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Influence of diurnal tides and other physico-chemical factors on the assemblage and diversity of fish species in River Pra Estuary, Ghana

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Abstract: To broaden knowledge of the importance of estuaries to fisheries and encourage their management, this research investigated the influence of diurnal tides and other physico-chemical factors on the assemblage and diversity of fish fauna in the Pra estuary in Ghana; an estuary highly silted by illegal gold mining activities. Fish species composition, diversity and size distribution together with salinity, dissolved oxygen (DO) and turbidity were studied monthly at high and low tides from February 2012 to December 2013. Fish were caught using a cast net while physico-chemical parameters were recorded using water quality checker. Data were analyzed for fish numerical composition, length range, modal sizes and monthly Shannon-Wiener diversity along with monthly trends of physico-chemical factors. A total of 2310 fish belonging to 38 species from 22 families comprising finfishes and shellfishes of marine, brackishwater and freshwater sources were sampled. Majority were juveniles of commercially important fishes that utilized the estuary as a nursery habitat. On daily basis, assemblage and diversity of fish were mainly regulated by salinity and turbidity through tidal influxes. Over a long term, however, DO appeared to be the key driver of overall fish diversity, with an increase in DO being followed by a similar trend of rise in species diversity. A clarion call is made to rekindle efforts on clamping down illegal mining activities that continually silt the estuary. Hopefully, this will safeguard the estuarine environment and provide suitable physico-chemical conditions that support richer and more diverse fish community to improve Ghana's dwindling marine fishery.

Key words: Dissolved oxygen, estuarine ecosystem, fish community, management, salinity, species richness, tidal influx, turbidity.

Introduction

Estuarine environments are highly dynamic ecosystems experiencing continuous tidal and freshwater influxes as well as changing physical environment and water chemistry (Miththapala 2013). Despite their unstable environments, they are among the most biologically productive ecosystems in the world (Beckman 2012), supporting the world's fisheries by providing breeding and nursery habitats for diverse marine and freshwater fishes (Blaber 1997). Given the vital ecological roles played by estuarine ecosystems in fisheries, understanding how the changing physico-chemical factors influence assemblage, structure and diversity of fish communities in estuaries has remained a key issue of interest in fisheries ecology research works around the world (Albaret *et al.* 2004; Chowdhury *et al.* 2010; Gutiérrez-Estrada *et al.* 2008; Marais 1988; Segbefia *et al.* 2013). The ultimate goal is to broaden knowledge of the ecological functional roles of these systems to encourage and facilitate their management and conservation from local levels to global scale.

Concerning how environmental factors influence fish communities, data from available studies show that the parameters that mainly account for the occurrence and diversity of estuarine fish biota differ among estuaries. In the Tagus estuary in Portugal for example, Gutiérrez-

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Estrada *et al.* (2008) indicated nitrate concentration, depth, dissolved oxygen and temperature as the most important predictors of fish diversity. Also, while Hossain *et al.* (2012) pointed out temperature and rainfall as the principal factors influencing fish abundance and distribution in the Meghna estuary in Bangladesh, Chowdhury *et al.* (2010) reported salinity and turbidity as the major controllers of fish occurrence and distribution in the Naaf estuary in the same country. In Africa, the work of Marais (1988) on 14 estuaries in South Africa reported a positive correlation between fish abundance and catchment area size, and a negative correlation between fish abundance and water transparency and salinity. Other studies in West Africa such as Segbefia *et al.* (2013) cited temperature and salinity as primary driving forces influencing fish abundance in the Volta estuary in Ghana while Albaret *et al.* (2004) could not clearly point out which factors influenced fish occurrence and diversity in the in the Gambia estuary. Although all these findings affirm the critical roles of physico-chemical factors in fish assemblages, it is also noteworthy to draw some lessons from the works of Albaret *et al.* (2004) as well as Chowdhury *et al.* (2010) that estuaries which do not face severe pollution from agricultural, industrial and other anthropogenic activities have richer and much diverse fish fauna.

The Pra River Estuary, being the second largest estuary in Ghana after the Volta estuary, plays a significant ecological role in supporting the country's fisheries, yet remains the most silted estuary from illegal gold mining activities. The consequent implications of such grave anthropogenic disturbance on the estuarine environment, coupled with tidal influxes which subject the ecosystem to daily environmental instabilities, makes it imperative to understand how the fisheries ecology of the system responds to the changing environment on both short and long term scales. To this end, the present study investigated the influence of diurnal tides and other physico-chemical factors on the assemblage and diversity of fish fauna in the estuary to provide a contributory scientific information focused on understanding the ecological dynamics of the ecosystem to help inform management and conservation objectives. The specific objectives were to investigate the species composition, diversity and size distribution of the fish community in the Pra estuary, and how tides, salinity, dissolved oxygen and water turbidity influence fish diversity in the ecosystem.

Materials and methods

Study area

River Pra Estuary is located in the Shama District of the Western Region of Ghana, West Africa (5°01'00"N, 5°03'30"N and 1°36'30"W, 1°38'00"W). It is the second largest estuary in Ghana after the Volta Estuary, with about 1,000 ha of adjoining mangrove swamp, marshland and floodplain which provide important fishery resources for communities located along the periphery such as Shama, Anlo Beach and Krobo. Mangroves of the genera *Avicennia, Rhizophora* and *Laguncularia* fringe the banks and extend over three kilometers on both sides of the estuary. The adjoining marshland has the saltwater grass *Paspalum vaginatum* (Poaceae) as the main vegetation. The estuary receives tidal influx from the Gulf of Guinea of the Atlantic Ocean, and freshwater inflow from River Pra.

Measurement of physico-chemical parameters

The physico-chemical parameters were measured from four locations across the length of the estuary, starting from the mouth at Shama and sampling at approximately 1 km interval up to the reverine end at Krobo; about 3 km stretch from the mouth. Sampling was conducted monthly from February 2012 to December 2013 during the second week of each month. Using a hand-held water quality checker (Horiba, model U-10), salinity, dissolved oxygen concentration (DO) and turbidity were recorded at low tide and high tide for five consecutive days between 6 hrs GMT and 18 hrs GMT each day depending on time of occurrence of the tides. Three replicate recordings were taken per location during each tide, amounting to twelve replicates in the estuary per tide for a day, and sixty replicates per tide for a month. Monthly means and standard deviations were computed based on the sixty replicates.

Fish sampling and data collection

Fish were caught from the estuary at high and low tides using a 20 mm stretched mesh cast net to determine fish community composition, richness and diversity as well as size distribution of the populations. Samples were preserved in 10% formalin soon after capture and transported to the laboratory for further examination. The fish were sorted and identified to their families and species using manuals and keys on finfishes and shellfishes for Ghana and West Africa (Dankwa *et al.* 1999;

Paugy *et al*. 2003; Rutherford 1971; Schneider 1990), and the number of individuals belonging to each species was recorded. The total length (TL) of finfish, carapace width (CW) of crabs and body length (BL) of shrimps were measured to the nearest 0.1 cm. The fish community was analysed for species composition, species richness and diversity. Richness and diversity were ascertained using Margalef's index and the Shannon-Wiener index (Krebs 1999) respectively.

Margalef index (*d*) is given as:

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

where *s* is number of species in the community, and *N* is the number of individuals in the community. The Shannon-Wiener index (H') is given as:

$$H' = -\sum_{i=1}^{s} P_i(lnP_i)$$

where *s* is the number of species in the community and P_i is the proportion of individuals belonging to species *i* in the community.

The evenness or equitability component of diversity was calculated from Pielou's index (Pielou 1966) given as:

$$J' = H'/H_{max}$$

where H_{max}= ln*s*.

The gonads of some fish were also examined for maturity while maturity information for other species were obtained from published literature. Size distribution was analysed at 1 cm class interval for species with more than five specimens.

Results

Occurrence and size distribution of fish species

The occurrence of fish species in the estuary is presented in Table 1. A total of 2310 individuals belonging to 38 species from 22 families of finfish and shellfishes were sampled, of which 23 species were of marine origin, 3 brackishwater and 12 freshwater species. The common marine fishes were the grey mullets *Liza* spp. and *Mugil* spp. (Mugilidae), bonga shad *Ethmalosa fimbriata* (Clupeidae), threadfin *Galeoides decadactylus* (Polynemidae), snapper *Pomadasys peroteti* (Haemulidae), crevalle jack *Caranx hippos* (Carrangidae), ladyfish *Elops lacerta* (Elopidae), the flounder *Citharichthys stampflii* (Bothidae), sole *Cynoglossus senegalensis* (Cynoglossidae), swimming crab *Callinectes amnicola* (Portunidae) and the pink shrimp *Penaeus notialis* (Penaeidae). Brackishwater fishes found were the black-chinned tilapia *Sarotherodon melanotheron* (Cichlidae), the mudskipper *Periophthalmus barbarus* (Gobiidae), and the crab *Goniopsis pelii* (Grapsidae) while common freshwater species included catfishes *Chrysichthys nigrodigitatus* (Claroteidae) and *Clarias gariepinus* (Clariidae), cichlids *Tilapia zillii* and *Hemichromis fasciatus* (Cichlidae), gobbies *Gobioides africanus* and *Gobionellus occidentalis* (Gobiidae) and freshwater shrimp *Macrobrachium microbrachion* (Palaemonidae).

The size range and modal sizes of some common fishes encountered were also compared with their maturity sizes (see Table 1). With the exception of a few species such as the catfish *Chrysichthys nigrodigitatus*, the tilapia *Sarotherodon melanotheron* and the crab *Callinectes amnicola* that had modal classes that were equal or bigger in size than reported maturity sizes, the remaining species caught had modal sizes smaller than their respective maturity sizes indicating the presence of a large number of juvenile marine and freshwater fishes in the estuary.

Fish numerical composition

Table 1 indicates that the black-chinned tilapia *S. melanotheron* was the most dominant fish in the Pra estuary constituting 44% of the ichthyofauna. The bagrid catfish *C. nigrodigitatus* and the sickle-fin mullet *L. falcipinnis* were also considerably present (10% each). The banana mullet *M. bananensis*, swimming crab *C. amnicola* and red breast tilapia *T. zilli* were fairly represented with a composition of 7, 5 and 3% respectively, while each of the remaining species made up less than 3 % of the fish community.

Changes in the fish species diversity with tides and other physico-chemical factors

Fig. 1 illustrates the monthly fluctuations in salinity, dissolved oxygen and turbidity in the estuary along with changes in fish species diversity at high and low tides over the twenty-three month period. The highest salinities were recorded during the dry season (October to March) with peaks in December 2012 (22‰) and 2013 (23‰), and lowest recorded during the rainy season in June-July 2012 and 2013 where levels reduced below 3‰. In addition, high tide salinities were about twice higher than low tide in the dry season, but declined to almost the same level as low tide in the rainy season. Contrary to salinity trends, turbidities were lower during the dry season with the lowest in February, but increased steadily to highest levels in

Table 1. Occurrence and size distribution of fish sampled from the Pra estuary (species with n > 5 were analyzed; % composition of modal class in parenthesis).

Family	Species	N	Size-TL (cm)		Maturity Size
			Range	Modal class	
Finfish					
Claroteidae	*Chrysichthys nigrodigitatus* (F)	239	5.3–16.5	9.0–9.9(78.4)	11.5–16.7[g]
Bothidae	*Citharichthys stampflii* (M)	24	7.1–10.0	7.0–7.9(84.6)	-
	Scyacium micrurum (M)	4	6.5–8.0	-	-
Carangidae	*Caranx hippos* (M)	42	4.2–9.0	6.0–6.9(77.9)	55.0–65.0[b]
	Caranx latus (M)	2	4.1	-	-
Cichlidae	*Sarotherodon melanotheron* (BW)	1024	3.4–15.3	10.0–10.9(46.0)	10.0[a]
	Tilapia zillii (F)	75	3.8–16.4	7.0–7.9(63.4)	-
	Hemichromis fasciatus (F)	16	7.7–13.3	11.0–11.9(26)	-
Clariidae	*Clarias gariepinus* (F)	3	35.3–41.3	-	-
Clupeidae	*Ethmalosa fimbriata* (M)	36	6.4–12.1	8.0–8.9(86.6)	22.0[e]
	Sardinella aurita (M)	64	5.3–7.1	6.0–6.9(64.1)	17.5–21.5[f]
Cynoglossidae	*Cynoglossus senegalensis* (M)	5	14.1–29.0	-	-
Eleotridae	*Eleotris senegalensis* (F)	2	9.4	-	-
	Kribia kribensis (F)	1	4.3	-	-
Elopidae	*Elops lacerta* (M)	15	5.8–21.5	11.0–11.9(64.0)	-
Gerreidae	*Eucinostomus melanopterus* (M)	2	6.3	-	-
Gobiidae	*Porogobius schlegelii* (F)	10	4.9–6.7	5.0–5.9(24.3)	4.9[a]
	Periophthalmus barbarous (BW)	6	6.4–21.3	-	-
	Gobionellus occidentalis (F)	12	7.4–11.2	8.0–8.9(31.0)	-
	Bathygobius soporator (F)	1	4.6	-	-
	Gobioides africanus (F)	27	7.7–10.5	9.0–9.9(21.9)	-
Haemulidae	*Pomadasys peroteti* (M)	64	4.3–14.3	9.0–9.9(78.8)	-
	Plectolynchus macrolepsis (M)	14	4.6–10.2	7.0–7.9(75.1)	-
Lobotidae	*Lobotes surinamensis* (M)	6	5.9–11.8	-	-
Mugilidae	*Liza falcipinnis* (M)	235	4.1–23.2	9.0–9.9(63.0)	11.6–12.1[d]
	Mugil bananensis (M)	155	5.0–22.6	6.0–6.9(56.9)	13.2[a]
	Mugil curema (M)	12	11.3–22.6	12.0–12.9(40.0)	16.0[a]
	Liza dumerillii (M)	26	4.2–12.1	7.0–7.9(67.6)	-
	Mugil cephalus (M)	6	6.5–7.4	-	-
	Liza graudisquamis (M)	8	7.1–7.8	-	-
Poecilidae	*Aplocheithys spilauchen* (F)	7	5.3–6.8	-	-
Polynemidae	*Galeoides decadactylus* (M)	6	10.7–11.4	-	-
Sciaenidae	*Pseudotholithus senegalensis* (M)	13	11.1–17.3	13.0–13.9(60.0)	24.2[a]
Serranidae	*Epinephelus aeneus* (M)	12	7.9–9.4	-	-
Shellfish					
Palaemonidae	*Macrobrachium microbrachion* (F)	9	4.3–9.3**	-	-
Penaeidae	*Penaeus notialis* (M)	11	5.0–20.6**	-	-
Portunidae	*Callinectes amnicola* (M)	104	2.6–10.1*	5.0–5.9(59.0)	5.3–6.2[c]
Grapsidae	*Goniopsis pelii* (BW)	5	9.5*	-	-

*denotes carapace width; **denotes body length; M = Marine; BW = Brackishwater; F = Freshwater; a = smallest mature specimen observed in the current samples; b = Ospina-Arango *et al.* (2008); Panfili *et al.* (2006); c = Impraim (2009); d= Lawson *et al.* (2010); e =Blay & Eyeson (1982); f = Mensah (1975); g = Offem *et al.* (2008).

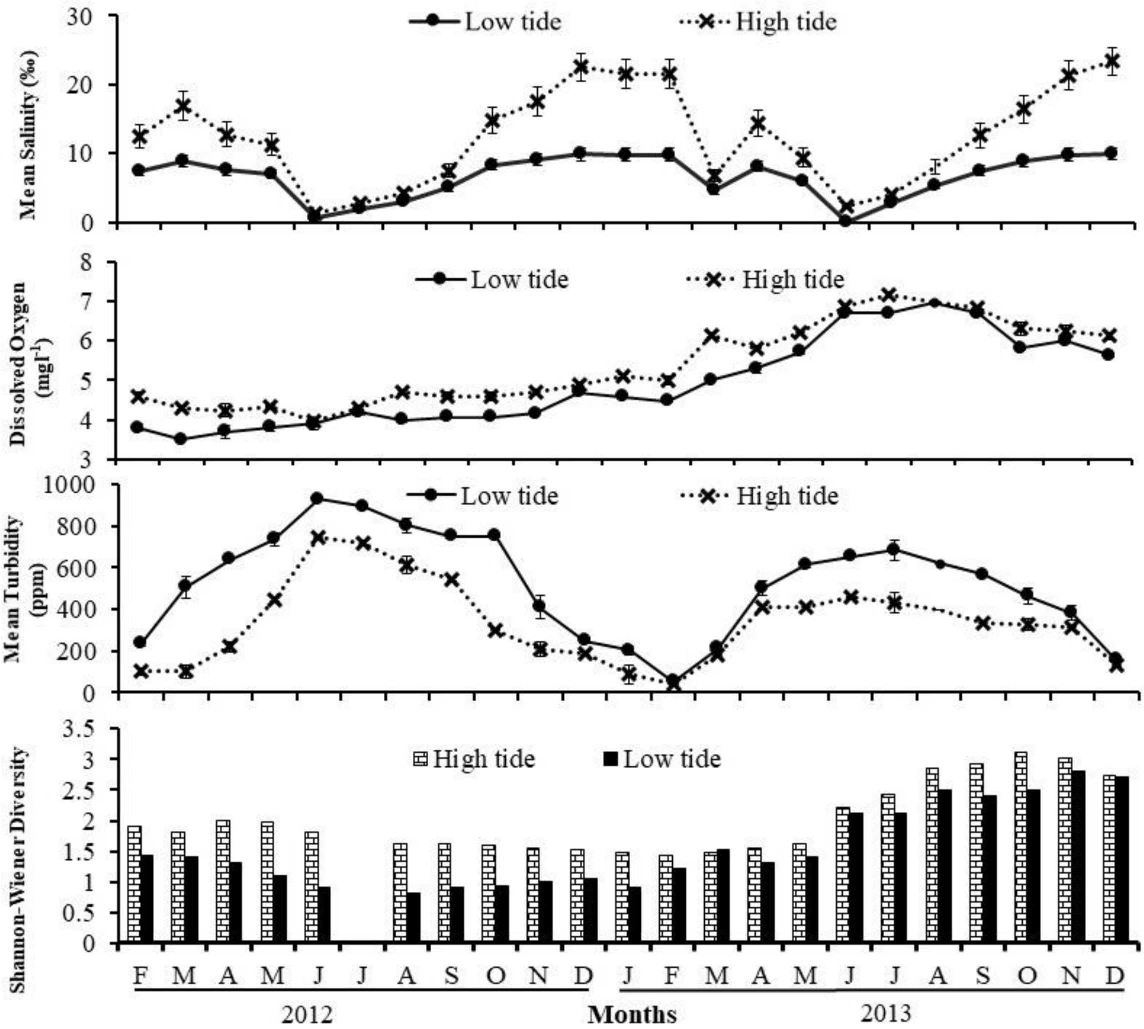

Fig. 1. Monthly changes in salinity, DO, turbidity and fish species diversity in the Pra estuary at high and low tides from 2012 to 2013 (±1SE).

the rainy season with peaks in June-July 2012 and 2013. The water was more turbid at low tide than high tide, except from December to February where turbidities were almost the same at both tides. Noticeably, the peaks of turbidities in June 2012 (low tide ≈ 700 ppm, high tide ≈ 900 ppm) were considerably higher than the peaks in July 2013 (low tide ≈ 400 ppm, high tide ≈ 600 ppm) indicating that turbidity generally reduced from 2012 to 2013. Dissolved oxygen concentration remained below 5 mg l^{-1} throughout 2012 but increased progressively in 2013 reaching around 7 mg l^{-1} in July and showing imperceptible decline afterwards.

A total of 38 species from 22 families were sampled from the estuary, with overall Margalef's richness (*d*) of 4.8, Shannon-Wiener diversity (*H'*) of 2.2 and Pielou's evenness (*J'*) of 0.6. In general, the fish community was more diverse at high tide than low tide throughout the monthly samples. Over the study period, fish diversity had a similar trend of change as dissolved oxygen, remaining below 2.0 in 2012 and increasing remarkably in the following year where it reached 3.1 in October 2013 at high tide and showed a very little decline thereafter.

Discussion

The present 38 fish species from 22 families recorded in the Pra estuary is higher than the 20 species belonging to 12 families reported in the Whin estuary (Okyere *et al.* 2011), 28 species from 14 families in the Kakum estuary (Blay 1997) and the 32 species from 21 families in the Volta estuary (Segbefia *et al.* 2013) in Ghana, but far less than the

70 species from 32 families in the Gambia estuary (Albaret *et al*. 2004). Deteriorating water quality due to increased turbidity could result in reduced fish diversity in aquatic ecosystems as many fish need clear water to spot their prey (Bilotta & Brazier 2008), and the silt could also cause fish gill clogging and irritation (Simenstad 1990). Pertinently, reasons for the occurrence of much higher number of species in the Gambia estuary than the Pra estuary could be attributed to the prevalent high turbidity of the Pra (> 500 ppm) resulting from siltation from extensive illegal gold mining activities upstream which renders the estuary less favourable for aquatic life, unlike the Gambia estuary which according to Albaret *et al*. (2004), remains free from perturbations.

Out of the thirty-eight species occurring in the estuary, only five namely *Sarotherodon melanotheron*, *Chrysichthys nigrodigitatus*, *Liza falcipinnis*, *Mugil bananensis* and *Callinectes amnicola* together constituted 76% of the community. This is consistent with observations on other tropical brackishwater habitats where although several species may be present, typically few species constitute over 70% of the fish community (Blay 1997; Little *et al*. 1988; Okyere *et al*. 2012; Quinn 1980). Also, the occurrence of a large number of immature marine and freshwater fishes at sizes smaller than their maturity sizes reiterates the fact that the Pra estuary is an important nursery habitat for juveniles of commercially valued freshwater and marine fishes as also reported for the Kakum (Blay 1997) and Whin (Okyere *et al.* 2011) estuaries in Ghana. This raises a clarion call to safeguard the estuary and its environs from the excessive siltation arising from the pervasive illegal mining activities in the Pra River.

Different studies have attributed the occurrence and diversity of fish species in brackish-water habitats in the tropics and subtropics to different environmental factors on temporal and spatial scales although salinity is commonly mentioned as a key influencing factor (Chowdhury *et al*. 2010; Little *et al*. 1988; Segbefia *et al*. 2013). In the current study, there was a higher diversity of fish fauna in the estuary during high tide than low tide, and this is largely attributable to the combined effects of the changes in turbidity and salinity during tidal influxes in the estuarine environment. During high tides, the influx of clearer and saline marine waters into the estuary reduced the turbidity from suspended silt in the Pra river inflows, pushing the silted river waters further to the upper reaches and maintaining less turbid and saline waters within the estuary which favoured the entry of more marine species and increased diversity. To buttress this point, many of the fishes caught at high tide were of marine origin, the commonest being juvenile *Liza* spp., *Mugil* spp., *Ethmalosa fimbriata*, *Pomadasys peroteti*, *Elops lacerta*, *Cynoglossus senegalensis*, *Penaeus notialis*, *Callinectes amnicola,* among others. At low tides when large river inflows with reduced salinities and increased turbidities were recorded, diversity declined and the community generally shifted to dominance of brackishwater and freshwater tolerant catfish *C. nigrodigitatus*, cichlids *S. melanotheron*, *H. fasciatus*, *T. zillii* and gobbies *Gobioides africanus* and *Gobionellus occidentalis.* It is, therefore, apparent that assemblage and diversity of fish species in the Pra estuary on daily basis are principally regulated by salinity and turbidity through tides. This is similar to the Naaf estuary in Bangladesh where Chowdhury *et al.* (2010) reported salinity and turbidity as the main controllers of fish occurrence and distribution.

Over the twenty-three month period, it could be noticed that the progressive increase in overall fish diversity followed a similar trend with rise in dissolved oxygen concentration (DO) in the estuary. In running waters, DO of 5 mg l^{-1} is reportedly the threshold for survival of aquatic life (Hynes 1970; Palanna 2009). Low DO is stressful to most aquatic organisms as it could cause suffocation (Gupta 2011). When DO in the Pra estuary remained below mg l^{-1} throughout 2012 species diversity was below 2.0, and when DO improved in the following year to its peak of 7 mg l^{-1} in July 2013 fish diversity also increased remarkably reaching a peak of 3.1 in October of the same year. This suggests that DO drives the overall diversity of fish in the estuary over a long term. The increase in DO and the consequent rise in fish species diversity in the estuary in 2013 could be ascribed improvement in water turbidity. In turbid waters, as explained by LaSalle (1990), the suspended particles absorb heat from sunlight, making turbid waters warmer and reducing the concentration of oxygen in the water. Costa *et al.* (2013) further indicate that the suspended particles scatter light thereby decreasing the photosynthetic activity of plants and algae which contributes to lowering of the oxygen concentration even more. It is therefore possible that the higher turbidity in 2012 engendered the poorer oxygen levels and lower fish diversity, and the improvement of water turbidity in 2013 which occurred after an a operation of Ghana National Security taskforce to clamp down illegal mining activities, enhanced higher DO levels which fostered the survival of a more diverse species in the estuarine community.

In conclusion, this study has demonstrated that the Pra estuary which has been seriously silted from pervasive illegal mining activities over the last decade, supports at least 38 fish species from 22 families, most of which are juveniles of commercially valued freshwater and marine fishes that utilize the estuary as an important nursery habitat. On daily basis, the assemblage and diversity of these species in the estuary are principally regulated by salinity and turbidity through tides. Over a long term however, dissolved oxygen concentration appeared to be the driving factor for overall fish diversity as the two showed a similar trend, with a progressive increase in DO been followed by a significant rise in species diversity. Since improvement in DO is also contingent on improvement in turbidity, it is recommended that the Ghana National Security taskforce should rekindle their effort on clamping down the activities of illegal gold miners as they executed in 2013 which yielded some reduction in water turbidity. It is hoped that this will safeguard the Pra riverine and estuarine environments to provide suitable physico-chemical conditions that support a richer and more diverse fish community to improve Ghana's dwindling marine fishery.

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