similar to pieces of plastic products with white, red, and clear colors (Figure 3). Fragments were known to come from the result of cutting plastic products and the breakdown of rigid plastics with solid synthetic polymers. Sources of fragments found in sediments could come from plastic waste generated by local human activities (Sutton et al. 2016) such as in Andai and Aipiri (Siburian et al. 2022). The fiber was morphologically similar to fibers or fishing nets with dark blue, light blue, and red colors. The fiber was widely used in clothing, boats, fishing nets, and household appliances, so microplastic fiber types are easier to find and widely distributed in sediments and waters. Browne (2015) stated that microplastic fibers found in marine habitats could come from domestic waste. Marine activities such as fishing were a source of fiber because most fishing nets are made of fiber (Browne 2015; Alomar et al. 2016; Sutton et al. 2016; Lots et al. 2017; Piñon-Colin et al. 2018; Zhao et al. 2018). The dominant type of microplastic found in this study was the same as several studies on the coast of Indonesia, including Yona et al. (2019) in sediments in East Java; Manalu et al. (2017) in Jakarta.

Table 1. Microplastic percentage and abundance at Andai and Aipiri Beaches, Manokwari, West Papua, Indonesia, in both observation periods

Microplastic Type	Andai			Aipiri		
	Abundance by weight (items/g dry sediment)	Abundance per area (items/m2)	Percentage (%)	Abundance by weight (items/g dry sediment)	Abundance per area (items/m2)	Percentage (%)
Periode I						
Fragment	0.052	1.04	83.9	0.004	0.08	22.2
Foam	-	-	-	0.006	0.12	33.3
Fiber	0.006	0.12	9.7	0.008	0.16	44.4
Film	0.004	0.08	6.4	-	-	-
Periode II						
Fragment	0.030	0.6	71.4	0.008	0.16	44.4
Foam	0.002	0.04	4.8	0.002	0.04	11.1
Fiber	0.010	0.2	23.8	0.008	0.16	44.4
Film	-	-	-	-	-	-

Table 2. Percentage and mean abundance of microplastics on Andai and Aipiri Beaches, Manokwari, West Papua, Indonesia

Microplastic type	Andai			Aipiri		
	Abundance by weight (items/g dry sediment)	Abundance per area (items/m2)	Percentage (%)	Abundance by weight (items/g dry sediment)	Abundance per area (items/m2)	Percentage (%)
Fragment	0.041	0.82	77.7	0.006	0.12	33.3
Foam	0.001	0.02	2.4	0.004	0.08	22.3
Fiber	0.004	0.16	16.8	0.008	0.16	44.4
Film	0.005	0.04	3.2	-	-	-



A B C D

Figure 3. Examples of microplastics which were found on the coast of Manokwari, West Papua, Indonesia. A. Fragment; B. Foams; C. Fibers, D. Film

Spatial variability

The in situ weathering process of plastic waste is the mechanism that probably produces most of the microplastics on the beach (Andrady 2011). Plastic is the dominant type of marine waste on beaches, resulting from mechanical processes due to waves and tides and the influence of oxygen and sunlight, which affects the fragmentation of plastic into smaller pieces (Rosevelt et al. 2013; Topçu et al. 2013; Laglbauer et al. 2014; Urban-Malinga et al. 2020). The abundance of microplastics on the Manokwari coast found on the Andai coast (0.02-0.82 items/m^2) and the Aipiri coast (0.08-0.16 items/m^2) did not show a substantial difference (Table 2). Film-type microplastics were the least present, only found on the Andai coast. These microplastics were also only found in period I of observation. Microplastic films were identified as polymers of polyethylene and polypropylene, which were commonly used in plastic wraps and bags. This microplastic was easily destroyed and had a low density.

According to Kingfisher (2011), the film is a secondary plastic polymer derived from plastic bags or plastic packaging fragmentation and has a low density. A possible explanation for the emergence of microplastic films is that currents transported them in period I, which moved from the south along the coast and were then deposited on the Andai coast. It is reinforced by the not-so-strong average current velocity (0.2 m/s), making it easy to deposit. Next, no microplastic film was found in the second period of observation due to the direction of the average current, which tends to move away from the coast towards the open sea (out of the Manokwari coast) with a reasonably strong speed, which is twice the speed in the previous period (0.4 m/s). Surprisingly, the type of microplastic foam appeared at both observation sites. In fact, Aipiri Beach which has lower exposure to anthropogenic activities has four times the abundance of Andai Beach. This condition indicated that the higher number of microplastic particles found in the sediment could not be a measure or an indicator of a higher level of contamination for microplastic studies on the coast. Microplastics were easily transported as suspended particles by currents, waves, tides, and erosion processes on the coast from one place to another. Thus, there was a quantity of microplastic present in the sediment according to where it was deposited in a short time on the beach. According to Stolte et al. (2015), microplastics were distributed more evenly by natural forces than macroplastics which usually accumulated near urban areas and recreational areas. Added by Reisser et al. (2015), the amount and distribution of plastic were influenced by the depth and vertical mixing, where the amount of plastic was more abundant on the surface. In addition, distance to land (Uneputty and Evans 1997), season, wind, ecosystem location, and ecosystem use affected the amount and distribution of microplastics (Abu-Hilal and Al-Najjar 2004). The characteristics of microplastics determine their distribution and impact on the environment. For example, plastic particles with a heavy density will be easier to contact with sediment grains than microplastics with a lighter density. This difference is important because it can affect the degree of degradation, surface characteristics, and shape of the microplastic particles. The specific density of plastic particles varies greatly depending on the polymer and the manufacturing process (Lie et al. 2018). After the mixing process, large-sized sediments will be quickly deposited while small-sized particles will remain in a state of suspension or float and can be transported by physical water factors (Hidalgo-Ruz et al. 2012).

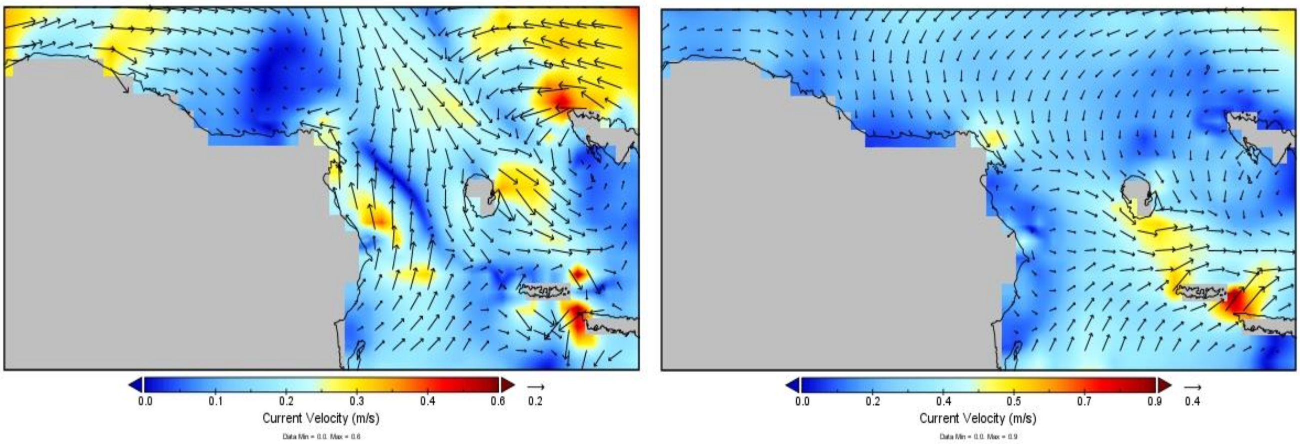


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Figure 4. The average flow pattern in March 2020 in the Manokwari Waters, West Papua, Indonesia. A. Current direction in observation period I; B. Current direction in observation period II

Microplastic distribution vs. coastal slope

The spatial variability and composition of microplastic deposited on the beach vary significantly because it follows the morphology of the beach. In this study, many microplastic types were found on Andai Beach (Figure 5), indicating that beaches with gentle slopes tended to be easier to deposit microplastics. This condition was related to the combination of interactions between tides and waves as the main factor in determining the direction and distribution of sediment on the coast. Sloping coastal slopes tend to have large high tide limits. These conditions indicated that the tidal area (coastal line) in Andai was under high pressure due to waves and tidal currents (Tapilatu et al. 2022), so the sediment in the vicinity was eroded and displaced. It was indicated by the grain size of the sediments found to be more varied, including gravel, sandy, and muddy sand. This condition caused microplastics on beaches with gentle slopes with a grain size of sandy sediments to accumulate more easily than the microplastics transported by tides and waves. According to Rey et al. (2021), the highest density of microplastics was found on coarse sandy beaches, indicating that densities were higher on beaches with high wave energy. McLachlan and Brown (2006) also found that suspended particles in water bodies and sediment surfaces were transported by waves to the sand bodies and adsorbed to the surface of the sand grain size. In addition, storms that generate tidal waves also cause coastal erosion. These remobilizing microplastics were buried back into the water column and might be suspended in the water column or transported back to shore (Vedolin et al. 2018). The highest microplastic densities were usually associated with coastlines and physical processes in the ocean (Lie et al. 2018). Diffusion of microplastics on the coast was strongly related to tides, which was caused by the accumulation of microplastics along the highest tide line, especially at high tide (Jualaong et al. 2021).

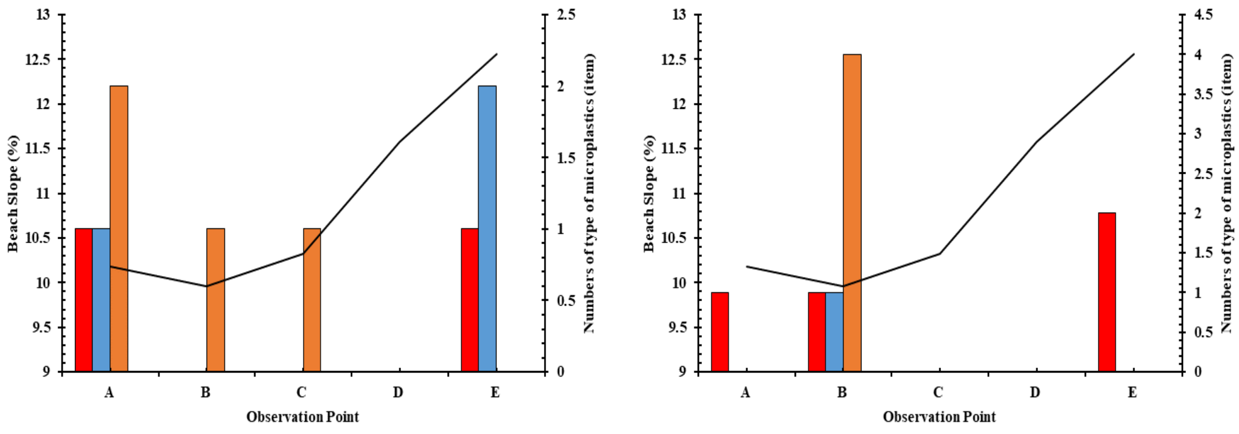

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Figure 5. Distribution of microplastics vs. Coastal Slope at Aipiri Beach, Manokwari, West Papua, Indonesia. A. Observation of period I; B. Observation of period II. Note: Bar chart: type of microplastic (red: fragment, blue: foam, orange: fiber, green: film); Line chart: Coastal slope

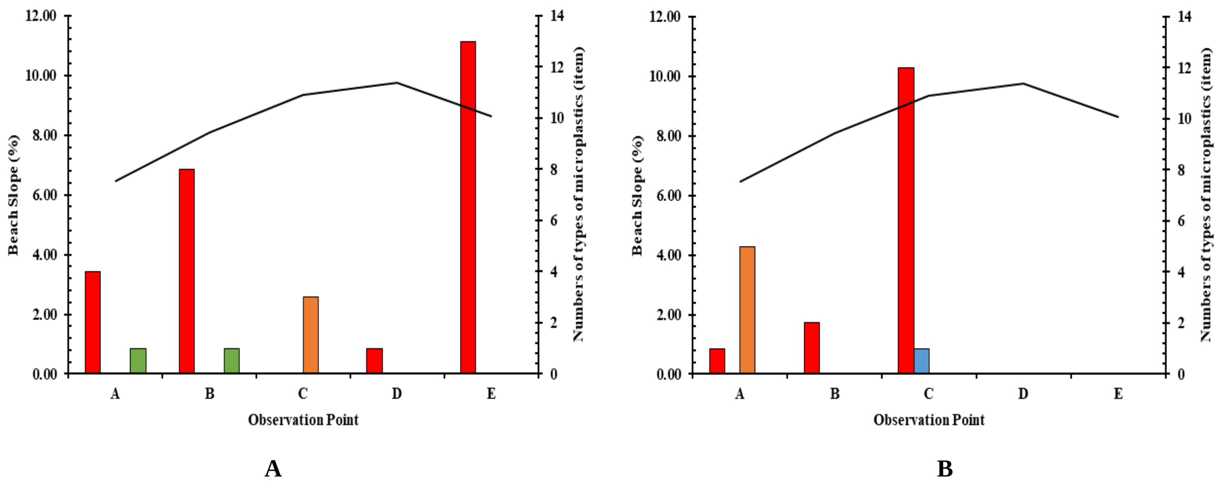

Figure 6. Distribution of microplastics vs. coastal slope at Andai Beach, Manokwari, West Papua, Indonesia. A. Observation of period I; B. Observation of period II. Note: Bar chart (red: fragment, blue: foam, orange: fiber, green: film); Line chart: Coastal slope

Most of the microplastic present in sediments was carried from other places and arrived at the depositional site by tides, waves, and currents. Therefore, the slope would be a determining factor in the accumulation process of microplastics on the beach. However, it was interesting that the accumulation of microplastic types on the beach was also strongly influenced by the characteristics of each type of microplastic itself. First, it caused spatial and temporal variability in the composition of microplastics found on the coast. Therefore, the abundance of microplastics in sediments on the coast was not directly related to activity at the location where the microplastics were deposited. Next, microplastics generally had a low density, so waves easily transported them through currents, tides, and erosion processes on the coast as suspended particles. Finally, microplastics also had a short residence time in sediments. These characteristics were hazardous because they had a high potential to pollute the water column and threaten marine organisms and ecological systems. Thus, they were difficult to clean from the fragile marine environment.

In conclusion, the microplastics found on the Andai and Aipiri coasts, Manokwari consisted of fragments, foam, fiber, and film. Fragments are the most common type of microplastic found on the coast. The average abundance of microplastics was between 0.001 and 0.041 items/gram of dry sediment. The abundance of microplastics was found on Andai Beach (0.02-0.82 item/m^2) and on Aipiri Beach (0.08-0.16 item/m^2). There was no substantial difference in the abundance of microplastics found on the unexposed beach with other beaches. However, beaches with gentle slopes tend to be easier to deposit microplastics.

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Coastal and mangrove economic valuation associated fisheries and problems in Kwale County, Kenya

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Abstract. *Ahmed HA, Mwaura F, Thenya T, Kairo JG. 2022. Coastal and mangrove economic valuation associated fisheries and problems in Kwale County, Kenya. Indo Pac J Ocean Life 6: 17-27.* The coastal fisheries in Kenya are essential to the livelihoods of the coastal communities. They provide employment, income, and food and support other auxiliary industries. Despite the socio-economic importance of coastal fisheries, various anthropogenic andclimate change impact threatened their existence. Fish habitats, including mangroves, coral reefs, and seagrasses, are threatened by human activities such as aquaculture, mangrove extraction, unplanned expansion of coastal cities, and marine pollution. Usually, coastal fisheries are also neglected in key policy-making agendas. That is attributed to inadequate information and a lack of data on the socio-economic contribution of coastal communities engaged in fisheries. This study aimed to estimate the economic value to providecrucial information for policy making of mangrove ecosystem-based coastal fisheries in Kwale County. The study also attempted to establish the coastal fishery production trend for the past decade, to estimate the economic value of mangrove ecosystems to fishery production, and the future of coastal fisheries projecting based on Climate Compatible Development (CCD) and Business As Usual (BAU) scenarios. Combining the primary data from interviews with 242 respondents with secondary data, including a decade of fish catch data, were analyzed, which exhibited a continuous increase from 1,908 tonnes in 2004 to 2,450 tonnes in 2013 coastal fisheries production. The coastal fisheries value was estimated to be Ksh.182 million (US$ 2.2) annually after deducting all fishing-related costs in 2013. This study also estimated that mangrove ecosystems could support the production of 160kg/ha/year, comprable to Ksh.11,610/ha/year (US$ 198/ha/year). Moreover, the estimated values could be much higher than the calculated ones because a considerable amount of fish caught is unrecorded. The future projections reveal that the scenario of Business As Usual (BAU) is not sustainable. Hence, the study demands a shiftto the scenario of Climate Compatible Development (CCD), which incorporates mitigation measures, climate change adaptation, and investment in infrastructure. The study recommendsreviewing the existing fishery policies regarding the unique characteristics of coastal fisheries to ensure sustainable exploitation and address the challenges. The research also recommends further economic studies on the coastal fisheries value chain.

Keywords: Coastal, communities, fish, socio-economic, mangrove

INTRODUCTION

Ecosystems provide various products and services essential to human welfare (Spalding et al. 2010; de Groot et al. 2012; Puligheet al. 2016; Wolsink 2016; Lacy and Shackleton 2017; Palliwodaet al. 2017; Sulistyorini et al. 2018; Muhlisin et al. 2021; Siahaya et al. 2021). However, the environmental goods and services benefits that have been realized are often undervalued in decision-making because organizations and individuals often more consider market prices than the true economic values (Campus and Schuhmann 2012). Economic valuation generates the real economic costs arising from habitat degradation, species loss, and the benefits of rehabilitation activities and conservation, often conveyed in monetary terms (in theory), as a 'universal currency' that is understood by policy-makers and data on the decision-making of limited resources (Turner et al. 2003).

Globally, coastal marine ecosystems and estuarine are the most endangered ecosystems (Halpern et al. 2008). The sum of 50% of the salt marshes, 30% of coral reefs, 29% of seagrasses, and 35% of mangroves, have degraded or lost since 1950 because of intensive and expanding human activities (FAO 2007; Barbier et al. 2011). Moreover, those degradation has resulted in a decline of 33% in fisheries production, 69% in habitat provision (e.g., seagrass, oyster reefs, and wetlands),and 63% in services such as filtering and purification functions (Barbier et al. 2011). The decline of coastal ecosystem services and degradation negatively affect the livelihoods of communities and national economies, particularly in developing countries with the largest populations (UNEP 2011a)

Mangrove forests in subtropical and tropical regions are the most productive ecosystems, providing economic and environmental products and services. They also support coastal fishery production. Over the past decades, unfortunately, the cutting and conversion have resulted in a global decline of these coastal ecosystems (FAO 2007; Spalding et al. 2010), having both economic and environmental adverse impacts in the coastal areas. On the other hand, mangrove forests have huge potential for preventing flooding, climate change mitigation and adaptation, and protection against storms. In addition, mangroves as important carbon sinks, and their removal would release large carbon stocks trapped beneath them (Siikamäki et al. 2012; Pricillia et al. 2021).

The coastal fishery production is intact in mangrove habitats (Hamilton et al. 1989; Rönnbäck 1999), providing a habitat for various fish species. However, due to the turbidity and dense structure, predation on juvenile fishes may be reduced; the trees, branches, aerial roots, and trunks are submerged at high tide, which could inhibit predators through impending sight and movement (Huxham et al. 2004; Nagelkerken et al. 2008). Hence, mangrove ecosystems' degradation makes fish stocks more vulnerable because of their effects on juvenile fish recruitment.

Although mangrove habitats have a vital role are exploited for direct products such as aquaculture, timber production, and firewood and are removed for tourism infrastructure and other uses. For example, mangrove clearance for intensive prawn farming in Asia has reduced the buffering ability andincreased the vulnerability to tsunamis and storms; conservation should understand the relationship between prawns, fish, and mangroves' importance on aquatic ecosystems' at different locations. Moreover, 80-90% of fish caught in South East Asia and Florida, the USA, is associated with mangroves (Rönnbäck 1999; Nagelkerken et al. 2008).

Studies on Tudor creek carried out by Little et al. (1988) and Gazi bay by Kimani et al. (1996), Wakwabi (1999), and Huxham et al. (2004) in Kenya emphasized the importance of mangroves in coastal fisheries. For example, 109 species of fish belonging to 44 families were identified in Gazi bay mangroves, of which 78.5% comprised Atherinidae, Gerreidae, and Clupeidae. Moreover, Huxham et al. (2004) and Mirera et al. (2010) reported while the densities were similar, there was more richness in fish species in forested than un-forested mangrove sites.

Kenya's coastal communities exploit fisheries and mangroves for their livelihoods (ASCLME Project 2011). An estimated amount by UNEP (2011b) to the economic contribution of mangrove fisheries production in Gazi bay, Kenya, is US$ 44/ ha/year. The economic value of the forest of reforested mangroves in Gazi bay was also calculated by Kairo et al. (2009), and their contribution to fisheries production is estimated to be US$113.09/ha/year. However, to the best knowledge, no research has been conducted on estimating the economic value of coastal and mangrove-associated fisheries in Kenya.

The aims of this study are: (i) To determine trends of coastal and mangrove-associated fisheries production in Kwale County over the past 10 years. (ii) To identify mangrove-associated fish species from catch data and their economic value estimation. (iii) Estimate the economic value of coastal fisheries annually in Kwale County. Finally, (iv) Project the future of coastal and mangrove-associated fisheries based on Climate Compatible Development (CCD) and Business As Usual (BAU) scenarios.

MATERIALS AND METHODS

Study area

Geographical location and demographic characteristics

The study area, as shown in Figure1, was located along the Kwale County coastline; Kwale county is on the southern coast of Kenya, neighboring the republic of Tanzania toward the southwest, and the following counties: Kilifi toward thenorth, Mombasa toward the northeast, Taita Taveta toward the west, and the Indian Ocean toward the east. The county covers 8,270.2 km^2 and accounts for 1.42% of Kenya's surface area. The population of this county was 649,931 (49% male and 51% female), with a population density of 79 people per km^2 and a growth rate of 2.6% annually.

Climate

The climate of Kwale County, especially along the Coastal strip, is warm and humid. The county's climate is influenced mainly by two prevailing winds, the South-East Monsoon winds from April to October and North-East Monsoon winds from November to March, which bring changes in temperatures and rainfall. The average annual precipitation along the Kwale County coast lies between 1,000-1,600 mm. The high humidity usually occurs throughout the year, reaching a peak between April-July.

During this decade, the average temperature on the Earth's surface has increased slightly, but Earth's temperature increasing by 1.4-5.8^{0}C is expected during the 21st century. The IPCC's Fourth Assessment Report recognizes the threat climate change poses to the developing world (IPCC 2007). The climate change elements important for Kenya are rainfall (amount and distribution) and temperature (especially the maximum and minimum). The impending climatic change has many possible impacts, including accelerated melting of polar belts glaciers, which can significantly raise sea levels and place many coastal towns and islands such as Lamu, Malindi, Mada Mombasa, and Zanzibar at great risk ofelimination by submergence. The projection from the National Climate Change Response Strategy on the following impacts of climate change on the marine and coastal environment, including Kwale county (Goverment of Kenya 2010). (i) Approximately 4,600 ha or 17% of the land mass in Kenya could be inundated due to a sea level rise of only 0.3 m, thereby affecting coastal development sectors, especially tourism. (ii) Sea rising level will lead to the displacement and submergence of coastal wetlands and result inhigh salinity and accelerated erosion of the shorelines due to the intrusion of saline water into coastal aquifers. (iii) The distribution of mangrove forests will change, particularly for wood/timber products, fisheries, and coastal hazard buffering, thereby jeopardizing the coastal communities' livelihoods that depend on them. (iv) Increased risk of high tides and flooding in lower-lying coastal areas. (v) Coral reef bleaching may increase due to global warming, affecting the coral reef ecosystems, a key tourist attraction.

Coastal fisheries

Kwale County has a coastline that is approximately 110 km long. Coastal fisheries along the coastline are the major source of livelihood for the coastal communities by providing employment, food, and generating income. The coastal fisheries in Kwale county are characterized as less capital intensive, labor intensive, multi-gear and multi-species, and tied to coastal communities and settlements. The locally crafted vessels cannot withstand thedeep rough seas, and the fishing activities are limited to the near shore, approximately 15 km from the county shore. The county has 46 fish landing sites, with limited infrastructure due to remote areas. Only one landing site at Vanga has operational fish storage with a coolingsystem (Republic of Kenya 2012). The tourism industry contributes to the county's economy in the Northern part of Kwale's coastline, where intensive tourism infrastructure is present. In addition, agricultural production that contributes to the county's economy is practiced mainly in the county's hinterlands.

Mangrove ecosystems

Mangrove forests happen along the coastline of Kwale County. These forests border terrestrial forests on the land side and are connected with coral reefs and seagrass beds on the seaside. The county has approximately 6,490 ha of mangrove forests concentrated in four major areas, Gazi, Shimoni, Vanga, and Funzi (Figure 1). All nine mangrove species in Kenya are also found in Kwale county, with Rhizophora mucronata, Avicennia marina, and Ceriops tagal being the dominant species (Huxham et al. 2015). Mangrove forests are of great importance in ecological andeconomic to the county. They are nutrient-rich ecosystems that directly andindirectly support a wide range of food chains, support the coastal fisheries production in the county, and function as habitats and feeding grounds for fish and invertebrates. Mangrove forestsare also exploited for extractive uses such as medicine, timber, and firewood.

Sample Size and Sampling Procedure

A sample of 242 fishermen was randomly selected by first obtaining the list from seven major fishing villages of fishermen in each village from the respective beach management units; Vanga, Funzi, Bodo, Gazi, Majoreni, Shimoni, and Kinondo were interviewed. Then, the fishermen wereinterviewed at the fish landing sites after landing their catch in the afternoon or before they started their fishing expedition in the morning.

Data collection

Primary data

Primary data was generated using a questionnaire survey, focused group discussions, and key informant interviews.

Questionnaire survey

A questionnaire survey was one main tool for information and data gathering. The questionnaire survey (Appendix 1) was divided into three major parts. Part one was on the fishermen's personalinformation to establish their characteristics. Part two engagedfishing-specific questions such as the cost of fishing (labor costs, boat ownership, gear ownership, buying price, and maintenance costs), seasonality, and the third part concerns coastal fisheries management measures (licenses and permits) and opportunities for Climate Compatible Development (CCD). The questionnaire was administered in six fish-landing villages (Vanga, Funzi, Bodo, Gazi, Majoreni, and Kinondo).

Focus group discussion

Furthermore, to collect qualitative data utilizing the focus group discussions by forming groups (7-10 people) consisting of elders, fishermen, and youth to create free discussion with the participants and explore for answers regarding the study's research questions. Finally, for the scenario analysis, scenario panels consisted of experts from stakeholders, including government agencies, local communities, and NGOs, to build storylines for the next 20 years on the coastal fishery sector under both Business as Usual (BAU) and Climate Compatible Development (CCD) scenarios.

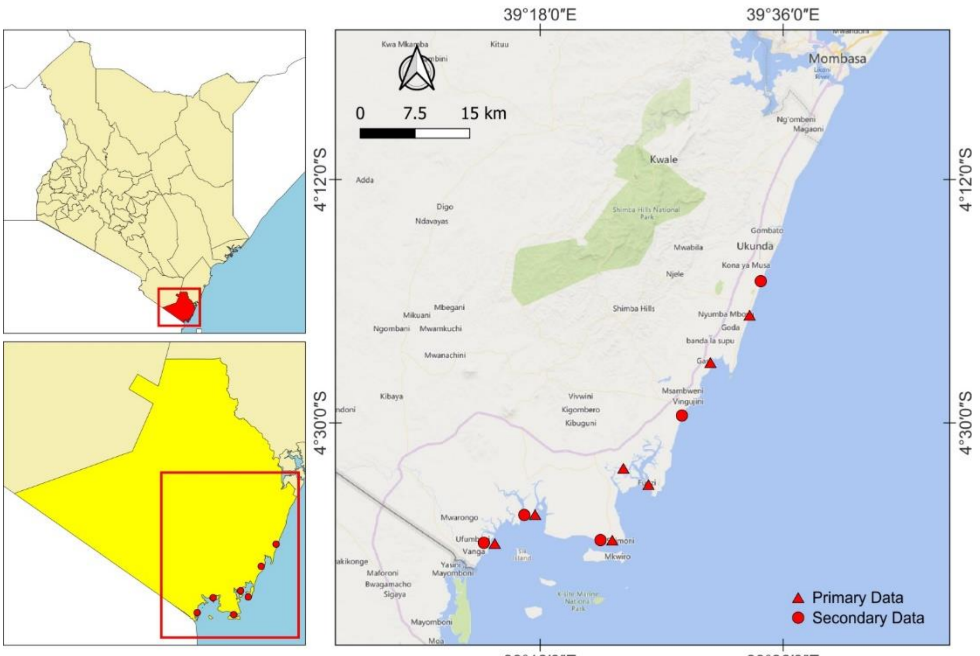

Figure 1. Map of the coastline of Kwale County, Kenya

Key informant interviews

Interviews with key informants were used to collect data from individuals considered to be the village opinion leaders and government officials.

Secondary data

Mostly the secondary data was used in the study obtained from the fisheries department and Kenya Marine and Fisheries Research Institute (KMFRI) . This data was used to construct annual datasets of fish landings, which detail the species of fish landed, the amount of fish landed in kilograms (Kg), and the auctioning pricesof fish in Kenyan shillings (Ksh) at the landing site over 10 years to enable trend analysis. In addition, to identify mangrove-associated species from the catch data, the study also utilized published scientific literature and expert.

Economic valuation methodology

The function of production and market price approaches to economic valuation is commonly used in evaluating coastal and mangrove-associated fisheries; even though they fall under the provisioning category of ecosystem services, a wide range of valuation methods can be applied (Barbier 2000, 2007).

The function of production treats an ecosystem's ecological function or biological resource as an input to the production of marketed output. Therefore, its value is determined by equating it tooutput changes (Barbier 2000). At the same time, applying this method has demanded economic and ecological data requirements. Also, it needs various assumptions, like a Cob-Douglas production function which limits an optimal catch of fisheries model, the elasticities of substitution amonginputs, and long-run competitive equilibrium. Moreover, this approach fails to consider the conceptual problems with biophysical models of ecosystem services and the reality of insufficient data (Parks and Gowdy 2013).

The study uses the market price approach due to the lack of the specific data required for adopting production functions and their inherentcomplexities and suitability to the study's circumstances, e.g., the kind of data available.

Data analysis

Descriptive statistics in average counts were made to determine the coastal fisheries characteristics between sites. Graphical analyses and representation were done in Excel 2007. The estimation model below was used to undertake data analysis and estimate the economic valueof coastal and mangrove-associated fisheries in Kwale County.

Estimation model

$$V = \sum P_{s,y} \times Q_{s,y} - \sum C_{i,y}$$

Fish price ($P_{s,y}$) = market price of fish species *s* in year *y* (Ksh/kg)Fish catch ($Q_{s,y}$) = quantity of fish species *s* in year *y*

Fishing cost ($C_{i,y}$) = Cost of boat + operating costs + cost of gear + labour costs

Where:

Cost of the vessel and gear = $\frac{P_{v,g}}{l_{v,g}+r_{v,g}}$, for boat and gear owners.

$P_{v,g}$ = price of vessel or gear, $l_{v,\ g}$ =life span of vessel or gear in years, $r_{v,g}$ = repairing costs forvessel and gear

The cost of a boat renting was considered for non-boat owners.Operating = fuel used if the motorized.

Cost of gear = the cost of buying or renting gear such as nets.

The estimated profitability of coastal fisheries was the ratio of annual fishing income to annualfishing revenue (Teh et al. 2011).

$$P = \frac{NI}{TR}$$

Where, $NI = TR - TC$

P = profitability, NI = net income per year, TR = total revenue per year, and TC = total cost peryear.

Scenario analysis

The storylines building under the BAU and CCD scenarios and the current management regime of coastal fisheries were first analyzed. Secondly, a scenario panel comprised multidisciplinary experts from institutions, stakeholder organizations, and representatives. The panel comprised government officials (the fisheries department, NEMA, KFS, KMFRI, and CDA), NGO (WWF and wetlands international), academia, and corporate (Base Titanium). Under the guidance of the researcher, the panel identified the drivers and descriptors of change and discussed the scenarios' focal questions. The scenario-building process was based on twoassumptions that were; assumed a continuation of the surrounding coastal fisheries situation of Kwale County under the BAU scenario, while the CCD scenario assumed that major policy shifts are made concerning the management of coastal ecosystems, investing in programs that integrate development with adaptation mechanisms and mitigations. Based on those two scenarios, a storyline was developed on how future coastal fisheries might look under BAUand CCD. This approach follows scenario analysis on the millennium ecosystem assessment methodology (Alcamo et al. 2005).

RESULTS AND DISCUSSION

Demographic characteristics of the respondents

Age and gender

Most respondents were between 25 and 34 years, constituting 31% of the respondents. On the other hand, fishermen below the age of 45 constituted 78% of the respondents. That indicates that most fishermen are youthful, with an average age of 35 years (Figure 2). Regarding gender, 100% of the respondents were male because females do not go on fishing but are engaged in fishing-related activities such as fish processing and marketing.

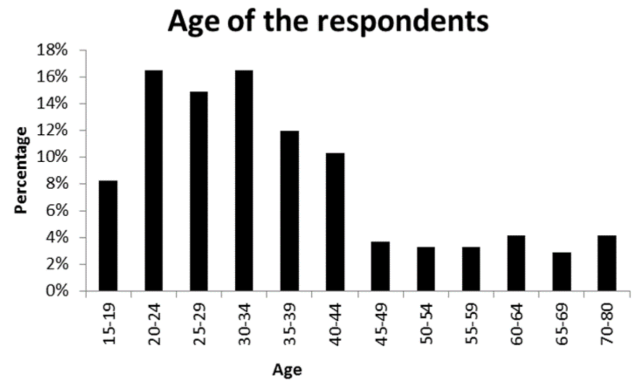

Figure 2. Age of the respondents

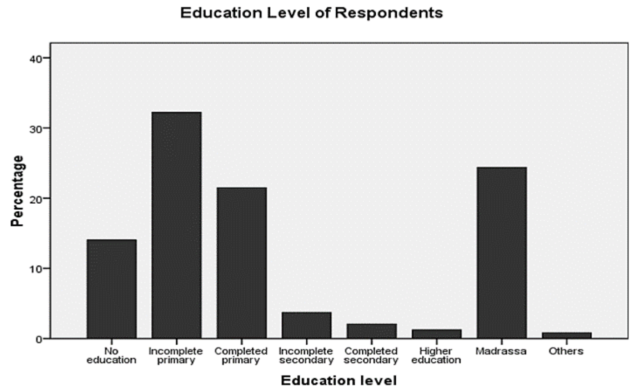

Figure 3. Education level of the respondents

Education and occupation

Primary school dropouts comprised 32.2% of the respondents; 21.5% completed primary school, while 14% had no education. The combined percentage of fishermen with incompleteprimary and complete primary school and no education comprised 68% of the respondents. Secondary school dropouts comprised 4%, and only 2% of the respondents completed secondary school. About 24% attended madrassa schools since most fishermen in Kwale County are Muslims by religion (Figure 3).

From the above discussion, in Kwale County, the level of education among the fishermen can be concluded to be low. That is because the number of schools in the coastal areas is less, and there is a slight motivation for higher education amongst fishing communities as there are only a few higher graduates to motivate younger generations. In addition, that is because of other competing livelihood activities, such as fishing, selling, and farming, that youth get engaged in to support theirfamilies.

Regarding occupation, 85% of respondents reported fishing as their mainstay occupation. In comparison, 15% stated that fishing was a part-time job and engaged in other sources of livelihood,such as farming and business (Figure 4). Furthermore, very few individuals are employed in the civil service due to the low level of formal education.

Vessel and gear types

The exploitation of coastal fisheries in Kwale county by multiple vessels and gears is used. Although locallycrafted dugouts/canoes are the type of vessels most commonly used (61%), it was also found that 20% of the interviewees do not own vessels but rather walk to the sea and fish by diving and swimming (Figure 5). The coastal fishermen use several gears to catch fish from the water;hand lines make up 28% of the gears used, then spear guns (15%) and gill nets (13%) (Figure 6). The survey data shows that the number of respondents who uses illegal fishing gear is 23%(beach sien, spear gun, and monofilament net).

The trend of coastal fisheries

The Kwale County annual production of coastal fisheries from 2004 to 2013 generally exhibited an increasing trend with time, although various. For example, production increased from 1,908 tons in 2004 to 2,450 tons in 2013, reaching its peak in 2009 at 2,530 tons. The price of catch and revenue generated similarly has shown a consistently increasing trend in the past decade, reaching a maximum revenue generation of about Ksh.260 million in2013 (Figure 7).

The total production in 2013 contributed by demersal fish contributed 48%, then by Pelagic fish and Molluscs,26% and 11%, respectively. On seasonality, the lowest production was recorded between April and August (Figure 8).

The economic value of mangrove-associated coastal fisheries

The study identified 14 species of data fish caught in Kwale County associated with mangrove habitats at least during one life cycle stage. In addition, published scientific studies were utilized to identify mangrove-associated fisheries. As a result, mangrove-associated fisheries accounted for 1,036.7 tonnes (42.3%) of the total catch in 2013 and amounted to Ksh.107.8 million (41.5%) of the total revenue from coastal fisheries (Table 1). KwaleCounty has approximately 6,490 hectares of mangrove forests, estimated to contribute close to 160 Kg/ha/year of coastal fishery production and an amount of Ksh.16,610/ha/year in incomegeneration.

The economic value of coastal fisheries

In the base year of the study of 2013, a total fish catch of 2,450.773 tons was recorded in Kwale County, generating estimated revenues of about Ksh.260 million (Ksh.106,091/ton). Furthermore, the cost of fishing operations was estimated to determine the economic values of coastal fisheries (total revenue generated less the total cost of fishing). As a result, Kwale county's annual fishing cost was estimated at Ksh.78 million. The fishing cost comprises the annual average cost of fishing vessels, operating cost, labor cost, and the average cost of fishing gear. The opportunity cost of labor forms the largest component of fishing at Ksh.52 million (67%). Moreover, considering the depreciation cost of fishing vessels and gears, the estimated annual average cost was Ksh.13 million (17%) and Ksh.8 million (10%) of the total cost, respectively. Operating costs, including fuel, constitute the remaining Ksh. 5 million (7%) of the total fishing cost. Therefore, the economic value of coastal fisheries is the total estimated fishing revenue, less the cost associated within, at Ksh.182 million in 2013. This net income hadan average profit margin of 0.7 annually.

Coastal fishery scenarios under Business As Usual (BAU) and Climate Compatible Development (CCD) scenario

Business As Usual (BAU) scenario

The data were analyzed on the current management measuressurrounding coastal fisheries and their enforcement from the survey questionnaire under the BAU scenario. In addition, a scenario panel consisting of multidisciplinary experts from institutions, stakeholder organizations, and representatives identifies the future change drivers that could affect coastal fisheries.

Management measures

This section analyzed the current management issues measures of coastal fisheries, such as licensing, illegal fishing, and changes in catch sizes with time, to provide baseline information for scenario analysis.

Fishing license

The fisheries act regulates the operations of coastal fisheries and mandates fishing permits for fishermen and licensing of vessels and boats (Cap 387). However, among the interviewed fishermen, 51% had neither fishing permits nor boat licenses, 6% owned boatlicenses, 27% had fishing permits, and 16% had both fishing permits and boat licenses (Figure 9).

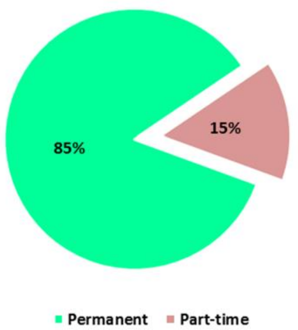

Figure 4. Basis of fishing occupation

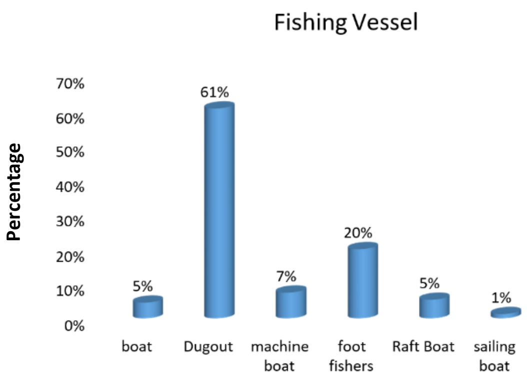

Figure 5. Type of fishing vessel used

Illegal fishing gears

On the occurrence of illegal fishing gear, 47% of the respondents reported using illegal fishinggear, using illegal fishing nets (22%), and dynamite fishing (17%) (Figure 10). Moreover, it was discovered from the FGD and key informant interviews that sometimes the locals/villagerstip off fishermen engaged on impending patrols of law enforcement agencies in illegal fishing. It was also found that to evade law enforcement officers or BMU, the catch from using outlawed gears was not landed at the official landing sites.

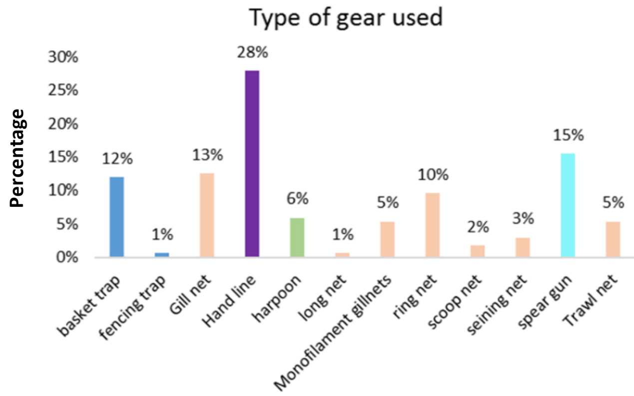

Figure 6. Type of fishing gear used

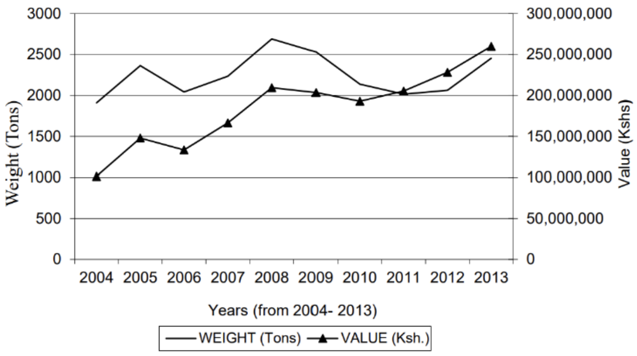

Figure 7. The trend of fish production in Kwale County, Kenya (2004-2013)

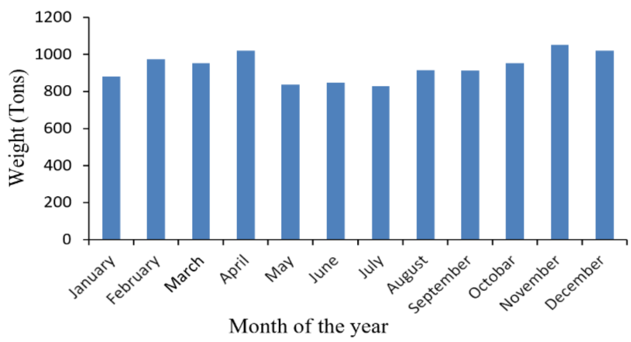

Figure 8. Average monthly production of coastal fisheries from 2005-2013

Table 1. Mangrove-associated fish species in Kwale County, Kenya

		Mangrove-associated species				Total catch landings			
English name	**Family name**	**Mangrove-associated species**	**Ref.**	**% of total catch**	**% of total revenue**	**Weight (Kg)**	**Revenue (Ksh)**	**% catch of total catch**	**% of total revenue**
Dermasals									
Rabbitfish	Siganidae	M	1,4	6.4	7.7	157971	19965860	6.4	7.7
Scavengers	Lethrinidae	M	1,2,4	5.2	5.7	127058	14703370	5.2	5.7
Snappers	Lutjanidae	M	1,2,3,4	3.7	3.8	91271	9923450	3.7	3.8
Parrot fish	Scaridae	M	1,3,4	5.7	5.1	138953	13299830	5.7	5.1
Surgeon	Acanthuridae	M	1, 3	2.6	2.2	64092	5773120	2.6	2.2
Unicorn	*Naso brevirosyris*					59230	5105080	2.4	2.0
Grunter	Haemulidae	M	1, 3	0.8	0.7	20269	1897420	0.8	0.7
Pouter	*Cephalopholis argus*					70526	6296470	2.9	2.4
Black skin	*Gaterin sordidus*					104660	10487610	4.3	4.0
Goatfish	Mulidae	M	1,2	1.5	1.7	36059	4317710	1.5	1.7
Streaker	*Aprion virescens*					34084	3130040	1.4	1.2
Rock cod	Serranidae					71467	7579850	2.9	2.9
Catfish	Aridae					40499	3881280	1.7	1.5
Mixed dem.						152617	14344910	6.2	5.5
Sub-total						1168756	120706000	47.7	46.5
Pelagics									
Cavalla.j.	*Euthynnus pelamis*					40259	4924990	1.6	1.9
Mullets	Mugulidae	M	1,2	3.1	2.8	75602	7370520	3.1	2.8
Mackerel	*Kanaguta*					118355	11396070	4.8	4.4
Barracuda	Sphyranidae	M	1,2,3,4	3.5	3.3	86646	8493780	3.5	3.3
Milkfish	Chanidae	M	1,2,4	1.3	1.2	32330	3115640	1.3	1.2
Kingfish	Scombridae	M	1	1.0	1.2	23664	3222310	1.0	1.2
Queenfish	*Chorinemustol*					17229	1842090	0.7	0.7
Sailfish	Istiophoridae					5660	800480	0.2	0.3
Bonito/tuna	Arangidae					69602	7022840	2.8	2.7
Dolphinfish	Colyphaenidae					12817	1378860	0.5	0.5
Mixed pel.						154307	16900410	6.3	6.5
Sub-total						636471	66467990	26.0	25.6
Sharks/rays	*Carcharhinidae* /others					50815	4392440	2.1	1.7
Sardines	*Clupeidae*	M	1,2	4.7	2.3	116212	5981200	4.7	2.3
Mixed/others						101887	7626865	4.2	2.9
Sub-total						268914	18000505	11.0	6.9
Crustacea									
Lobsters	*Penulirus* spp.					17581	10705350	0.7	4.1
Prawns	*Paenus* spp.	M	5	0.9	1.5	21664	3801400	0.9	1.5
Crabs	Scyllaridae	M	5	1.9	2.3	45406	6001865	1.9	2.3
Sub-total						84651	20508615	3.5	7.9
Miscellaneous									
Bech-de-mer	Holothuroidae					8796	1340110	0.4	0.5
Octopus	*Vugaris* spp.					181334	19967560	7.4	7.7
Squids	*Sepia oligo*					101851	12799370	4.2	4.9
Sub-total						291981	34107040	11.9	13.1
Grand-total				42.3	41.5	2450773	259790150	100.0	100.0

Note: M-Mangrove-associated species; 1. Kimani et al. (1996), 2. Huxham et al. (2004), 3. Lugendo et al. (2007), 4. Crona and Rönnbäck (2007), 5. Huxum (2013)

Changes in catch size

The coastal fisheries' catch size depends on several variables, including time spent fishing, seasonality, and the type of fishing gear and vessel employed. While holding these variables constant, 19% of the interviewed fishermen said there was no change, while 77% reported a change in average catch size as it was in the past 10 years (Figure 11). The respondents who reported the change in catch size (49%) mostly believe that declining fish catch is attributed to climate change and its extreme weather conditions. The focus group discussions also confirmed the decline incatch per fisherman. From interviews with key informants, some fishermen are employing multiple gears and increasing the effort by spending more time at sea while others get engaged in part-time jobs to maintain the fish catch.

Drivers of change

The direct and indirect drivers of change were identified for the scenarios analysis to be plausible and their likely consequences under businesses as usual and climate-compatible development scenarios.

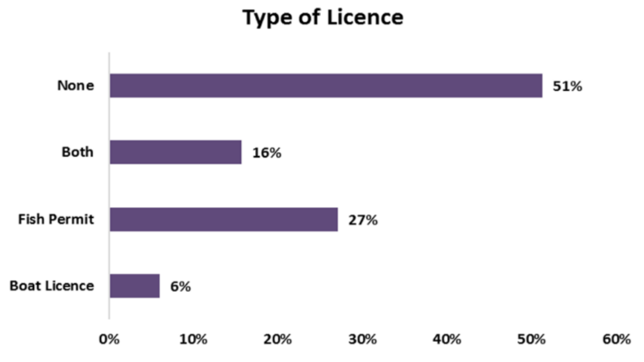

Figure 9. Type of license owned

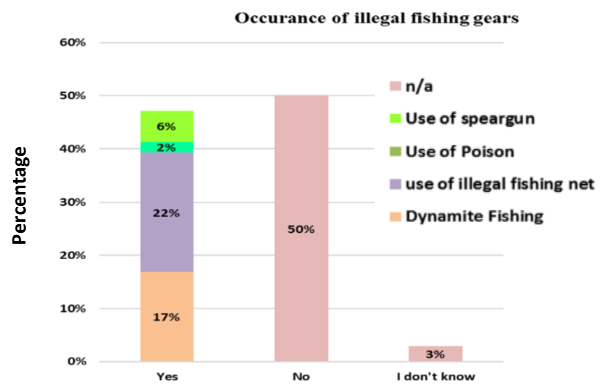

Figure 10. Occurrence of illegal fishing gears

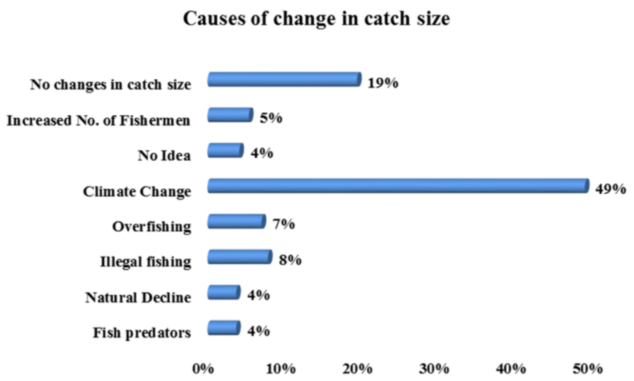

Figure 11. Causes of change in catch size

The scenario panel categorized the direct drivers of changes as positive, neutral, and negative. The positive drivers include restoration and ecosystem conservation (e.g., creation of Locally Managed Marine Areas (LMMA), Marine Protected Areas (MPA), and restoration of mangrove habitats), sustainable resource management, and adoption of environmentally sound technologies. Land use change in coastal areas was identified as a neutral driver, which could have negative or positive impacts depending on thecontext. The negative drivers include habitat destruction (coral reefs, mangroves, and seagrasses), pollution, and overfishing.

The indirect drivers in the context of coastal fisheries were identified as population dynamics, climate change, policy instruments, unsustainable inland and offshore development, and technological innovations. Among the indirect drivers, climate change was identified as the most serious impact it would have on the sustainability of coastal fisheries and their.

Climate Compatible Development (CCD) scenario

The scenario panel projected that under Climate Compatible Development, assuming that major policy shifts are made concerning coastal fisheries management in the 20 years to come. The organ of the Kenyan government that are concerned with environmental development and protection, such as the National Environment Management Agency (NEMA), Kenya Forestry Service (KFS), Fisheries Department, and Kenya Wildlife Service (KWS), will achieve well-coordinated and integrated working practices that will strengthen law enforcement and policy implementation. That will lead to the thorough application of the existing progressive laws, which will encourage and strengthen the existing community-based organizations and the growth of new community-based groups, including Community-Based Organizations(CBO), Community Forest Associations (CFA), and Beach Management Units (BMU). Furthermore, it will promote control of resources and community ownership, especially in fisheries and forestry, and this will further help address inequality and poverty.

The scenario panel further envisioned that the negative effects surrounding coastal fisheries would be addressed in the CCD scenario by adopting development strategies coupled with adaptation and mitigation mechanisms. Adaptation measures include climate-proofing infrastructure, ecosystem adaptation adoption, capacity building, and disaster preparedness. In contrast, mitigation measures would entail better designing cooling storages to reduce energy consumption, technical innovations to reduce fossil fuel use, and protecting and restoring mangrove ecosystems. Those declining temperatures will initially suffer sensitive species from the impacts of climate change, like coastal fisheries. These effects will be addressed through rehabilitating and conservating important habitats, including mangroves and coral reefs, and establishing locally managed marine areas and new marine protected areas. BMUs have become more effective in avoiding overfishing and enforcing appropriate fishing methods through effort-based management systems. The value of the catch will increase through improved fish processing, marketing and value addition chains, new storage and freezing facilities, and increased fish demand. The Kenyans would encourage deep-sea commercial fishing to tackle illegal offshore fishing and create new employment opportunities. The production of aquaculture in theregion doubles under the CCD scenario.

Discussion

The trend of coastal fisheries

The fisheries production increasing trend could be attributed to increasing fishing efforts, which concurs with the findings of Ochiewo (2004) and the Republic of Kenya (2012), who reported on the fishing effort that has been increasing with time, fishing gear, fishing vessels, and the number of fishermen, over time in Kwale County. The increase in fishing efforts is due to the increasing population growth, fish demand, and limited other sources of livelihood.

As shown in (Figure 2), the study has established that the production of fish is high between September and March and low in April and August. That aligns with the findings of Ochiewo (2004) and Benards (2010), who established that seasonal variations of the monsoon winds influenced fishing activities. For example, during the North-eastern (NE) monsoon blows from September to March, fishing activities are intensive due to the calm sea. On the other hand, during the Southeastern (SE)monsoon, this blows between April and August; the sea is rough in this period, and fishing activities are low due to their artisanal vessels cannot resist the rough sea. In the Northeastern season, migratory fishermen from Tanzania with better expertise, fishing vessels, and gears contribute to higher fish production this season.

Mangrove ecosystems and their contribution to coastal fisheries production

The mangroves' contribution to the value of fisheries production depends on many factors, site characteristics, climate variability, the species under consideration, and the presence of predatory competitors and their abundance among them (Faunce and Serafy 2006; Aburto-Oropeza et al. 2008). Nevertheless, the results on mangroves' contribution to the Kwale County coastal fishery production indicate that mangroves are critical to fishery production in the county. For example, in 2013, mangrove ecosystems were associated with 42.3% of the total fish catch and the total revenue at 41.55. In other words, mangroves are attributed to fish production of 160 Kg/ha/year with a value of Ksh. 16610/ha/year (US$ 198/ha/year).

The revenue of mangrove contribution to fisheries production is consistent with Kapetsky (1989), who estimated that the average fin and shellfish production to about 90 kg/ha/year with a maximum yield of 225 kg/ha/year in mangrove areas. However, the calculated results in both catch and value are higher than those estimated by Kairo et al. (2009) and UNEP (2011a,b), managed in Gazi bay, Kenya. For example, Kairo et al. (2009) that estimated the catch of mangrove-associated fin fish to be 94.62 kg/ha/year and a net income of US$ 113.09/ha/year; at the same time, UNEP (2011a,b) calculated the value of fish production on mangroves to be US$ 44/ha/year. This study estimated the higher value of the mangrove contribution to fisheries production could be explained by the spatial coverage of the study and the extensive data compiled that was not used in the previous studies.

Since the fisheries data records are not usually captured, the value within the mangrove forests (on-site) fisheries to the value of mangroves associated with fisheries production could be much higher than estimated. On-site fisheries are also composed of the harvest of resident species, such as the capture of prawns and fish that use mangroves for feeding duringhigh tide and mangrove crabs and oysters, which are harvested for subsistence across the coast of Kenya (Bosire et al. 2012) using hand lines, fence traps, and a range of other gears (Samoilys et al. 2011).

The economic value of coastal fisheries

These findings indicate that the livelihoods and welfare of coastal communities in Kenya are critically related to coastal fisheries. For example, in Kwale County, among the main sources of income generation are coastal fisheries that provide food security through fish consumption and using income derived from buying other stable food such as maize flour. They also support smaller industries such as boat repair and making, tourism, and transport along the coastal villages.

The coastal fishery production in 2013 amounted to Ksh.182 million or (US$ 2.2 million) which is lower than the value estimated by Barnes-Mauthe et al. (2013). They calculated the value of small-scale fisheries in Velodriake, Madagascar, to be US$ 6.9 million, which couldbe because some species with high prices (sea cucumber and Octopus) of the production of small-scale fisheriesare exported to developed countries. The Kwale County coastal fisheries value is higher than that of small-scale fisheries in Navakavu, Fiji, estimated at US$ 790,226 annually by O'Garra (2012). Moreover, the coastal fisheries value compared to thecalculated could be higher because there are unrecorded catch data, constituting 20% of fishermen that are landed in smaller landing sites or caught by foot fishers (Republic of Kenya 2012).

The average profitability ratio calculated (0.7) in Kwale County shows that coastal fisheries are highly profitable and could be a poverty buffer for coastal communities. That aligns with Barnes-Mauthe et al. (2013), who reported an average profitability ratio of (0.87), for small-scale fisheries in Velondriake, Madagascar. In addition, Teh et al. (2011) also found in Sabah, Malaysia, that small-scale fisheries play a significant role in preventing poverty in those coastal communities. Furthermore, Béné et al. (2007) also hypothesized the coastal fisheries importance in poverty prevention which play a major role in coastal zones to food securityand poverty prevention.

Business As Usual (BAU) and Climate Compatible Development (CCD) scenarios

The analysis of the current management regime reveals their weak enforcement even though policies and regulatory frameworks exist. This weak regulation enforcement could beattributed to poor infrastructure in many of the remote fish landing sites, poor financing of the enforcement agencies, and a shortage of monitoring and surveillance equipment. The currently prevailing weak enforcement regime, if not addressed, would result in the longer-term depletion of the stock of coastal fisheries.

The projected climate changes are also expected to affect coastal fisheries and their habitats adversely. Changes in temperature and salinity will affect oceanographic processes such as ocean acidification and upwelling, resulting in coastal fisheries' vulnerability in terms of fish catch and diversity. Climatic factors such as rising sea levels, increasing water temperature, and storms will negatively affect the coastal ecosystems' productive capacity, such as mangroves, sea grasses, and coral reefs, affecting coastal populations' livelihoods. The expected fishing days are to be reduced by bad weather, damaging fishing vessels and gear.

Stockholm Environment Institute (2009) assessed the impact of sea level rise in conjunction withthree IPCC socio-economic scenarios in Kenya that describe population density and growth as well as future GDP (A1FI, A1B, and B1) (Figure 12). The analysis shows that coastal inundation due to rising sea levels would affect people between 10,000 to 86,000 in coastal areas and reduce the area of coastal wetlands such as mangrove forests, coastal forests, and salt marshes. The study further estimated the associated economic costs of $7-58 million annually if adaptation measures are not taken by 2030.

In the Business As Usual (BAU) scenario, no changes will be introduced, and the direct and indirect drivers will behave as they are currently. However, the current population growth, doubled with the limitedother sources of livelihood, will further increase fishing efforts excreted on coastal fisheries and may result in the depletion of the resources. For example, the projection of mangrove loss from 1992 - 2010 was 13.5 %to the 20 years to come; with the BAU scenario 43%, the mangrove cover in Kwale County will be lost by 2032 (Huxham et al. 2015). Furthermore, this mangrove loss will negatively affect the other adjacent fish habitats, seagrasses, and coral reefs throughsedimentation.

Under the country's vision 2030 framework, the proposed development projects in Kwale county, which include bio-fuel projects, sugarcane farming, the construction of a resort city, and the ongoing project on titanium mining, are envisioned to have environmental and social impacts. Under the poor law enforcement regime in the BAUscenario, these projects could lead to the loss of fishing grounds, the degradation of coastalecosystems, and pollution.

The effects combined of the weak enforcement regime, direct and indirect impacts and environmentally insensitive development projects threaten the sustainability of coastal fisheries under the BAU scenario through habitat degradation, overfishing, and reduced fish diversity and catch, which then undermines the coastal fisheries' importance to the welfare of coastal communities.

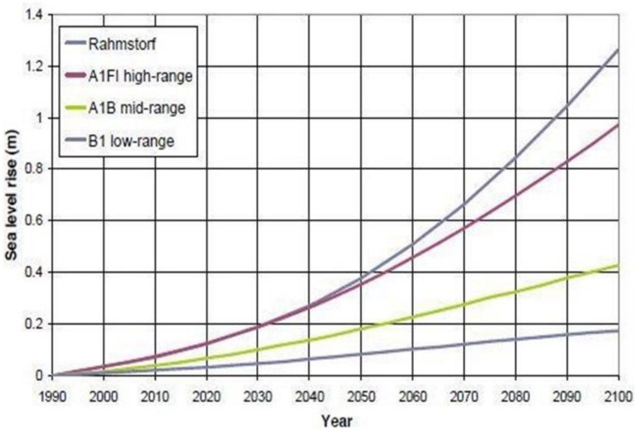

Figure 12. Sea level rise scenario

The stakeholders participating in the scenario-building exercise believed that regulations governing environmental matters and the current policies could contribute to realizing CCD. In the context of coastal fisheries, identifying and achieving the combination of mitigation, adaptation, and development (triple wins) are straightforward. Investments in adaptation measures, such as disaster risk reduction, improved infrastructure, capacity building, and mitigation measures, such as harnessing clean energy in cooling storages and protection and restoration of mangroves, would address to create of alternative sources of employment and the adverse impacts of climatechange. Furthermore, their sustainable utilization and conservation would foster economic development in coastal areas beyond coastal fisheries and contribute to the coastal communities' livelihoods.

Moreover, under both BAU and CCD scenarios, projections will, directly and indirectly, affect coastal fisheries catch and revenue. For example, under the BAU scenario, it is anticipated that within 20 years, mangrove forests will decline by 43% as an essential fishery habitat. An assumption on the corresponding loss in catch and revenue of the mangrove-associated finfish and crustaceans species will result in a loss of 446 tonnes in catch and Ksh.46 million in revenue annually. On the other hand, in the CCD scenario, the catch and revenue of mangrove-associated fisheries are expected to increase through the expansion and rehabilitation of mangrove forests.

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Conservation-based ecotourism development at Pasir Putih Prigi Beach, Trenggalek District, East Java, Indonesia

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Abstract. *Sulistyaningrum N, Kurniawati B, Nugroho GD, Sunarto, Kusumaningrum L, Sujarta P, Nisyawati, Thenya T, Setyawan AD. 2022. Conservation-based ecotourism development at Pasir Putih Prigi Beach, Trenggalek District, East Java, Indonesia. Indo Pac J Ocean Life 6: 29-35.* One of the contributors to state revenue is the tourism sector. To advance the tourism sector, the government has begun to develop tourism based on sustainable tourism. Sustainable tourism is useful for helping nature conservation efforts. Moreover, creating sustainable tourism, it can be done by creating ecotourism. This research was conducted in June 2022 with 50 respondents around the research location. Respondents aged 20-70 years consisted of traders, homemakers, fishermen, and Pasir Putih Prigi Beach management staff. This study examines conservation and ecotourism efforts by the community around Pasir Putih Prigi Beach and social perceptions of ecotourism. Several aspects studied in the Pasir Putih Prigi Beach conservation efforts include protection, preservation, utilization, and public perceptions of Pasir Putih Prigi Beach ecotourism. The study results show that protection employs local wisdom called *Larung Sembonyo*, a form of gratitude for the fishing community for the marine products that have been obtained. This ceremony is also a request for the safety of the fishing community when looking for fish in the sea. Preservation by regularly cleaning the beach while utilizing the beach as a recreation and trade center improves the community's economy. Recreation offered at the beach is swimming, boat rides, snorkeling, and deep diving. More than 90% of the coastal communities of Pasir Putih Prigi Beach do not understand the concept of ecotourism. People think that ecotourism is the same as tourism in general. Ecotourism conservation and development efforts are carried out by the Tourism and Culture Office of Trenggalek District through the TIU of Tourism Destinations with the community groups. Cooperation between the government and the community will increase coastal conservation and the economic benefits the community receives.

Keywords: Beach, conservation, ecotourism, Pasir Putih Prigi Beach, preservation

INTRODUCTION

Indonesia is one country that offers much tourism, ranging from nature tourism, culinary tourism, and cultural tourism. As an archipelagic country, Indonesia has thousands of islands with vast seas, so it is possible to have many diverse natural tourism potentials (Kodir et al. 2019). In addition, the coastal environment, as a transition between land and sea, has various environmental characteristics to support the community's economy.

Almost all regions in Indonesia have tourism icons with unique and interesting characteristics so that they can bring in various local and foreign tourists. Increasing visitors to the tourism area can help the country increase the country's foreign exchange earnings (Kodir et al. 2019). For example, the contribution of the tourism sector to the Gross Regional Domestic Product (GDP) of East Java Province was 17.30% in 2013, 17.14% in 2014, 17.46% in 2015, and 17.76% in 2016 (Ariani and Hayati 2020). This upward trend gives tourism the potential to become an economic base (Zen and Wulandari 2016). Currently, the tourism sector in Indonesia is regulated and managed by the Indonesian Ministry of Tourism and Creative Economy.

Along with an increasing public interest in the tourism sector, it also brings indications of negative impacts because it causes damage to existing ecosystems (Purwaningrum 2020). Therefore, the development of the tourism sector in Indonesia has begun to be increased to become tourism based on sustainable tourism. A sustainable tourism development concept based on the environment, often referred to as ecotourism, is one of the real steps to help nature conservation (Irwansyah et al. 2021). Thus, ecotourism is appropriate and useful in maintaining the integrity and authenticity of ecosystems in natural areas (Prihanta et al. 2020). In addition, ecotourism can economically increase local community involvement in environmental management (Sumarmi et al. 2021). The existence of ecotourism in an area also affects the lives of people around the area (Setyaningrum et al. 2020; Sumarmi et al. 2020). Therefore, ecotourism is rapidly gaining popularity as an alternative tourism development that will advance conservation and sustainable development.

One of the tourist sites in Indonesia is in East Java, precisely in Prigi Bay. The coastal waters of this bay have several beautiful beaches, namely Prigi Beach, Karanggongso Beach, Pasir Putih Prigi Beach, and Damas Beach. One of the famous beaches is Pasir Putih Prigi Beach. Pasir Putih Prigi Beach is one of the natural attractions in Tasikmadu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia.

Based on field observations, Pasir Putih Prigi Beach has waves that tend to be small, making it suitable for visitors who want to try or have a hobby of swimming or other water sports. Furthermore, Pasir Putih Prigi Beach has facilities and water sports facilities such as banana boats and swimming equipment such as life jackets that visitors can rent. This beach also offers boat rides for rent according to visitors' inner satisfaction. In addition, this beach can offer deep diving and snorkeling activities that will be accompanied by trained staff so that the safety of visitors is guaranteed.

As the manager, the Tourism and Culture Office of Trenggalek District has tried to attract visitors by fixing existing facilities, providing trash cans, and making promotional efforts directly and through social media. However, there are still some shortcomings in the development and conservation efforts at Pasir Putih Prigi Beach. In addition, the management's lack of knowledge about the ecotourism-based development of Pasir Putih Prigi Beach causes serious problems. Therefore, this study examines conservation and ecotourism efforts by the community around Pasir Putih Prigi Beach and social perceptions of ecotourism.

MATERIALS AND METHODS

Study area

The study was conducted in June 2022 at Pasir Putih Prigi Beach (8°17'56.65" S, 111°.44'23.96" E), in Tasikmadu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia. This beach is included in one of the leading tours in Trenggalek, which contributes a lot to regional income and empowers the community around the coast. Pasir Putih Prigi Beach has located approximately 3 km beside Karanggongso Beach. The two beaches are connected using a connecting bridge that can be accessed on foot. This beach has white sand, so it is called *Pasir* (sand) *Putih* (white) Prigi Beach in Indonesia. The following is a map of Pasir Putih Prigi Beach, shown in Figure 1.

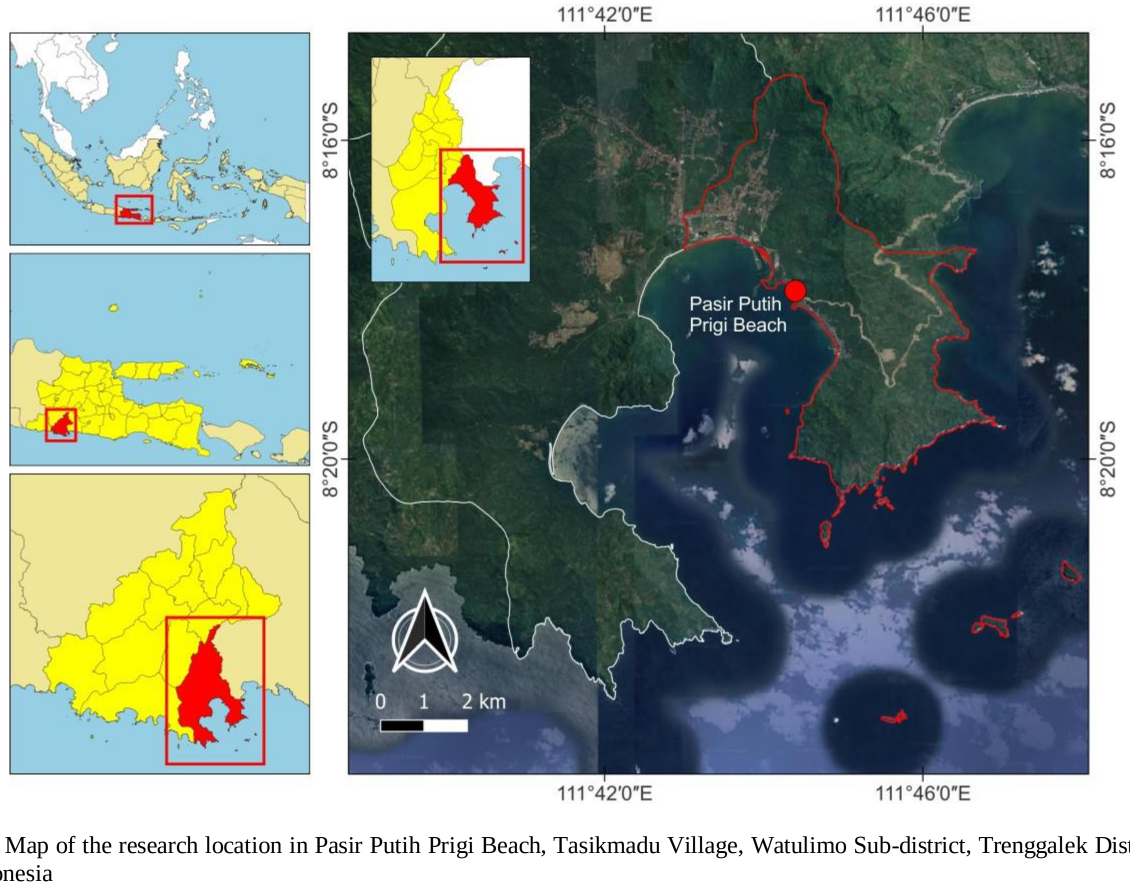

Figure 1. Map of the research location in Pasir Putih Prigi Beach, Tasikmadu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia

Data collection and analysis

Data were collected by observation, structured interviews, and literature study (Setiawan et al. 2017). Observations and in-depth interviews were used to collect data on community conservation efforts. The structured interview used a questionnaire to determine the community's perception of ecotourism development. Finally, a literature study was used to collect data about the general description of Pasir Putih Prigi Beach and the literature that supports the research. Key individuals were sampled in conservation efforts, which were determined using snowball sampling, which is a non-probability technique in which a researcher starts with a small population of known individuals and expands the sample by asking those initial participants to identify others who should participate in the study (Setiawan et al. 2017). The Tourism and Culture Office of Trenggalek District and the Implementation Unit (TIU) of Tourism Destinations of Pasir Putih Prigi Beach were interviewed as key respondents and the residents directly affected by the ecotourism activities there. This research was conducted with structured interviews with 50 respondents around the research location. Respondents aged 20-70 years consisted of traders, homemakers, fishermen, and Pasir Putih Prigi Beach management staff. The average education of respondents is Elementary School (SD) or equivalent, with a percentage of 64% (Table 1).

Then, conservation efforts were analyzed descriptively based on the Indonesian Government Regulation No. 5/1990 on Conservation Efforts. Then, the data about community perception of ecotourism development was also analyzed descriptively. In addition, the community's perception of the development of coastal ecotourism is categorized by the scoring method that can be seen in Table 2.

Table 1. Respondent profile (n= 50)

Profile	Category	Number	Percentage (%)
Gender	Male	21	42
	Female	29	58
	Total	50	100
Age	20-30	5	10
	31-40	11	22
	41-50	16	32
	51-60	14	28
	61-70	4	8
	Total	50	100
Education	Elementary School or below	32	64
	Junior High School	10	20
	Senior High School	8	16
	Total	50	100
Work	Trader	37	72
	Homemakers	3	6
	Fisherman	6	12
	Pasir Putih staff	4	8
	Total	50	100

RESULTS AND DISCUSSION

Pasir Putih Prigi Beach is one of the leading tourist attractions in the Trenggalek District. The length of this coastline is approximately 2 km. This beach is located on the edge of the Indian Ocean, so it allows this tourist area to experience changes in coastline due to the influence of wind/waves, currents, and tides. The factors that cause Pasir Putih Prigi Beach to be visited by tourists are easy to access by vehicle, beautiful sea views and the waves on this beach are relatively calm, making it suitable for recreational, swimming, bathing, and other activities to relieve stress. The more crowded the visitors at this beach must be balanced with the conservation efforts to remain sustainable to manage and utilize natural resources wisely to ensure their current and future existence. This conservation effort includes three main activities: protecting, preserving, and utilizing natural resources (Government Regulation of the Republic of Indonesia No. 5 of 1990).

Protection of Pasir Putih Prigi Beach

Coastal wetlands, such as beaches, are under pressure from human activities and natural causes due to climate change (Finkl and Makowski 2017). In addition, according to Finkl and Makowski (2017), it is estimated that about 50% of the world's coastal wetlands have been destroyed by urbanization, industrialization, and commercial development. The remaining 50% are under extreme threat from various anthropogenic activities such as logging, sand mining, oil and gas exploitation, agricultural and cultivated land expansion, wildlife hunting, and recreation. Furthermore, tourism development has been recognized as a direct contributor to changing coastal wetland ecosystems due to environmentally damaging infrastructure development and indirectly by introducing non-native species into the ecosystem (Mejía and Brandt 2015).

Pasir Putih Prigi Beach is managed by the Tourism and Culture Office of Trenggalek District, one of the organizations in the Trenggalek government whose task is to carry out government affairs in the tourism and culture sector in Trenggalek District, East Java, Indonesia. The Technical Implementation Unit (TIU) of Tourism Destinations assists the service in managing Pasir Putih Prigi Beach. The management members of Pasir Putih Prigi Beach are taken from residents and led by the TIU's head of Tourism Destinations. TIU of Tourism Destinations for Pasir Putih Prigi Beach has rules that apply to visitors and traders in the beach area, namely not to litter, not to damage existing facilities on the beach, and always to keep the beach clean. However, if visitors or traders cause the damage, it must be reported to the TIU of Tourism Destinations or directly to the Tourism and Culture Office of Trenggalek District. The report will be taken care of, and the perpetrators of destroying the environment and facilities will receive strict sanctions by applicable regulations.

Then, the Larung Sembonyo traditional event is held every Suro Month on the Javanese calendar. *Larung Sembonyo* is a marine alms culture carried out for generations by the ancestors of the local fishing communities around Pasir Putih Prigi Beach manifested in traditional ceremonies. That is a form of gratitude for the fishing community for the marine products that have been obtained. This ceremony is also a request for the safety of the fishing community when looking for fish in the sea. This habit has been carried out for a long time and has become part of the culture of the Trenggalek community, especially those living on the coast. With these factors, it will benefit visitors' inner satisfaction because it contains certain aesthetic values (Lelloltery et al. 2016), making Pasir Putih Prigi Beach tourism very special and projected as one of the icons of Trenggalek. In addition, according to Uspayanti et al. (2021) and Abas et al. (2022) indirectly, the existence of local wisdom in a place will make the community around the location have a conservation spirit to protect nature, in this case, the nature of the Pasir Putih Prigi Beach.

Preservation of Pasir Putih Prigi Beach resource

Pasir Putih Prigi Beach is a leading tourist attraction that is the mainstay of contributors to Regional Original Income (ROI) in the Trenggalek District. According to data from the Tourism and Culture Office of Trenggalek District (2022), the tourism sector's Regional Original Income (ROI) is 60% or around 4.2 billion rupiahs. The daily visitors of Pasir Putih Prigi Beach can reach thousands, and for 1 year, it can reach hundreds of thousands of visitors. So it is not surprising that the preservation of the Pasir Putih Prigi Beach resources must be well maintained by the surrounding community and the Tourism and Culture Office of Trenggalek District. Ecotourism development must utilize natural resources optimally by their carrying capacity so that they do not cause damage, respect the socio-cultural community, ensure sustainable economic benefits, and are distributed fairly to all stakeholders (Arintoko et al. 2020).

To preserve the resources of Pasir Putih Prigi Beach, the Tourism and Culture Office of Trenggalek District, through the TIU of Tourism Destinations, carried out a plan consisting of five stages, namely (i) carrying out an inventory of all available facilities and the potential possessed by Pasir Putih Prigi Beach, (ii) estimating the tourism market and trying to project tourist traffic in the future, (ii) paying attention to the amount of tourist interest and offers that can be given, (iv) researching the development of activities that are by the characteristics possessed by the Pasir Putih Prigi Beach Prigi, and (v) carrying out certain protections for the natural resources owned and carry out the maintenance of cultural heritage and customs that exist around the ecotourism area of Pasir Putih Prigi Beach. The tourism industry development planning carried out by the Tourism and Culture Office of Trenggalek District has gone hand in hand with the increasing number of visitors every year, which is one of the strategies used to promote the region as a tourist destination to increase the economy and job opportunities for the local community.

The implementation of those five stages that can be done to preserve the ecotourism of Pasir Putih Prigi Beach, namely carrying out regular community service to maintain the cleanliness of the coast, prohibiting the use of explosives and hazardous chemicals in fishing, planting trees in the coastal area, calling for to all visitors to dispose of garbage in the trash cans provided by the Tourism and Culture Office of Trenggalek District. Suppose the management of these potential natural resources is carried out properly; in that case, it will increase the country's foreign exchange, the availability of new job opportunities, and the development of new businesses. In tourism, management can be done through education that can increase public and tourist awareness about the importance of natural resource conservation. This education can be supported by developing coastal and marine ecotourism (Pasak et al. 2017). However, there are still shortcomings in implementing these steps, such as visitors having difficulty implementing regulations and appeals from the beach manager. In addition, there is also a lack of supervision from beach managers because there are too many beach visitors, especially during holidays, so managers are overwhelmed in controlling the visitors. In this case, visitors will usually be encouraged to go to other destinations provided by the Pasir Putih Prigi beach manager. The destination is Karanggongso Beach, located right beside the white sand beach. Both are connected by a bridge that can be accessed on foot while looking at the beach view.

Utilization of Pasir Putih Prigi Beach

Coastal wetlands, such as beaches, provide various ecosystem services to support human well-being. These ecosystem services include protection from storm surges and floods, regulation and purification of water, habitat protection, biodiversity conservation, carbon sequestration, education and research, and recreation (Dushani et al. 2021). In addition, according to Dushani et al. (2021), a wide variety of recreational activities can be carried out on the beach, including sunbathing, swimming, diving, snorkeling, boating, recreational fishing, bird watching, and mangrove viewing.

Especially at Pasir Putih Prigi Beach, based on the management staff, local communities, and direct observations, this beach has many benefits, namely preventing tidal water from directly flooding the land, a center for trading marine products, and a habitat for organisms that live in water, for fishing, and recreation areas. Recreational offered at the Pasir Putih Prigi Beach Prigi is swimming on the beach, boat rides, snorkeling, and deep diving. In addition, the well-maintained Pasir Putih Prigi Beach area makes coral reefs, and the fish that live in them also develop rapidly. That is one of the attractions and superior value of this beach that is rarely offered by other beaches.

Furthermore, to increase the number of tourists visiting Pasir Putih Prigi Beach, the manager is aggressively promoting social media, improving existing facilities around the beach, conducting conservation, and offering beach tourism based on local wisdom, which makes tourists never get bored of crowding the Pasir Putih Prigi Beach area. With the Pasir Putih Prigi Beach, the local community's economy also increases. The Tourism and Culture Office of Trenggalek District empower the surrounding community by recruiting beach management staff. The rest are empowered by providing a place to sell food and drinks typical of Pasir Putih Prigi Beach. Usually, the fishermen will do fish netting at certain times, and then they will be bought by traders to be sold again in the Pasir Putih Prigi Beach area. Well-managed sustainable tourism in and around coastal wetlands can provide significant economic and ecological benefits while enabling sustainable ecosystem services (Latif et al. 2021).

Community perception of ecotourism development

Public perception of ecotourism development is divided into several aspects, including public knowledge about ecotourism, willingness to participate in ecotourism development, economic benefits for the community, damage caused by visitors, and sustainability of coastal ecotourism development at Pasir Putih Prigi Beach. Community knowledge about ecotourism is measured based on people's understanding of the difference between ecotourism and ordinary tourism.

The concept of ecotourism is used as a strategy for economic development and conservation. Ecotourism focuses on nature-based elements where visitors undertake travel activities that can enhance the experience, increase curiosity, minimize adverse impacts on the environment and consider the welfare of local communities (Bandara and Vlosky 2016). The concept of ecotourism offers many advantages: visitors will not only travel in nature. Still, they will also learn about something from nature and carry out various environmentally friendly tourism activities (Kiper 2013). In addition, this ecotourism concept also provides economic benefits and develops the surrounding community. That differs from ordinary tourism (mass tourism), which generally consists of artificial tourism and does not empower local communities (Basyuni et al. 2016).

More than 90% or as many as 46 respondents of the Pasir Putih Prigi Beach coastal communities do not understand the concept of ecotourism. People think that ecotourism is the same as tourism in general. Community members who understand the concept of ecotourism are people who participate in ecotourism management, know about ecotourism from extension programs, and are active in community group activities. After determining the level of community knowledge, measurements were made on six aspects of ecotourism development (Setiawan et al. 2017). The six aspects of the perception of ecotourism development are shown in Table 2.

Based on structured interviews with 50 respondents, the first aspect relates to activity planners, tour guides, handicrafts, and homestays. Most respondents prefer to participate in making handicrafts or selling them (62% in Table 2). That is no different from the people in Gandoriah Beach, Pariaman City, West Sumatra, Indonesia, where people are more and like to do business activities by selling beach food and handicrafts (Jayanti 2019). They consider selling handicrafts, services, or special foods more profitable. The participation of the local community in ecotourism activities was very important because they would provide most of the attractions and determine the quality of the tourism products (Pangastuti et al. 2016).

The second aspect is the public's perception of the Pasir Putih Prigi Beach tourism manager. Two (2) sub-aspects comprise the community's willingness as the manager of the Pasir Putih Prigi Beach and the willingness of the community to carry out ecotourism support activities as business actors. The community's willingness to carry out coastal management is 40%. Meanwhile, the community's willingness to support ecotourism activities as business actors is 60%. Most people prefer to participate as business actors because the community considers the results of selling directly to tourists. The community considers income as a business actor to get a more certain income. In addition, most people have education between primary and secondary schools which causes them to lack the confidence to participate as managers. So most people choose to support ecotourism as a business actor.

Table 2. Community perception of ecotourism development (n = 50)

Behavior	**Agree/ willing (%)**	**Not agree/ willing (%)**
Willingness to participate in ecotourism development		
Planning activities	40	60
Tour guide activities	50	50
Souvenir activities	62	38
Providing homestay	18	82
Community perception of ecotourism group		
Manager	40	60
Businessmen	60	40
Government intervention in Pasir Putih Prigi Beach		
Partial intervene		100
Full intervene	100	
Ecotourism's impact on economic benefits		
Increase economic benefit for the community	100	
Economic benefit only for some participants		100
Visitors affect the environmental damage		
Garbage in forest area	0	100
Garbage in village	0	100
Damaging the mangrove trees	0	100
Damaging the ecotourism facilities	0	100
Willingness to develop sustainable mangrove ecotourism	100	0

Based on the data obtained in a third aspect, namely the public's perception of government intervention or intervention in the management of the Pasir Putih Prigi Beach, the community agrees that the management of the Pasir Putih Prigi Beach requires government intervention with a percentage of 100%. People prefer that tourism management has government intervention because it is more profitable than without government intervention. The management of tourism that involves the community considers the government to be more structured and controlled to make it easier for the community to carry out other activities to support the development of ecotourism. In addition, the government's tourism management is considered better in various aspects. Through the research of Sumarmi et al. (2021), local governments and communities should consider alternative policies and developments to support the environment and ensure the sustainability of the quality of natural tourism.

The fourth aspect is the impact of ecotourism on the economy of the community around Pasir Putih Prigi Beach ecotourism. The impact of ecotourism brings economic benefits to the surrounding community (Faizal et al. 2017). As many as 50 respondents, with a percentage of 100%, agree that ecotourism activities can improve the economy of all communities around the Pasir Putih Prigi Beach tourist spot. With the Pasir Putih Prigi Beach, some people trade around the ecotourism area. Then, the fishermen, after catching fish, the fish they catch are sold to traders who sell smoked fish or cooked seafood products. In addition, not far from there are several shops selling food, drinks, and handicrafts. Then there are also plenty of bathroom rentals and places of worship. Therefore, the management could increase the number of tourists attending using local communities and their wisdom (Sumarmi et al. 2020).

The fifth aspect is the environmental damage caused by visitors to the Pasir Putih Prigi Beach ecotourism. From the results of direct observation, it is rare to find garbage in coastal areas because there are staff on duty to clean up if there is garbage that has accumulated. The surrounding community and visitors know how important it is to keep Pasir Putih Prigi Beach clean. However, some visitors still throw garbage around the beach areas. Moreover, damaged facilities are rare in the ecotourism area of Pasir Putih Prigi Beach. Improving the quality of coastal ecotourism must be done by optimizing beach facilities that are useful for maintaining and developing environmentally friendly beach facilities (Yahya et al. 2013). The facilities offered by Pasir Putih Beach include trash cans on every corner of the beach, homestays, vehicle parking, souvenir businesses, grocery stores, prayer rooms, toilets, and the Pasir Putih Prigi Beach help center. All of these sub-aspects have the same average result, namely the percentage of 100% (Table 2). The community and ecotourism managers of the Pasir Putih Prigi Beach agree that ecotourism visitors do not cause significant damage or waste in the Pasir Putih Prigi Beach area.

The various benefits of ecotourism make the community, and the government wants to manage Pasir Putih Prigi Beach sustainably (Table 2). Pasir Putih Prigi Beach is an attraction for tourists because of its varied forms and atmosphere, based on the aspects of exploration, conservation, and integrated management. One aspect of development in the field of ecotourism is expected to realize sustainable ecosystem management through the development of ecotourism. One of the efforts to develop ecotourism is made using coastal conservation. Conservation management must be in line with the concept of tourism development which aims to maintain the process of ecological sustainability in living systems, protect biological wealth, ensure the authenticity and use of ecosystems and species, and have a positive impact on the welfare of the surrounding community (Yuliana 2019).

In addition to community welfare, one of the goals of ecotourism development is to reduce pressure on the coast as an environmental service (Finkl and Makowski 2017). Based on this, the ecotourism development of Pasir Putih Prigi Beach needs to pay attention to the possibility of disturbance from visitors. Currently, disturbances caused by visitors damage coastal ecosystems and beach facilities. Visitors to the Pasir Putih Prigi Beach ecotourism generally come from various regions. One of the beach managers, Sunaryo, said that on a normal day, there are 500 visitors to Pasir Putih Prigi Beach, but there will be an 8-fold increase to around 4,000 visitors during Eid. A large number of visitors brings economic benefits to the surrounding community and increases the regional income of the Trenggalek District. Therefore, most people agree with the development of the Pasir Putih Prigi Beach ecotourism. However, limited facilities, infrastructure, and the number of managers are challenges to the sustainable development of coastal ecotourism. Therefore, communities need support and cooperation from government and non-government organizations to develop ecotourism on Pasir Putih Prigi Beach.

This study concludes that the Pasir Putih Prigi Beach protection is carried out using local wisdom called *Larung Sembonyo*. Preservation by regularly cleaning the beach while utilizing the beach as a recreation and trade center improves the community's economy. Recreation offered at the beach is swimming, boat rides, snorkeling, and deep diving. More than 90% of the coastal communities of Pasir Putih Prigi Beach do not understand the concept of ecotourism. People think that ecotourism is the same as tourism in general. Ecotourism conservation and development efforts are carried out by the Tourism and Culture Office of Trenggalek District through the TIU of the Tourism Destination with the community members. With the collaboration of the government and the community, coastal conservation and the economic benefits received by the community will increase so that the community will participate in the protection and preservation of the Pasir Putih Prigi Beach ecotourism.

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Assessment of physicochemical parameters and heavy metals contamination in Korle and Kpeshie Lagoons, Ghana

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Abstract. *Clottey CA, Nukpezah D, Koranteng SS, Darko DA. 2021. Assessment of physicochemical parameters and heavy metals contamination in Korle and Kpeshie Lagoons, Ghana. Indo Pac J Ocean Life 6: 36-50.* Lagoons are highly productive coastal systems that could provide natural services to the surrounding ecosystem; however, their pollutions cause adverse changes in their natural environment. Korle and Kpeshie Lagoons in Ghana receive waste from industries and municipal sewage. Controlling and monitoring contaminants in these systems is very important to environmental protection. This study examined the presence of heavy metals (arsenic, chromium, copper, cadmium, lead, and zinc) in sediments, crabs (*Callinectes amnicola),* and fish *(Sarotherodon melanotheron)* at Kpeshie and Korle Lagoons. Although lagoons are highly productive coastal systems that offer ecosystem services, their pollution has a negative impact on the surrounding environment. Municipal sewage and industrial waste are dumped into Ghana's Korle and Kpeshie Lagoons. Contaminant monitoring and control in these systems are crucial for environmental protection. The study compared the concentrations of the heavy metals (arsenic, cadmium, copper, chromium, lead, and zinc) in sediments, crabs (*C. amnicola*), and fish (*S. melanotheron*) at Kpeshie and Korle Lagoons to the environmental standards set by international organizations like the WHO and US EPA. The sediments from the Korle and Kpeshie Lagoons had traces of contamination in the following metal concentrations in *S. melanotheron*: cadmium, copper, zinc, lead, chromium, and arsenic, in that order: As, 0.397 ± 0.07; Cd, 1.10 ± 1.31; Pb, 1.227 ± 5.77; Cu, 3.494 ± 4.56; Cr, 5.895 ± 9.76; Zn, 23.225 ± 10.93, and in *C. amnicola*: As, 0.288 ± 0.07 $mgkg^{-1}$; Cd, 4.60 ± 2.69 $mgkg^{-1}$; Cr, 39.521 ± 55.89 $mgkg^{-1}$; Cu, 31.085 ± 16.26 $mgkg^{-1}$; Pb, 10.902 ± 12.95 $mgkg^{-1}$; Zn, 36.042 ± 17.8 $mgkg^{-1}$. The sediments are severely polluted with Cd and Pb, according to pollution indices like pollution load index (PLI), contamination factor (Cf), and potential ecological risk index (RI). The FAO/WHO-allowable limit for cadmium, chromium, and lead was exceeded in *C. amnicola* and *S. melanotheron*. Consumption of *C. amnicola* and *S. melanotheron* does not appear to pose a potential non-carcinogenic health risk on an individual's daily basis. The estimated target hazard quotient (THQ) in Kpeshie Lagoon of Cd, Cr, and Pb of the fishery investigated was less than 1.

Keywords: Coastal systems, controlling and monitoring, environmental, pollution

INTRODUCTION

Humans and other living creatures can benefit from waterbodies. They consist of the sea, the ocean, rivers, lakes, and lagoons. The current study focuses on coastal lagoons, which are shallow coastal pools completely or partially isolated from the ocean by either sand bars (Isla 2009) or embankments along the coast. They rank among the world's most productive aquatic ecosystems. Furthermore, they act as nutrient recyclers, toxins filters, habitats for various species, and nursery grounds in their systems to maintain biological activities. Coastal lagoons are created when marine sediments accumulate in low-lying areas and are either open to or closed to the ocean entrance (Woodroffe 2002). Due to persistent heavy metal contamination and other pollutants, such as Poly Aromatic Hydrocarbons (PAH), caused by nearby communities and industrial activities, these coastal lagoons are in danger of disappearing (Bourgoing 1996). According to Sparks (2005) and Mwatsahu et al. (2020), the sediments in coastal lagoons act as sinks for heavy metals. Heavy metals are adsorbed either on or in the suspended particulate matter of the water bodies. Unfortunately, due to anthropogenic environmental degradation, most lagoons are becoming less valuable ecologically and economically.

Heavy Metals (HM) are defined as any metallic or metalloid chemical elements with relatively high densities greater than 5 gcm-3 and are toxic even at low concentrations (Lenntech 2010). HM are a component of the earth's crust. Although some heavy metals are only minimally necessary for normal growth, they are still considered contaminants. These essential minerals include zinc, iron, copper, and manganese. However, such elements are only relevant at specific concentrations; otherwise, at higher concentrations, they become toxicants.

Wastewater and sewage sludge disposal, by-products from metal mining processes, runoff from agricultural fields, and atmospheric input are all ways heavy metals enter the environment. Heavy metals are considered serious environmental pollutants because of their persistence, toxicity, and capacity to enter the food chain (Kadhum et al. 2016). In addition, these metals can bind to organic substances in the body, leading to cell dysfunction by impeding transport procedures through the cell wall. When organisms and humans are exposed to most metals, the kidney, liver, blood pressure, and other organs are damaged, which can eventually result in death. In addition, according to Baird and Cann (2008), many heavy metals can cause cancer in people.

Lagoons Korle and Kpeshie are open and closed, respectively. The two lagoons are some of the most polluted coastal lagoons in the nation, even though they are not Ramsar Sites (Ramsar Sites have designated wetlands for conserving and wise use of wetlands and their resources under the Convention on Wetlands of International Importance, adopted in Ramsar, Iran, in 1971). Before the water finally enters the Gulf of Guinea, all of Accra's major drainage channels empty their contents through Korle. As a result, high volumes of domestic and industrial waste are discharged into the lagoonal systems, which could have supported socio-economic activities for nearby communities in the Metropolis and provided an attractive landscape (Karikari et al. 2009). In addition, the flow rate of Korle Lagoon has decreased due to high levels of siltation (Asumadu-Sarkodie et al. 2015), resulting in significant flooding in the city of Accra during torrential rains.

Being a closed lagoon (Biney 1984), Kpeshie's water level fluctuates based on hydrologic inputs and outputs (Haines 2009). As a result, the lagoon occasionally overflows into the sea through a small inlet to the ocean or when the water level rises above the sand barrier height. As a result of severe contamination, living organisms in these lagoons are essentially extinct (Boadi and Kuitunen 2002).

The main goal of this study is to assess the presence of heavy metals and their concentrations in crab, fish, sediment, and water in the Korle and Kpeshie Lagoons and compare those concentrations to the permissible limit established by international standards like the Sediment Quality Guidelines (SQG) Canadian Council of Ministers of the Environment (CCME), the United States Environmental Protection Agency (US EPA), and the World Health Organization (WHO). In addition, examining the pollution level in these lagoons was another study goal.

The study's specific goals are to (i) Identify the physical factors that affect metal concentration in water, including total dissolved solids, pH, temperature, electrical conductivity, and dissolved oxygen. (ii) Check the pH of sediment cores. (iii) Assess the levels of heavy metals (As, Cr, Cd, Cu, Pb, and Zn) in water, sediment cores, crabs, and fish from the lagoons. (iv) Compare the metal concentrations in these lagoons. (v) Lagoon contamination levels should be assessed. Finally, calculate the heavy metal Target Hazard Quotient (THQ) in fish and crabs.

MATERIALS AND METHODS

Study area

Ghana's Greater Accra Region includes the lagoons at Korle and Kpeshie, where the study was conducted. According to Boadi and Kuitinen (2003), these lagoons are shallow water bodies in low-lying coastal areas. They once featured beautiful dunes, open mangroves, marshes, and scrubs, and they offered a variety of water birds ample and suitable feeding, resting, and nesting grounds.

Its surface area is roughly 0.127 square kilometers, and is situated 7 meters above sea level in the Accra Metropolitan area's southwestern region. The Odaw River and two other significant drainage channels connect to the Korle Lagoon as it flows from the Abokobi, Adjankote Hills, through Ashongman, Atomic Energy. Then, West Legon, Achimota, Alajo, Avenor, and Agbogbloshie before emptying into the lagoon (Biney 1982). The Korle Lagoon (Figure 1), which is located at geographical coordinates of 0° 13' 20.60" W; 5° 31' 47.46"N and 0° 13' 07.72"W; 5° 31' 48.32"N, could support shellfish and fin fish in the mid-twentieth century. A catchment area of 400 square kilometers discharges industrial waste, sewage from the city, and floodwater into the lagoon, a significant basin. According to Mensah (1976), the discharge water picks up silt and debris as it moves into the lagoon, frequently obstructing the main outlet to the sea. The obstruction gradually lowers the flow rate, depriving the lagoon water of oxygen; where the tides assist in making this portion of the lagoon less polluted, the water quality changes toward the sea (Amuzu 1976).

With a surface area of 0.326 square kilometers, the Kpeshie Lagoon is located in the La-Dade Kotopon district of the Greater Accra Region along the main La-Teshie road (Figure 1). During times of flooding in Gulf of Guinea, the lagoon, which is close to the sea, overflows its barriers. Hospitality businesses are located directly southwest of the lagoon, the Whitler Barracks is to the east, and the La community is to the west. There aren't any significant manufacturing facilities in the catchment area, but several auto repair shops and educational facilities are strewn along the lagoonal stretch that discharges their wastewater into the lagoon. In addition, the lagoon's bank serves as a garbage dump and a place for defecation for the locals. The Kpeshie Lagoon is located at coordinates 0°08' 20.90" W; 5° 33' 54.72"N and 0° 08' 40.52"W; 5° 33' 46.37"N.

Climate, geology, and vegetation

Climate

The tropical savanna climate best describes the study areas. An average of 730 mm of precipitation falls in the region twice a year, during the minor, weaker rainy season that starts in early October and the main rainy season that runs from April to late July. However, rainfall is typically not prolonged but rather brief and intense, which leads to flooding, especially in low-lying areas where the drainage channels are blocked (Amoako and Boamah 2014).

The yearly temperature ranges from a mean of 27.6°C in March to a mean of 25.9°C in August, with very little variation. However, the cooler months are typically more humid than, the warmer ones. As a result, the city has a dry, breezy heat during the summer, especially during the windy Harmattan season.

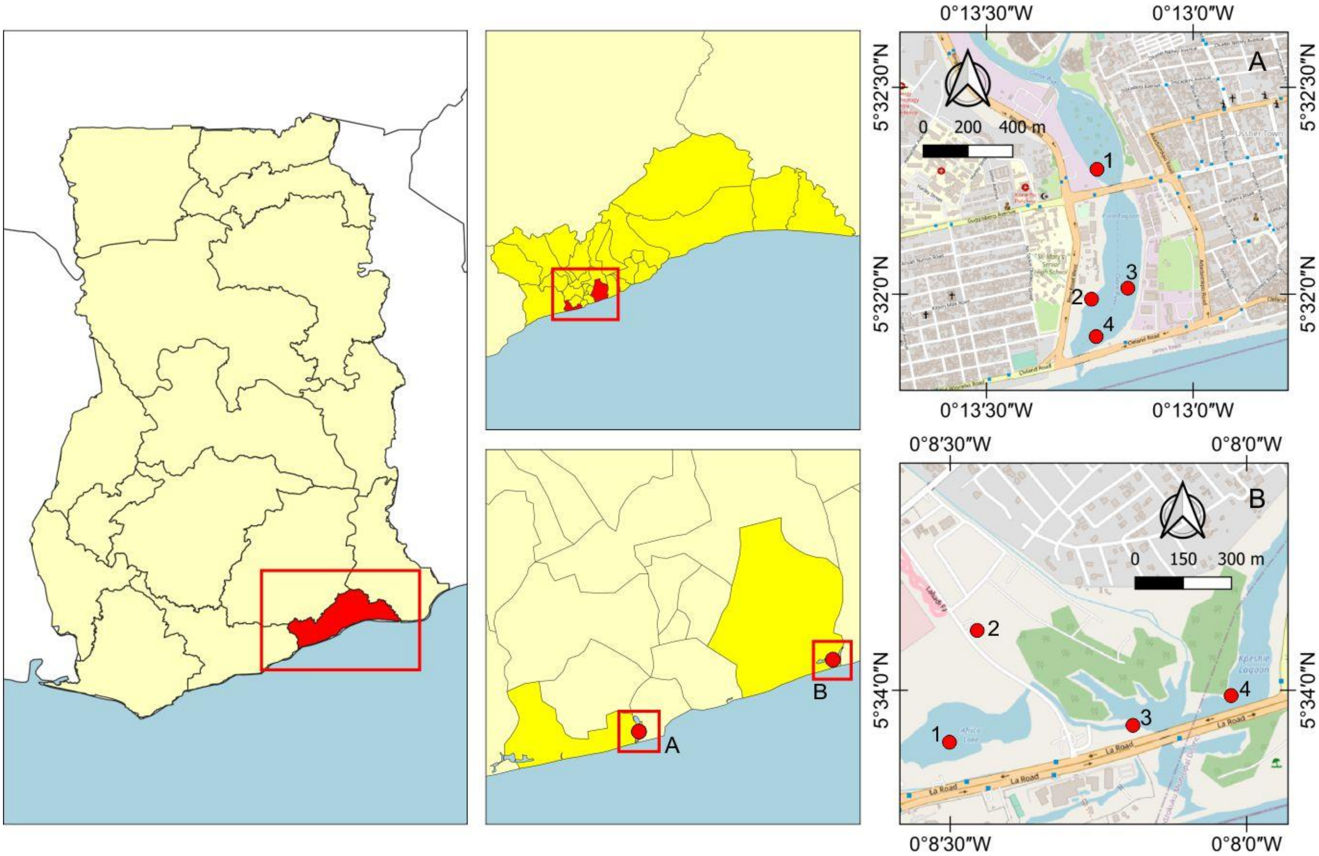

Figure 1. A. Map of Korle Lagoon, with sampling points at Korle Lagoon, Ghana, B. Map of Kpeshie Lagoon, with sampling points at Kpeshie Lagoon, Ghana

Due to their location in a coastal city, the study areas react to climatic changes like a rise in sea level and an increase in temperature, which are brought on by population growth and infrastructure improvements. The threat of silt, debris, and waste materials in drainage channels has serious consequences for public health.

Geology

Sand that receives regular moisture from the ocean makes up the lagoons' coastal shorelines. The Devonian era, which spans 354 to 417 million years, is when the rocks of Korle Lagoon were formed. Sandstone and shale make up most of the rock types of the Sekondian and Accraian units. Depending on the parent rock, the rocks weather into the silt and yellowish-brown clay and are only marginally permeable (Goudie and Viles 2008).

In contrast to the rocks of Korle Lagoon, those of Kpeshie Lagoon are different. The formation was formed between 2 and 1 point 8 million years ago during the Early Proterozoic. These belong to the Dahomeyan unit and are composed of felsic and mafic gneiss, schist, and migmatite rocks (Holm 1973).

Relief and vegetation

The Korle and Kpeshie Lagoons have a coastal savanna relief pattern characterized by low-lying flat land connected to numerous streams and rivers. On average, the lagoons are 7 meters high and gradually empty into the Gulf of Guinea.

The predominant vegetation in the study areas is coastal grassland, which includes scrubs and two different types of grass (Panicum maximum and Imperata cylindrical). In the study areas, many coconut trees are scattered among grassy clumps. In addition, mangrove trees line the lagoon's shores in Kpeshie.

Data collection

Field reconnaissance study

A three-day reconnaissance study was conducted from 20 to 22 October 2017, before data from the study area were collected, to observe the extent of anthropogenic activities like waste disposal, e-waste recovery, and various vehicle repair workshops near the lagoons. During the reconnaissance survey, ideas for the tools and strategy required for sampling were developed.

Sampling

Between November 2017 and April 2018, samples were collected. For example, core sediment samples were taken from four locations in the Korle and Kpeshie Lagoons. The sites were chosen based on activities along the lagoons and vantage points, considering the morphometry. These sample points (Table 1), depicted in Figure 1, were located using the Etrex Global Positioning System (GPS).

A homemade PVC corer measuring 1 meter long and 2 centimeters diameter collected sediment core samples from the lagoons at 30 centimeters depth. Before sampling, the

PVC Corer was cleaned with distilled and lagoon water. Then, the recovered cores were measured by tape, sliced into five cm-long pieces, bagged, and clearly labeled. After being put on ice and transported to the lab, the samples were placed inside a zip-locked plastic bag.

Each sample was homogenously mixed, re-labeled, and stored in polyethylene bags for analysis after being air-dried for 24 and 36 hours (US EPA 2000).

Water sampling

Water samples were taken at each location chosen for sediment core drilling using plastic bottles and distilled water as instructed by the World Health Organization and the United Nations Environment Programme (UNEP/WHO 1996). Before gathering the sample at each sampling location, the bottles were washed with lagoonal water. Nitric acid was added twice to bottles of the sample before being sealed. Water samples were labeled properly, kept on ice, and moved into a refrigerator for laboratory analysis. Using a handheld griffin pH meter, thermometer, dissolved oxygen sensor, electrical conductivity meter, and Total Dissolved Solids (TDS) meter, the following parameters were measured in situ: pH, temperature, Dissolved Oxygen (DO), Electrical Conductivity (EC), and TDS. This strategy was used, specifically for DO, to prevent water changes brought on by the loss of gases or the absorption of gases from the atmosphere (Manahan 2000).

Heavy metal determination in Callinectes amnicola

Fishing in the Kpeshie Lagoon, depicted in Figure 2, led to local fishermen purchasing crabs (Callinectes amnicola). Measurement tape was used to measure the lengths outside, and a weighing scale was used in the lab to record the weight. Atomic Absorption Spectrophotometry (AAS) was used to conduct a total heavy metal analysis on the samples, which were transported to the lab in sealable polyethylene bags with clear labels and kept frozen on ice in an ice chest.

Heavy metal determination in Sarotherodon melanotheron

The fishermen at Kpeshie Lagoon (Figure 3) sold tilapias (*Sarotherodon melanotheron*) on the local market. Next, using a tape measure, the samples' lengths were determined, labeled, and kept in polyethylene bags on ice for storage. Finally, the samples were delivered to the University of Ghana's Ecological Laboratory for examination.

Sample preparations and analysis at the laboratory

Sediment core samples

The lab ground the dried sediment samples with a mortar and pestle and sieved them through a 2 mm mesh. Nitric acid (HNO_3) and perchloric acid ($HClO_4$) were combined in a ternary mixture of 5 mL volume and used to digest one gram (1 g) of sediment in Folin-Wu digestive tubes. In a fume hood, the mixture was heated using a block digester for an hour at 80°C until the solution became colorless. It was then allowed to cool before filtering through Whatman No. 0.45 filter paper. The volume was then adjusted using distilled water. Before measuring the levels of heavy metals in the digested samples, Atomic Absorption Spectrophotometry (AAS) was calibrated using standard solutions of the relevant metals and de-ionized water, and 48 sediment core samples in all were examined. Next, the pH of the sediment was calculated using 10 g of the sediment samples. Then, thirty (30) minutes were spent stirring after adding twenty (20) mL of distilled water. The pH meter was then used to take readings after it had been allowed to sit for 30 minutes.

Water samples

Digestion tubes were filled with 10.5 mL of water samples to calculate the levels of heavy metals. First, add five (5) mL of a ternary mixture (1:1 of concentrated HNO_3 and $HClO_4$). Next, the mixtures were digested for an hour at 80°C, then cooled and filtered into a volumetric flask of 100 ml. Next, to the 100 mL mark, distilled water was added to the solutions. Then, following the procedure outlined by (Bentum et al. 2011), the metal contents were assessed using the Analyst 400 Perkin-Elmer Atomic Absorption Spectrophotometer (AAS). Before measuring the levels of heavy metals in the digested samples, AAS was calibrated using standard solutions of the relevant metals and de-ionized water. There were 24 water samples examined in total.

Table 1. Sampling points locations and descriptions

Points	Lagoon	Longitude	Latitude	Location descriptions
1	Korle	0° 13' 12.864"W	5° 32' 16.836"N	Sewage waste discharge point
2	Korle	0° 13' 08.259"W	5° 32' 04.736"N	Southeastern side
3	Korle	0° 13' 13.565"W	5° 31' 59.412"N	Southwestern side
4	Korle	0° 13' 12.975"W	5° 31' 54.379"N	Close to the estuary
1	Kpeshie	0° 08' 30.501"W	5° 33' 57.124"N	Africa, fishing point
2	Kpeshie	0° 08' 28.781"W	5° 34' 09.742"N	Close to the vehicle garage
3	Kpeshie	0° 08' 10.496"W	5° 33' 58.107"N	Behind the washing bay
4	Kpeshie	0° 07' 56.901"W	5° 34' 02.110"N	Close to the barracks, the fishing point

*Bigfisted swim crab (*Callinectes amnicola*) samples*

The big-fisted swim crab samples (Figure 2) were oven dried at 55°C for 24 hours before being ground to a fine powder in a stainless-steel mill to pass through 1 mm screening. Each powdered sample was weighed at one gram (1g) and digested for an hour in a 5 mL ternary solution of concentrated nitric acid and perchloric acid at a ratio of 1:4. In a 100 mL volumetric flask. The samples were filtered, cooled, and then diluted with distilled water. Before measuring the levels of heavy metals in the digested samples, AAS was calibrated using standard solutions of the relevant metals and de-ionized water. Analyses were performed on twenty-four (24) crab samples.

*Tilapia (*Sarotherodon melanotheron*) samples*

After being cleaned in distilled water, the fish samples (Figure 3) were dried in an oven for 24 hours at 55°C. First, the tissue from dried tilapia was ground into a powder. Then, in digestion tubes inside a fume chamber, one gram (1g) of samples was digested with 5 mL of a ternary mixture of concentrated 1:1 nitric acid and perchloric acid. Afterward, a 100 mL volumetric flask was filled with the sample mixtures. The 100 mL mark was then filled with distilled water. Next, the presence of heavy metals in the filtrates was determined by AAS. Before taking measurements, the AAS was calibrated using standard solutions and de-ionized water, and all 24 samples were examined.

Quality control

Standards and blanks were run before the analysis of the samples to ensure that the instrument was calibrated. The primary methods for examining the contaminations and precisions of the analytes were laboratory blanks and standards. Laboratory glassware was thoroughly cleaned as part of the quality assurance procedures (US EPA 1987).

Data analysis

Data were shown as mean SD in tables. Using SPSS's ANOVA statistical tools, the study's data on heavy metals levels in sediments, water, crabs, and fish were analyzed. The means in each case were compared using a 95% confidence level. Microsoft Excel 10 was used to create all descriptive statistics and graphs.

Contamination factor (Cf)

According to Hákanson (1980), the contamination factor (Cf) is the proportion of a study's metal concentration to the metal's background value in equation 1. This reveals the possibility of sediment contamination.

$$Cf = C_{metal} / C_{background}$$

Where, C_{metal} is the concentration of heavy metal in the sediment; $C_{background}$ is the background metal average concentration level (Taylor 1964) in this study.

Pollution Load Index (PLI)

Sediment environmental quality was evaluated using the pollution load index. The n-th root of the product of the total number of contamination factors (Cf) is used to calculate the pollution load index (Tomlinson et al. 1980), which is defined as follows:

$$PLI = m \sqrt{(Cf_1 \times Cf_2 \times Cf_3 \times \ldots \times Cf_m)}$$

Where: m is the number of analyzed heavy metals

Potential Ecological Risk Index (RI)

To calculate the potential ecological risk index (RI) and evaluate the traits and behavior of heavy metal contaminants in environmental samples, particularly sediment, Hákanson (1980) proposed a method (equation 3). The potential ecological risk index (RI) is defined as follows:

$$RI = \sum_{i=1}^{i=m} Er^i$$

Where Er^i is a single potential ecological risk factor, which is defined in equation 4 as the product of contamination factor (Cf) and the toxic response factor for a given heavy metal (Trf^i), and m is the number of analyzed heavy metal

Figure 2. Crustacean samples collected from the field

Figure 3. *Sarotherodon melanotheron* caught in Kpeshie Lagoon, Ghana

$Er^i = Cf \times Trf^I$

Following Hákanson (1980), the standardized toxic response factor (Trf^i)* accepted globally for As, Cr, Cu, Pb, Cd, and Zn are 10, 2, 5, 5, 30, and 1, respectively.

Target Hazard Quotient (THQ)

THQ calculation is to evaluate the non-carcinogenic health effect of heavy metals. THQ formula is defined in equation 5 by (US EPA 2011):

$$THQ = \frac{EFr \times Ed \times FIR \times C}{Rfd \times BWa \times ATn}$$

Where:

EFr is the exposure on the frequency (days per year; 365)

Ed is the exposure duration which is equivalent to the average lifetime (64 years for a Ghanaian adult; WHO 2016)

FIR is the crustaceans' and fish's daily average intake rate (crustacean: 5.42g/person/day; fish: 36g/person/day) (FAO 2005)

C in this study is the mean on heavy metal concentration in fish and crab (in $mgkg^{-1}$)

* Trf^i of a specific metal was derived by Hákanson (1980) from (a) the "abundance principle," (b) the "sink-effect," and (c) the "dimension problem."

Rfd is the trace element oral reference dose (Cd: $0.001mgkg^{-1}$/day; Cr: $0.003mgkg^{-1}$/day; Pb: $0.004mgkg^{-1}$/da) (US EPA 1991)

BWa is the average body weight (considered at 70 Kg for an adult)

ATn is the heavy metal average exposure time (365 days per year x Ed)

RESULTS AND DISCUSSION

Physicochemical parameters of the water

The table below (Table 2) lists the average values of the physicochemical parameters for the study areas.

Korle Lagoon

The pH ranges for the water and sediments of the Korle Lagoon were respectively 4.31- 8.62 and 7.5- 8.4. The mean pH for water was 6.61 ±1.11 and for sediment, 7.81 ±0.28. The lagoon's temperature ranged from 28 to 30°C, with a mean of 29°C. TDS values ranged from 21400 to 36700 mgL^{-1}, while electrical conductivity values ranged from 35200 to 56300 Scm^{-1}. Table 2 shows dissolved oxygen ranged from 0.87 to 3.12 mgL^{-1}, averaging at 1.86 to 0.74 mgL^{-1} (Table 2). Figure 4A shows a scatter plot of electrical conductivity versus TDS for the Korle Lagoons.

Kpeshie Lagoon

The pH range for water was 3.69-8.48, whereas the pH range for sediments was 7.1- 7.6, with mean values of 7.52-1.22 and 7.36-1.15, respectively. Kpeshie Lagoon's water temperatures ranged from 30.1 to 31.4°C, averaging 30.73 ± 0.41°C. With values ranging from 9600 to 44800 Scm^{-1} and 6050 to 27300 mgL^{-1}, respectively, the electrical conductivity and TDS were both relatively unstable. The scatter plots (Figure 4B) of Kpeshie Lagoon's electrical conductivity versus TDS. Table 2 shows dissolved oxygen values varied from 3.15 to 6.42 mgL^{-1}, averaging 4.58 0.98 mgL^{-1} (Table 2).

Mean heavy metal concentration in water

Heavy metal concentrations in Korle Lagoon water

The mean concentration of arsenic in the Korle Lagoon was 5.410 0.08 ugL^{-1} (all heavy metals in water were analyzed in mgl^{-1} except arsenic in gl^{-1} due to their low concentrations); site 1, the highest level in the water. Site 2, 3, and 4 were 4.968 ± 0.03 ugL^{-1}, 5.400 ± 0.05 ugL^{-1}, and 5.086 ± 0.03 ugL^{-1}, respectively. Site 1 had the highest mean level of cadmium in the water (0.071±0.02 mgL^{-1}), followed by site 2 (0.046 ± 0.01 mgL^{-1}), and site 3 (0.031± 0.02 mgL^{-1}). With a mean of 0.017±0.01 mgL^{-1}, Site 4 had the lowest concentration.

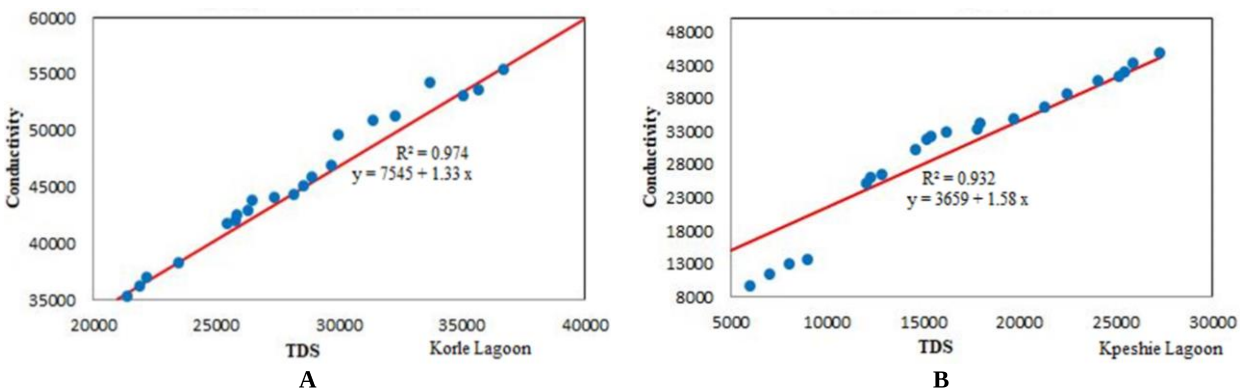

Figure 4. A. A plot of electrical conductivity against TDS of Korle Lagoon, Ghana, B. A plot of electrical conductivity against TDS of Kpeshie Lagoon, Ghana

Table 2. Mean physio-chemical parameters of water and sediments in Korle and Kpeshie Lagoon, Ghana

	Korle Lagoon	Kpeshie Lagoon	WHO 2005	US EPA 2004
PH_water	6.61 ± 1.11	7.52 ± 1.22	6.5-8.5	6-9
PH-sediment	7.81 ± 0.28	7.36 ± 0.15	6.5-8.5	6-9
Temp (°C)	29.41 ± 0.26	30.73 ± 0.41	25-30	25-32
DO (mg/L)	1.86 ± 0.74	4.58 ± 0.98	> 5	> 5
TDS (mg/L)	28390 ± 4633	16516 ± 6430	1000	1000
Conductivity (µS/cm)	45355 ± 6251	29860 ± 10633	1500	1500

The average chromium values on Korle Lagoon were 0.065 ± 0.01 mgL^{-1} at site 1; 0.045 ± 0.02 mgL^{-1} at site 2; 0.037 ± 0.03 mgL^{-1} at site 3, and 0.014 ± 0.01 mgL^{-1} at site 4. The mean values of lead and copper followed a similar trend with cadmium. Site 1 was the highest: 1.216 ± 0.48 mgL^{-1} for Pb; 0.397 ± 0.06 mgL^{-1} for Cu. The lowest value of lead was at site 2 which recorded 0.254 ± 0.14 mgL^{-1}, Followed by copper at site 4, which recorded 0.166 ± 0.05 mgL^{-1}. As indicated in Table 3, the mean concentrations of zinc for sites 1, 2, 3, and 4 were 0.101 ± 0.02 mgL^{-1}, 0.053 ± 0.02 mgL^{-1}, 0.050 ± 0.03 $mgL^{-1,}$ and 0.074 ± 0.01 mgL^{-1}, respectively.

Heavy metals concentration Kpeshie Lagoon water

At site 2, in the Kpeshie Lagoon, the average lowest concentration of arsenic was 4.867 ± 0.05 $µgL^{-1}$. Site 4 had the highest mean concentration at 5.316 ± 0.27 ugL^{-1}. Site 1 came in second with a mean value of 4.968 ± 0.08 ugL^{-1}, followed by site 3 with a mean value of 5.116 ± 0.02 ugL^{-1}. The lowest mean value for cadmium was recorded at site 1 and was 0.035 ± 0.02 mgL^{-1}. Site 3 came next with 0.037 ± 0.03 mgL^{-1}, followed by site 4 with 0.054 ± 0.01 mgL^{-1}, and site 2 with 0.068 ± 0.01 mgL^{-1}. The mean chromium levels were moderately low, with site 2 having the highest level at 0.073 ± 0.00mgL^{-1} mgL-1. In descending order, sites 3, 1, and 4 measured mean concentrations of 0.073 ± 0.00 mgL-1, 0.060 ± 0.03 mgL^{-1}, and 0.025 ± 0.00 mgL^{-1}.

The values for copper ranged from 0.033-0.566 mgL^{-1}. The average concentration at site 1 was 0.266± 0.15 mgL^{-1} (second highest), 0.241 ± 0.07 mgL^{-1} (second lowest), 0.485 ± 0.21 mgL^{-1} (highest), and 0.038 ± 0.01 mgl^{-1} (lowest). While the lowest mean concentrations of 0.216 ± 0.34 mgL^{-1} at site 3 and the highest of 1.056 ± 0.85mgL^{-} at site 4, lead concentrations ranged from 0.006-2.035 mgL^{-1}. These mean values are shown in Table 3. Zinc concentrations ranged from 0.008 to 0.254 mgL^{-1}. With a value of 0.240 ± 0.01 mgL^{-1}, site 4 recorded the highest zinc concentration.

Heavy mean metal concentration in sediment core

Korle Lagoon sediments

In the lagoon at Korle, arsenic levels were extremely low. The lowest mean was recorded at Site 2 and ranged from 0.4252 to 0.5143 $mgkg^{-1}$. The red line in Figure 5 denotes the SQG limit of arsenic in sediment and shows the low heavy metal concentrations of sediments in the Korle and Kpeshie Lagoons. With values ranging from 0.4825 to 0.5369 $mgkg^{-1}$, site 1 had the highest mean concentration (0.5089 0.02 $mgkg^{-1}$). The concentrations at sites 3 and 4 ranged from 0.3014 to 0.5417 $mgkg^{-1}$ and 0.4359 to 0.5141 $mgkg^{-1}$, respectively. The mean concentrations showed no discernible variations (p-value = 0.85; $p > 0.05$).

Cadmium concentrations in both lagoons are shown in Figure 6, with a recommended limit of 0.7 $mgkg^{-1}$ established by CCME (2001). The levels of cadmium in Korle Lagoon ranged from 1.10 $mgkg^{-1}$ to 54.5 $mgkg^{-1}$. According to Table 4, site 1 measured the highest mean cadmium at 19.067 ± 26.28 $mgkg^{-1}$, while site 3 measured the lowest mean at 5.034 ± 3.92 $mgkg^{-1}$. Sites 2 and 4 had average concentrations of 7.950 ± 1.05 $mgkg^{-1}$ and 6.250 ± 1.75 $mgkg^{-1}$, respectively. The mean concentrations did not vary significantly (p-value = 0.45; $p > 0.05$).

Table 3. Mean heavy metal concentrations of water samples in Korle and Kpeshie Lagoons, Ghana

Lagoon	*As (µg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Standard (WHO)	10.00	0.003	0.05	2.00	0.01	3.00
Korle						
Site 1	5.410± 0.08	0.071 ± 0.02	0.065 ± 0.01	0.397 ± 0.06	1.216 ± 0.48	0.101 ± 0.02
Site 2	4.968 ± 0.03	0.046 ± 0.01	0.045 ± 0.02	0.509 ± 0.23	0.254 ± 0.14	0.053 ± 0.02
Site 3	5.400 ± 0.05	0.031 ± 0.02	0.037 ± 0.03	0.182 ± 0.14	0.478 ± 0.34	0.050± 0.03
Site 4	5.086 ± 0.03	0.017 ± 0.01	0.014 ± 0.01	0.166 ± 0.05	0.482 ± 0.07	0.074 ± 0.01
Kpeshie						
Site 1	4.968 ± 0.08	0.035 ± 0.02	0.060± 0.03	0.266 ± 0.15	0.301 ± 0.04	0.037 ± 0.02
Site 2	4.867 ± 0.05	0.068 ± 0.01	0.075 ± 0.01	0.241 ± 0.07	0.448 ± 0.34	0.027 ± 0.02
Site 3	5.116 ± 0.02	0.037 ± 0.03	0.073 ± 0.00	0.485 ± 0.08	0.216 ± 0.34	0.063 ± 0.04
Site 4	5.316 ± 0.27	0.054 ± 0.01	0.025 ± 0.00	0.038 ± 0.00	1.056 ± 0.85	0.240 ± 0.01

Note: *As (µg/L) was analyzed in microgram per liter due to their low concentrations

Chromium concentrations ranged from 0 mgkg^{-1} to 50 mgkg^{-1}. Site 1 had the highest mean, which was observed to be 30.467 ± 16.02 mgkg^{-1}, with values ranging from 15.7 to 50.6 mgkg^{-1}. Site 2 averaged 14.617 ± 10.47 mgkg^{-1}, site 3 averaged 9.933 ± 7.29 mgkg^{-1}, and the lowest mean at site 4 was recorded at 6.450 ± 6.11 mgkg^{-1} with values between 0.3 and 14.7 mgkg^{-1} of Cr, as presented in Table 4. These values ranged from 0.5 to 24.5 mgkg^{-1}. Figure 7 shows the average chromium concentration in sediments, and the SQG (CCME 2001) limit is shown as a red line. The mean concentrations didn't vary in a statistically significant way (p-value = 0.64; $p > 0.05$).

Mean copper concentrations were 29.383 ± 37.35 mgkg^{-1} at sites 1, 2, and 3, 11.467 ± 9.02 mgkg^{-1} at site 1, 33.001 ± 0.69 mgkg^{-1} at site 4, and 5.150 ± 4.04 mgkg^{-1} at site 4, respectively. The mean was highest at site 3 and lowest at site 4, respectively. At site 1, their concentrations varied from 4.7 to 78.0 mgkg^{-1}, 5.1- 23.5 mgkg^{-1}, 32.1-34.1 mgkg^{-1}, and from 0.05) in their mean concentrations.

While site 1 recorded the highest mean value of 112.45 48 mgkg^{-1}, ranging from 76.8 to 174.6 mgkg^{-1}, lead concentrations in sediments at Korle Lagoon sampling sites were higher than other studied metals. Site 2 had the lowest concentrations, measuring an average of 42.917 ±26.23 mgkg^{-1} with values ranging from 25.1 to 78.1 mgkg^{-1}, while sites 3 and 4 had higher average concentrations, measuring 59.167 ± 5.92 mgkg^{-1} and 29.700 ± 12.34 mgkg^{-1}, respectively, as presented in (Table 4). The concentrations at sites 3 and 4 were between 51.1 and 63.5 mg kg^{-1} and 11 and 41 mg kg^{-1}, respectively. The mean concentrations did not differ significantly (p-value = 0.93; $p > 0.05$) according to a one-way ANOVA.

Site 3 in Korle Lagoon had consistently higher zinc concentrations than the other sites, averaging 209.001 ± 22.42 mgkg^{-1} and ranging from 189.9 to 241.7 mgkg^{-1}. At sites 1 and 2, the mean zinc concentrations were 100.583 93.39 mgkg^{-1} and 126.783 112.54 mgkg^{-1}, respectively. Site 1's values ranged from 39.5 to 221.9 mgkg^{-1}, while site 2's values ranged from 86 to 205.8 mgkg^{-1}. The zinc concentrations at site 4 ranged from 3 to 82 mgkg^{-1}, with an average of 13.817 ± 5.85 mgkg^{-1}. Site 3 was higher than Site 2 and Site 1 than Site 4, according to the mean zinc concentrations in sediment cores. However, their concentrations had no appreciable differences (p-value = 0.96; $p > 0.05$).

Kpeshie Lagoon sediment

Similar trends were observed for the arsenic concentrations in sediments at Kpeshie and Korle Lagoons (Figure 5), 0.5063 0.03 mgkg^{-1}, 0.5065 0.05 mgkg^{-1}, 0.5551 0.03 mgkg^{-1}, and 0.4502 0.03 mgkg^{-1}, respectively, were the mean values of arsenic at sites 1, 2, and 3. A one-way ANOVA revealed no significant differences in arsenic levels measured at the sampling sites (p-value = 0.79; $p > 0.05$). The mean values at sites 4 and 2 were the lowest and highest (Table 4).

At the four sampling locations, the cadmium concentrations in the sediments at Kpeshie Lagoon were comparatively similar. The highest mean level for cadmium at 13.867 6.13 mgkg^{-1} was recorded at site 1, with values ranging from 1.7 to 18.1 mgkg^{-1}, and site 3 recorded the lowest mean concentration at 5.350 1.51 mgkg^{-1} with values ranging from 3.8 to 7.3 mgkg^{-1}. Generally, cadmium concentrations vary with depth and are much higher than the limit set by CCME. According to (Table 4), the mean cadmium levels were 7.550 5.95 mgkg^{-1} at site 2 and 5.750 1.41 mgkg^{-1} at site 4. The single factor ANOVA (p-value = 0.93; $p > 0.05$) found no significant differences in cadmium levels between sampling sites.

Site 4 recorded the lowest mean of 18.033±13.70 mgkg^{-1}, with values ranging from 5.0-37.1 mgkg^{-1}. The chromium concentrations in the sediments at the four sampling sites were highly measurable. Site 1 came in second with an average value of chromium of 28.517 ±4.15 mgkg^{-1}. Site 3 recorded average chromium levels of 31.400 ±12.36 mgkg^{-1} with concentrations ranging from 18.9 - 45.9 mgkg^{-1}, while Site 2 recorded concentrations from 41.5 - 58.7 mgkg^{-1} with the highest mean of 50.833 ± 6.27 mgkg^{-1}. Chromium measurements taken at depth (Figure 7) were within the SQG limit of 52.3 mgkg^{-1}. At all sampling sites, their mean concentrations did not differ significantly (p-value = 0.99; $p > 0.05$).

Table 4. Mean heavy metal concentrations in sediment samples in Korle and Kpeshie Lagoon, Ghana

Lagoon	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Standard (CCME)	7.24	0.70	52.30	18.70	30.20	124.00
Korle						
Site 1	0.5089 ± 0.02	19.067 ± 26.28	30.467 ± 16.02	29.383 ± 37.35	112.450 ± 48.00	100.583 ± 93.39
Site 2	0.4728 ± 0.04	7.950 ± 1.05	14.617 ± 10.47	11.467 ± 9.02	42.917 ± 26.23	126.783 ± 112.54
Site 3	0.4956 ± 0.10	5.034 ± 3.92	9.933 ± 7.29	33.001 ± 0.69	59.167 ± 5.92	209.0 1 ± 22.42
Site 4	0.4852 ± 0.03	6.250 ± 1.75	6.450 ± 6.11	5.150 ± 4.04	29.750 ± 12.34	13.817 ± 5.85
Kpeshie						
Site 1	0.5063 ± 0.03	13.667 ± 6.13	28.517 ± 4.15	15.733 ± 16.20	44.333 ± 24.37	114.650 ± 107.22
Site 2	0.5065 ± 0.05	7.550 ± 5.95	31.400 ± 12.36	42.617 ± 2.91	42.283 ± 24.36	69.200 ± 58.28
Site 3	0.5551 ± 0.03	5.350 ± 1.51	50.833 ± 6.27	41.517 ± 40.79	188.433 ±139.77	70.367 ± 10.31
Site 4	0.4502 ± 0.03	5.750 ± 1.41	18.033 ± 13.70	2.408 ± 4.23	56.850 ± 17.05	18.400 ± 4.91

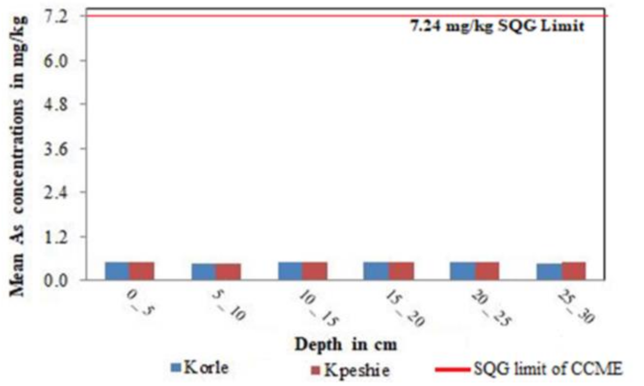

Figure 5. Arsenic concentrations in Korle-Kpeshie Lagoons

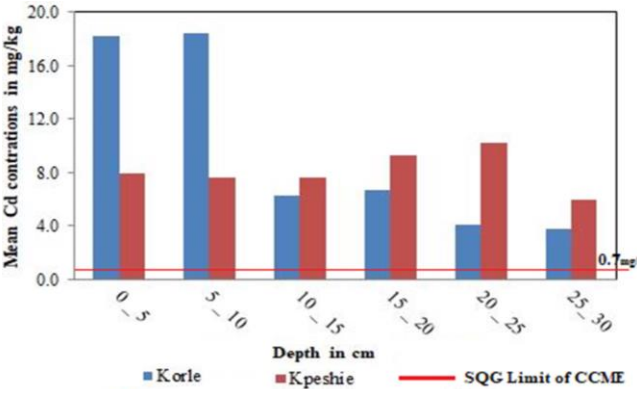

Figure 6. Cadmium concentrations in Korle-Kpeshie Lagoons

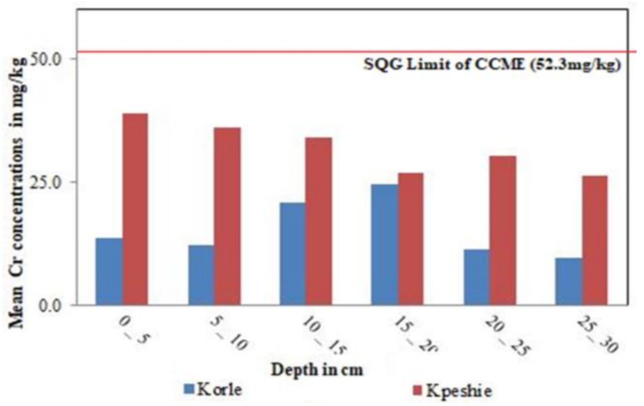

Figure 7. Chromium concentrations in Korle-Kpeshie Lagoons

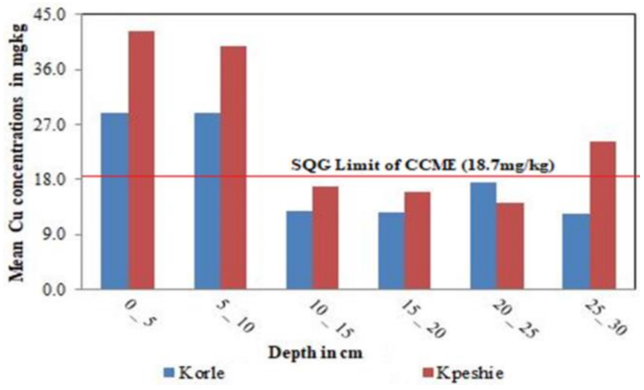

Figure 8. Copper concentrations in Korle-Kpeshie Lagoons

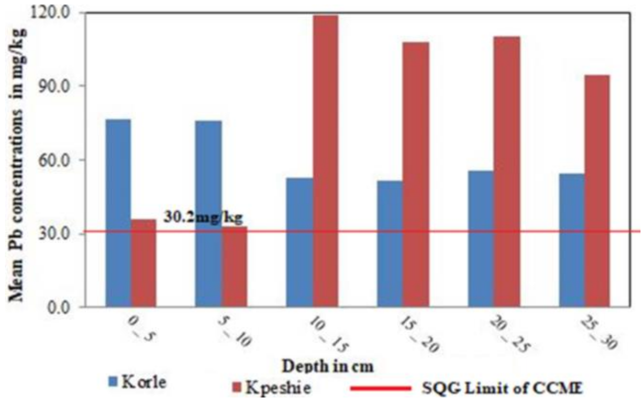

Figure 9. Lead concentrations in Korle-Kpeshie Lagoons

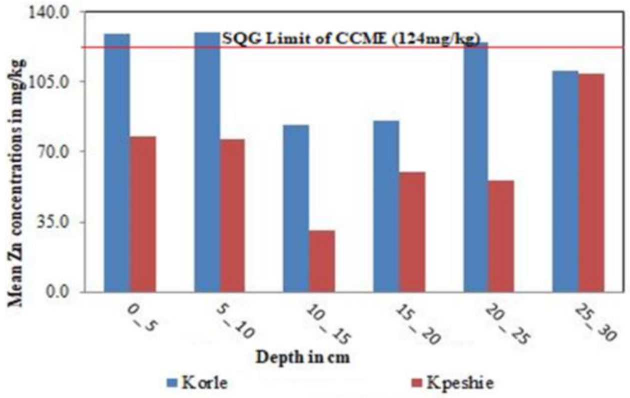

Figure 10. Zinc concentrations in Korle-Kpeshie Lagoons

In general, there was a moderate amount of copper in the sediments of Kpeshie Lagoon. The four sampling sites' copper concentrations yielded individual copper values ranging from <0.001-94.3 $mgkg^{-1}$. The copper levels measured vary considerably with the depth (Figure 8). The average levels were as follows: site 1 (15.733 ± 16.20 $mgkg^{-1}$), site 2, 42.667 ± 2.91 $mgkg^{-1}$, site 3, 41.517 ± 40.79 $mgkg^{-1}$, and site 4, 2.408 ± 4.23 $mgkg^{-1}$, as presented in Table 4.

The four Kpeshie Lagoon sampling locations had moderately high lead concentrations, ranging from 7.9 to 281.1 $mgkg^{-1}$. According to Table 4, the respective mean lead concentrations at sites 1, 2, 3, and 4 were 44.333 ± 24.37 $mgkg^{-1}$, 42.283 ± 24.36 $mgkg^{-1}$, 188.433 ± 139.77 $mgkg^{-1}$, and 56.850 ± 17.05 $mgkg^{-1}$ (Figure 9). Site 2 recorded the lowest mean concentrations, while Site 3 had the highest mean. The mean concentrations at all sampling sites did not differ significantly from one another, according to a single factor ANOVA (p-value = 0.67; $p > 0.05$).

Sites 2 and 3 had moderately low zinc concentrations in the sediments of the Kpeshie Lagoon. The highest mean zinc concentration was found in the sediment at site 1, where zinc levels ranged from 11.7-237.3 $mgkg^{-1}$. Following (Table 4, Figure 10), the average values for sites 2, 3, and 4 were 69.200 ± 58.28 $mgkg^{-1}$, 70.367 ± 10.31 $mgkg^{-1}$, and 18.400 ± 4.91 $mgkg^{-1}$, respectively. The average zinc concentrations at the sampling stations showed no significant differences ($p = 0.73$; $p > 0.05$).

Heavy metal concentration in crab (*Callinectes amnicola)*

The *C. amnicola* were harvested only at Sites 1, and 4 of Kpeshie Lagoon as Sites 2 and 3 could not support living organisms. The mean concentrations of cadmium, chromium, copper, lead, arsenic and zinc in *C. amnicola* of Site 1 were 5.483 ± 2.88 $mgkg^{-1}$, 71.908 ± 64.80 $mgkg^{-1}$; 26.812 ± 19.72 $mgkg^{-1}$; 13.667 ± 17.40 $mgkg^{-1}$; 0.303 ± 0.05 $mgkg^{-1}$; and 45.183 ± 20.70 $mgkg^{-1}$, respectively (Figure 11). The mean concentrations on Site 4 were: arsenic, 0.273 ± 0.08 $mgkg^{-1}$; chromium, 7.133 ± 6.64 $mgkg^{-1}$; copper, 35.358 ± 11.11 $mgkg^{-1}$; cadmium, 3.713 ± 2.26 $mgkg^{-1}$; lead, 8.138 ± 5.61 $mgkg^{-1}$; and zinc, 26.900 ± 7.40 $mgkg^{-1}$, as observed in (Table 5). Except for chromium and zinc, there were no significant differences in the mean concentrations of the sites according to the one-way ANOVA analysis ($p > 0.05$) (Table 5).

Heavy metal concentration in fish (*Sarotherodon melanotheron)*

Sites 1 and 4 at Kpeshie Lagoon were the only locations with fish samples because Sites 2 and 3 were empty. Arsenic and cadmium showed a similar trend in mean concentrations of metals when they were examined in *S. melanotheron* samples from Sites 1 and 4. Fish samples from Sites 1 and 4 had average arsenic levels of 0.3714 0.07 $mgkg^{-1}$ and 0.423 0.07 $mgkg^{-1}$, respectively. Cadmium levels averaged 1.517 1.65 $mgkg^{-1}$ at site 1 and 0.683 0.70 $mgkg^{-1}$ at Site 4. As shown in Table 6, the fish's mean concentrations of chromium, copper, and zinc were (site 1) 2.454 ± 4.58 $mgkg^{-1}$; (site 4) 9.321 ± 12.34 $mgkg^{-1}$, (site 1) 2.929 ± 2.2 $mgkg^{-1}$; (site 4) 4.058 ± 6.15 mgkg-1, and (site 1) 28.642 ± 11.33 $mgkg^{-1}$; (Site 4) 17.81 ± 7.58 $mgkg^{-1}$, respectively. Except for site 4 (28.3 $mgkg^{-1}$), all lead concentrations in *S. melanotheron* were Below the Detection Limit (BDL). Except for zinc, there were no significant differences between the mean concentrations ($p > 0.05$) (Table 6).

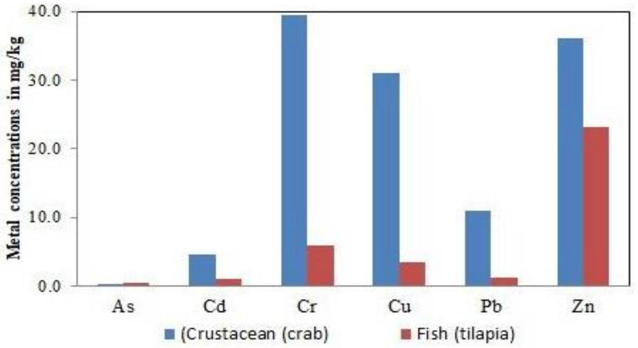

Figure 11. Heavy metal concentrations in crustacean and tilapia

Table 5. Mean heavy metals concentrations in *Callinectes amnicola*

Sampling sites (crustacean) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	US EPA 2010	p-value
As	0.303 ± 0.05	0.273 ± 0.08	0.50	0.29
Cd	5.483 ± 2.88	3.713 ± 2.26	0.50	0.11
Cr	71.908 ± 64.80	7.133 ± 6.64	0.50	0.002
Cu	26.812 ± 19.72	35.358 ± 11.11	70.00	0.20
Pb	13.667 ± 17.40	8.137 ± 5.61	0.50	0.31
Zn	45.183 ± 20.70	26.900 ± 7.40	80.00	0.008

Table 6. Mean heavy metal concentrations in *Sarotherodon melanotheron*

Sampling sites (fish) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	FAO/ WHO 2011	p-value
As	0.371 ± 0.07	0.423 ± 0.07	0.26	0.85
Cd	1.517 ± 1.65	0.683 ± 0.70	0.20	0.12
Cr	2.454 ± 4.58	9.321 ± 12.34	0.50	0.08
Cu	2.929 ± 2.20	4.058 ± 6.15	20	0.56
Pb	0.05 ± 0.00	2.404 ± 8.16	1.00	0.32
Zn	28.642 ± 11.33	17.81 ± 7.58	40.00	0.02

Table 7. Correlations between metals in the water column of the lagoons

	As	Cd	Cr	Cu	Pb	Zn
Korle						
As	1					
Cd	0.340	1				
Cr	0.361	0.464	1			
Cu	-0.189	0.525	0.420	1		
Pb	0.589	0.481	0.316	-0.027	1	
Zn	0.306	0.360	0.235	-0.203	0.824	1
Kpeshie						
As	1					
Cd	-0.141	1				
Cr	-0.615	0.215	1			
Cu	-0.301	-0.391	0.473	1		
Pb	0.691	-0.045	-0.578	-0.462	1	

Table 8. Correlations between metals of sediment in the lagoons

	As	Cd	Cr	Cu	Pb	Zn
Korle						
As	1					
Cd	0.061	1				
Cr	0.246	-0.024	1			
Cu	0.075	0.812	-0.167	1		
Pb	0.183	0.789	0.196	0.793	1	
Zn	-0.037	0.379	-0.284	0.795	0.495	1
Kpeshie						
As	1					
Cd	0.217	1				
Cr	0.444	-0.262	1			
Cu	0.305	-0.176	0.316	1		
Pb	0.431	-0.337	0.603	-0.318	1	
Zn	0.281	0.203	-0.070	0.306	-0.190	1

Table 9. Heavy metals relationship in organisms from Kpeshie Lagoon, Ghana

	As	Cd	Cr	Cu	Pb	Zn
Crustacean						
As	1					
Cd	0.316	1				
Cr	0.051	0.074	1			
Cu	-0.023	0.131	-0.762	1		
Pb	0.044	0.260	0.754	-0.598	1	
Zn	-0.092	0.207	0.528	-0.348	0.420	1
Tilapia						
As	1					
Cd	0.125	1				
Cr	0.333	-0.112	1			
Cu	0.353	-0.016	-0.067	1		
Pb	-0.347	0.450	-0.369	-0.184	1	
Zn	-0.562	-0.026	-0.189	0.454	-0.151	1

Correlation studies of the Korle and Kpeshie Lagoons

Using the Pearson Correlation Coefficient, the inter-metal correlation between the heavy metal pairs in Korle and Kpeshie Lagoons found in the water, sediment, crab, and fish was calculated. The results are shown in Tables 7, 8, and 9. Metals in the water column of Korle Lagoon had a few noteworthy positive relationships: Pb-As ($r = 0.589$, $p < 0.05$) and Cu- Cd ($r = 0.525$, $p < 0.05$), while metals in Kpeshie Lagoonal water observed both negative and positive significant correlations between Cr-As ($r = -0.615$, $p < 0.05$), Pb-As ($r = 0.691$, $p < 0.05$), and Pb-Cr ($r = -0.578$).

The Pearson's correlation of sediments in Korle observed a few significant links between Cu-Cd ($r = 0.812$, $p < 0.05$), Pb-Cd ($r = 0.789$, $p < 0.05$), Zn-Cu ($r =0.795$, $p < 0.05$) and Pb-Cd ($r = 0.793$, $p < 0.05$). On the other hand, sediment in Kpeshie did not observe any significant relationships except Pb-Cr ($r = 0.603$, $p < 0.05$).

The big-fisted swim crab showed positive significant metal correlations between Zn-Cr ($r = 0.528$; $p < 0.05$) and Pb-Cr ($r = 0.754$; $p < 0.05$), and significant trends existed in Pb-Cu ($r = - 0.598$; $p < 0.05$) and Cu-Cr ($r = - 0.762$; $p < 0.05$). Furthermore, the following was discovered by the correlation analysis in tilapia. A significant negative downtrend between Cd-As ($r = - 0.562$, $p < 0.05$), but significant positive correlations existed between Pb-Cu ($r = 0.454$, $p < 0.05$) and Zn-Cd ($r= 0.450$, $p < 0.05$).

Pollution indices of sediments

The degree of heavy metal contamination of the sediment samples from the Korle and Kpeshie Lagoons was determined using pollution indices. The calculated values of the study's sediments' pollution indices are shown in Table 7.

Contamination factor

Table 7 showed that the Cf values ranged from 0.06-97.83. The highest Cf values were found for Cd and Pb, and this trend was seen at all of the sampling locations in the Korle and Kpeshie Lagoons (Table 11). Regarding Cd and Pb, Site 1 at Korle Lagoon had the highest Cf. On the other hand, sites 3 and 4 in the same lagoon had the lowest Cf values for Cd and Pb, respectively.

The Cfs at Kpeshie Lagoon were distinct from those at Korle Lagoon. In Kpeshie Lagoon, cadmium had the highest Cf values. Site 1 had the highest Cd reading of 69 points, while Site 3 had the lowest reading of 26 points. Regarding Cf in Pb, Site 3 recorded the highest value (15.07), while site 2 recorded the lowest value (3.38).

Pollution load index

According to Tables 7 and 10, sediments at Korle Lagoon had a mean Pollution Load Index (PLI) of 1.24, with a range of 0.54 to 1.97. Except for Site 4, which is close to an estuary, all sampling sites had more than one PLI value. Kpeshie Lagoon's PLI values ranged from 0 to 64. A mean score of 1.36 out of 91. Except for site 4, which is close to Whitler Barracks, Sites 1, 2, and 3 all recorded more than one (PLI > 1).

Potential ecological Risk Index (RI)

Potential ecological risk indices of As, Cr, Cd, Cu, Pb, and Zn at all sampling sites were also presented in Tables 7 and 12 based on Hakanason (1980). Compared to Kpeshie Lagoon, where values ranged from 2.58 to 2877.50, sediments in Korle Lagoon recorded values between 1.23 and 5822.50.

Table 10. Average Contamination factor (Cf), Pollution Load Index (PLI), and potential ecological Risk Index (RI) of sediments

	Element	n*	As	Cd	Cr	Cu	Pb	Zn	PLI
Korle									
Site 1:	Cf	6	0.28	97.83	0.30	0.53	9.00	1.44	1.97
Site 2:	Cf	6	0.26	39.75	0.15	0.21	3.43	1.81	1.12
Site 3:	Cf	6	0.28	25.25	0.10	0.60	4.73	2.99	1.34
Site 4:	Cf	6	0.27	31.25	0.06	0.09	2.38	0.20	0.54
background values			1.8	0.2	100	55	12.5	70	
	RI		10.90	5822.50	1.23	7.18	97.71	6.43	
Kpeshie									
Site 1	Cf	6	0.28	69.33	0.29	0.29	3.55	1.64	1.45
Site 2	Cf	6	0.28	37.75	0.31	0.78	3.38	0.99	1.43
Site 3	Cf	6	0.31	26.75	0.51	0.75	15.07	1.01	1.91
Site 4	Cf	6	0.25	28.75	0.18	0.04	4.55	0.26	0.64
	RI		11.21	2877.50	2.58	9.30	132.80	3.89	

Note: *n is the number of samples collected at each site; background values were estimated by Taylor (1964)

Table 11. Heavy metals ranking for contamination factor of sediment in lagoons

	Korle	Kpeshie
Cf > 6 high contamination factor	Cd, Pb	Cd, Pb
3 ≤ Cf ≤ 6, considerable factor		
1 ≤ Cf ≤ 3, moderate factor	Zn	Zn
Cf < 1, low contamination factor	As, Cr, Cu	As, Cr, Cu

Table 12. Heavy metals ranking in the potential ecological Risk Index (RI) of sediment

	Korle	Kpeshie
RI > 380, very high ecological risk	Cd, Pb	Cd, Pb
190 ≤ RI ≤ 380, considerable ecological risk		
95 ≤ RI ≤ 190, Moderate ecological risk		
RI < 95, low ecological risk	As, Cr, Cu, Zn	As, Cr, Cu, Zn

Table 13. THQ estimation of fishery

Element	Cd	Pb	Cr	TTHQ
Callinectes amnicola	0.33	0.19	0.93	1.45
Sarotherodon melanotheron	0.52	0.34	0.92	1.78

Target Hazard Quotient (THQ)

The THQ of *S. melanotheron* and *C. amnicola* were evaluated using three elements (Cd, Cr, and Pb). Furthermore, chromium was evaluated based on its concentrations in the studied organisms (*C. amnicola* and *S. melanotheron*), while cadmium and lead were calculated based on the potential ecological risk index values. As a result, the THQ values for the corresponding elements in both organisms were less than one (Table 13).

Discussion

Physio-chemical parameters

The average pH of water samples taken from the Korle Lagoon was 6.61, while that from Kpeshie was 7.55. These showed that Kpeshie Lagoon was neutral to basic and Korle Lagoon was slightly acidic. Therefore, water pH in both lagoons was within the range of 6.5 to 8.5, which is considered acceptable (US EPA 2004; WHO 2005). A comparable investigation carried out by Addo et al. (2011) found that the average pH of the water in Kpeshie Lagoon was 7.8, comparable to this study's results. Therefore, within US EPA limits of 6 to 9, the sediment pH in the recorded Korle and Kpeshie Lagoons was acceptable.

While the water in Kpeshie varied from 30 to 31°C, the temperature at Korle Lagoon was between 28.9 and 30.1°C; these are typical of shallow tropical coastal lagoons, where the temperature ranges between 25 and 35°C (Biney 1990), the dissolved oxygen mean concentration in the lagoon water of Korle measured 1.86 mgL-1, while that of Kpeshie Lagoon measured 4.58 mgL^{-1}. That was a sign that the DO level in the lagoon at Korle was too low to support any possible aquatic life. Karikari et al.'s (2009) investigation into the water quality characteristics at the Korle Lagoon estuary data showed a DO level of 1.93 mgL^{-1}; this result is consistent with the current study. On the other hand, Kpeshie Lagoon was very close to the legal limit of 5 mgL^{-1}. This could explain the lagoon's fisheries did not develop. Mangroves are also covered in the Kpeshie Lagoon, which helps to oxygenate the water there. Similar research conducted by Addo et al. (2011) found DO to be 2.42 mgL^{-1}, which is not consistent with the results of the current investigation. That may be due to the Kpeshie Lagoon receiving less phosphorus in recent years.

The lagoons' mean TDS measurements were very high (28415 mgL^{-1} at Korle and Kpeshie Lagoons, respectively), exceeding the US EPA's (2004) recommendation of 1000 mgL^{-1} by a factor of 20. These suggested a high ion concentration in the lagoons, which might prevent the growth of aquatic life. The sources of these ions may include the organic and inorganic materials found in industrial wastewater, sewage discharge, or runoff from dumping sites for waste and discarded materials that are close to the lagoons. High ion concentrations could be corrosive and make lagoonal water unfit for domestic, industrial, or agricultural use (Oram 2014). a study by Apau et al. (2012) at Kpeshie Lagoon showed a range of TDS and conductivity values of 24.1-45.4 gL^{-1} and 54.8-101.8 Sm^{-1}, respectively. These numbers are comparable to the results of recent research.

The increase in conductivity with TDS has been noticed. R2, the regression coefficient, showed that most of the points fell along the regression line. The number of dissolved salts and metals in the surface water is indicated by conductivity. In the current study, the conductivity level of water samples from Kpeshie Lagoon was lower than that from Korle Lagoon. This may be because there aren't any significant industrial discharge facilities or waste dump sites close to the Kpeshie Lagoon. The mean conductivity values of both lagoons were higher than the US EPA's secondary surface water guideline. Furthermore, in Korle Lagoon, Addo et al. (2011) found a mean conductivity of 47040 Scm^{-1}. Aglanu and Appiah (2014) also found conductivities range at Kpeshie Lagoon from 19370 to 28500 Scm^{-1}. Those mean conductivity values agree with the results of the current investigation.

Heavy metal concentrations in water, sediments, crab, and fish

In both lagoons, the levels of heavy metals in water samples were lower than in sediments. Due to sediments' role as a temporary sink for heavy metals, this may have occurred (Sparks 2005). Long residence times and slow lagoon flushing rates may be responsible for low levels of heavy metals found in water samples from both the Korle and Kpeshie water sources. In the only place where the fish species *C. amnicola* and *S. melanotheron* were harvested, their metal concentrations were higher than those of the water column.

Arsenic

Concerning all sampling locations and all other metals examined in the study lagoons, arsenic concentrations were found to be the lowest. The mean arsenic concentrations in Korle and Kpeshie's water column were less than the 10 gL^{-1} thresholds the World Health Organization set in 2005.

The average As concentration in the sediments of the Korle Lagoon was 0.4906 $mgkg^{-1}$, while it was 0.5045 $mgkg^{-1}$ in the sediments of Kpeshie. The mean values fell within the Canadian Council of Ministers of the environment's (CCME 2001) limit of 7.24 $mgkg^{-1}$ for the Sediment Quality Guideline (SQG). Similar trends in both lagoons were observed in As concentrations in sediment values. These results suggested that there was no direct anthropogenic input of arsenic into either lagoon. However, the recycling and burning of electronic waste at the lagoon's banks may be to blame for the current levels of As in both lagoons.

The mean concentrations of arsenic in *C. amnicola* and *S. melanotheron* were 0.2879 $mgkg^{-1}$ and 0.3971 $mgkg^{-1}$, respectively. While *S. melanotheron'*s mean arsenic level exceeded the allowed limit of 0.26 $mgkg^{-1}$ (FAO/WHO 2011), *C. amnicola*'s mean arsenic level was below the recommended limit of 0.50 $mgkg^{-1}$ (US EPA 2010). Arsenic levels in *S. melanotheron* exceeded the threshold value despite being low in sediments from Kpeshie Lagoon. The transfer of heavy metals from one species of organism to another is probably to blame for this.

Cadmium

One of the most harmful heavy metals that can cause health issues in people is cadmium, according to Manahan (2000). According to the study, the average Cd concentration in the water column of the Korle Lagoon was 0.036 mgL^{-1}, whereas the Kpeshie Lagoon had a reading of 0.048 mgL^{-1}. Compared to WHO (2005), the mean levels of heavy metals were higher than the safe level of 0.003 mgL^{-1} for surface water. Aglanu and Appiah (2014) found 0.001 mgL^{-1} of Cd in the water of the Korle Lagoon, which is less than what was found in the current study. That might signify a rise in Cd contamination in the catchment area.

The cadmium in the sediment core at Korle Lagoon gradually decreased throughout a 0-cm depth. In the sediment of the Korle Lagoon, the first 10 cm revealed extremely high Cd concentrations, and the final 20 cm revealed a relatively stable trend. Due to increased municipal and industrial wastewater discharge, the trend in concentrations may indicate that cadmium's anthropogenic input into Korle Lagoon has quadrupled in recent years (Boadi and Kuitunen 2002).

On the other hand, Kpeshie Lagoon was relatively stable, with Cd concentrations ranging from 7.63 $mgkg^{-1}$ to 10.28 $mgkg^{-1}$. The only possible source of cadmium in Kpeshie Lagoon is urban waste or runoffs since there are no manufacturing facilities nearby.

The mean Cd concentrations in *C. amnicola* and *S. melanotheron* were 4.60 $mgkg^{-1}$ and 1.10 $mgkg^{-1}$, respectively. For fish and crustaceans, these mean values were higher than the permissible limits of 0.5 $mgkg^{-1}$ set by the US EPA in 2010 and 0.05 $mgkg^{-1}$ by FAO/WHO in 2011. In an earlier investigation by Fianko et al. (2013), the cadmium concentration in tilapia at Kpeshie Lagoon was Below the Detection Limit (BDL). Given that some fish samples read below the detection threshold in the current study, this is comparable.

Chromium

According to the USGS (1996), chromium has no known health benefits for people or animals. Hexavalent chromium poses a threat to human health and is toxic. Chromium concentrations decrease as pH and water hardness increase (Codex 1995). While Kpeshie Lagoon's mean chromium concentration was slightly above the WHO limit, Korle Lagoon's average concentration was below the permissible limit of 0.05 mgL^{-1} (WHO 2005). Chromium levels found in Kpeshie's water column are comparable to those in Apau et al. (2012).

Within the SQG recommended limit of 52.3 $mgkg^{-1}$, chromium levels in sediments from the Korle and Kpeshie Lagoons were generally found (CCME 2001). Compared to sediment concentrations in Korle Lagoon, those at Kpeshie Lagoon have higher and more stable chromium concentrations. The runoff from the Agbogbloshie market may be the source of chromium in the Korle Lagoon. In contrast, wastewater from the hospitality sector may be the source of chromium in the Kpeshie Lagoon.

Chromium was measured at 39.52 $mgkg^{-1}$ in *C. amnicola* as opposed to 5.88 $mgkg^{-1}$ in *S. melanotheron*. Compared to tilapias, which are pelagic and filter feeders, it is more exposed to higher levels of heavy metals in the benthos as a crustacean benthos bottom feeder (Signor and Vermeij 1994). Metal levels in *C. amnicola* and *S. melanotheron* were above the standard limits of 0 $mgkg^{-1}$, even though sediment metal concentrations were within the standard ranges (US EPA 2010).

Copper

Copper is a crucial element needed for metabolic processes. Furthermore, the copper amount found in the water column of the Korle and Kpeshie Lagoons was less than the WHO-recommended limit of 2.0 mgL^{-1}. In the lagoonal water of Korle, 0.049 mgL^{-1} was discovered by Aglanu and Appiah (2014) in a similar study.

Copper concentrations were higher in the sediments than the 18.7 $mgkg^{-1}$ SQG recommended limit. Both lagoons' sediments revealed a rise in copper levels in recent years. These may be caused by the burning of tires from cars or electronic waste at the edges of both lagoons. Klark et al. (2012) at Kpeshie found varying copper concentrations between 21 and 51 mg kg^{-1}, similar to the current study's trend.

The *S. melanotheron* averaged 3.49 $mgkg^{-1}$, whereas *C. amnicola* measured higher copper concentrations with an average of 31.09 $mgkg^{-1}$. The permissible limits for tilapias and crustaceans, respectively, are 20 $mgkg^{-1}$ and 70 $mgkg^{-1}$, according to FAO/WHO and the US EPA, respectively. Because the element is necessary for normal metabolic functions and is essential to organism health, copper levels in *C. amnicola* and *S. melanotheron* were within the allowable limit (USGS 1996).

Lead

Average lead concentrations in both lagoons' water columns were 0.62 mgL^{-1}, which is higher than the WHO-(2005) permissible limit of 0.01 mgL^{-1}. However, the mean lead concentrations in lagoonal water were lower than those in the sediments.

A different pattern was observed in the sediments of the Korle and Kpeshie Lagoons. Lead sediment levels in the Korle Lagoon were largely stable but have risen recently. On the other hand, Kpeshie Lagoon saw a decrease in concentration in recent years. In addition, the lead values were higher than the SQG limit that the CCME had recommended. These might indicate a rise in the amount of e-waste recovered in the Korle Lagoon catchment areas and atmospheric input from vehicular activity.

The *S. melanotheron* had an average lead concentration of 1.23 $mgkg^{-1}$ and *C. amnicola* of 10.9 $mgkg^{-1}$. These lead levels in tilapia and crustaceans were higher than the recommended limit of 1 $mgkg^{-1}$ (FAO/WHO 2011). Crustacea recorded higher metal concentrations than tilapia. This observation might be brought about by significant physiological variations in how their bodies operate. Additionally, the variation shows how much a particular species can take in from the water around it, especially in the form of sediments while feeding (Olowu et al. 2010).

Zinc

Zinc is necessary for metabolism and advantageous; it appears safe even at relatively high concentrations of 20,000-40,000 mgL^{-1}. Low values of 0.07 mgL^{-1} and 0.09 mgL^{-1} for zinc were found in the water column of the Korle and Kpeshie Lagoons, respectively. The concentrations were under the allowable 3 mgL^{-1} limit (WHO 2005). a study by Addo et al. (2011). Similar trends in zinc concentrations were found in a 2011 study done in the water of the Kpeshie Lagoon.

Higher zinc concentrations were found in the sediments of both lagoons than in the water column. Even though the levels of zinc were high, most of the concentrations were below the SQG limit of 124 mgkg-1, which is advised (CCME 2001). The measured concentrations may be related to urban runoff from nearby slum areas like Sodom and Gomorrah, tire burning along lagoon banks, and continued use of dry cells and construction materials.

The *S. melanotheron* and *C. amnicola* had average zinc concentrations of 23.23 $mgkg^{-1}$ and 36.04 $mgkg^{-1}$, respectively. These concentrations were within the recommended limits of 80 $mgkg^{-1}$ for crustaceans and 40 $mgkg^{-1}$ for tilapias, respectively (FAO/WHO 2011). Accordingly, there was no zinc contamination. These organisms' metabolic processes have probably used zinc, an essential element.

Pollution indices

Most of the estimated Cf values for the investigated heavy metals (As, Cr, and Cu) were less than one, indicating a low level of contamination. However, the values (Cf) for zinc revealed a moderate contamination factor, while those for Cd and Pb revealed a high level.

Additionally, the levels of contamination (CD) in Korle and Kpeshie showed a similar pattern to the contamination factor, with As, Cr, and Cu recording low levels of contamination. In the majority of the study sites, the PLI values were discovered to be generally high (>1). The data sets suggested that both lagoons' sediments were seriously contaminated with Cd and Pb.

Target Hazard Quotient

THQ calculated about Cd, Cr, and Pb in *C. amnicola* and *S. melanotheron* were less than one. A THQ (<1) indicates that heavy metals might not pose any non-carcinogenic health effects to consumers. The chromium THQs were very close to one, however, for both *C. amnicola* and *S. melanotheron*. Therefore, for the time being, daily consumers of crab and tilapia may not experience any non-carcinogenic health effects from chromium, but caution should be taken with the consumption rate.

In conclusion, the current research discovered the pollution in Korle and Kpeshie Lagoon was contaminated. However, just enough dissolved oxygen is present in the Kpeshie Lagoon to support fisheries. The analysis results show that the lagoon waters in both locations are contaminated with cadmium and lead. That indicates fewer environmental regulations and more domestic, municipal, and industrial waste are dumped into these lagoons. Arsenic, copper, and zinc concentrations among the heavy metals examined were low (US EPA 2004; WHO 2005). The sediments of both lagoons are heavily contaminated with chromium and copper and lead to varying degrees. Cadmium and lead were ranked as high contaminants in the sediments by the degree of contamination. Both lagoons are extremely contaminated with cadmium and lead, according to the ecological potential risk index calculated on the levels of sediments heavy metals. The cadmium, chromium, and lead metal high concentrations were found in the tissues of tilapia and crustaceans due to fish analysis in the Kpeshie Lagoon. In addition, the current study found that, except for arsenic, *C. amnicola* had higher metal concentrations than *S. melanotheron* (Cr, Cd, Cu, Pb, Zn). THQ calculated that the levels of metals in fishery resources were less than one (1) based on the values of the heavy metal concentrations in *C. amnicola*, *S. melanotheron*, and the rank of the ecological potential Risk Index (RI). That indicates people who regularly eat tilapia and crab from Kpeshie Lagoon are safe from non-carcinogenic health effects. However, the cadmium, chromium, and lead levels, which have no nutritional value, tend to bioaccumulate, so it's best to keep intake under control.

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