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Diel and Tide Variation of Fish Speciesi Kakum River Estuary in the Central Region,Ghana

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Research Article

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ABSTRACT

The sequence of day and night has a strong impact on the relative distribution of numerous fish species, causing a change in the richness and the composition of fish assemblages. Changes in fish abundance occur mainly due to the tidal cycle, moon phase, and alternation of night and day. Periodic monitoring of the biodiversity of these estuarine ecosystems requires to be vigorously pursued to assess their status. This study investigated the diel variation related to tidal levels of fish community in Kakum River Estuary in the Central Region of Ghana. On each sampling date, ten castings were done during both day and night capture for a total of twenty casting on each sampling date. A total of 1,223 fish belonging to 25 species, 16 families, and a biomass of 10,832.8 grams were recorded during the entire sampling periods from November/2016 to April/2017. The diurnal catches had 24 species, contributing to 52% of the total fish caught and 45% biomass. The nocturnal catches had 19 species, which contributed to 48% of the total catch and 55% biomass. Catch weights of most abundant species in the Kakum River Estuary, the herbivore-phytoplankton *Mugil curema*, were highest only during the night. Mean fish species were significantly different between tide-time of day and night (F_3,20=187.789, p=7.3764) with the highest species values (36) recorded at low tide (Medium salinity) on 10/01/2016 during the day and lowest species of (19 on 12/01/2017 and 21 species on 17/03/2017) were recorded at the peak tide during the nocturnal period. The study provides strong indication that fish inhabiting Kakum River Estuary establish their niches along a temporal scale in Subject to the interaction with the tidal and the diel cycles. The fish community occurred in the estuary at different times during sampling and the abundance of fish changed on an irregular basis. This suggests that temperature may play an important role in determining the behavior of marine migrants. The geomorphological setting of the estuary plays an important role in influencing how fish use the estuary according to the tidal cycles.

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INTRODUCTION

Diel succession strongly influences the relative distribution of several species, causing a change in the composition and richness of the assemblages of fish species [1]. The distributions of the species are mainly determined by numerous responses to both the biological and physical aspects of their environment. These responses permit individual fish species to select environments that offer the best combination of a high potential for reproductive output and growth with the lowest risk of mortality [2]. The requirements of these individual species changes, and a suitable environment at one hunger state and time of day, or stage in the life history may not be suitable for another. This Therefore causes many species to move from one habitat to another at a variety of temporal and spatial scales. Moreover, the species' habitats do not remain constant but then vary frequently on a diurnal and seasonal basis. Therefore, several studies have been conducted. Diel and tidal variation in surf zone fish assemblages of a sheltered beach were studied by Félix-Hackradt, et al., in southern Brazil. Again, Spatial, and temporal variations of the fish community structure, and trophic ecology have been studied [3-5]. According to Oliveira-Neto, et al., Short-term changes in fish abundance occur mostly because of the moon phase, tidal cycle, and alternation of night and day. However, many studies have identified dissimilar patterns of fish habitat use with greater catches during the day and a higher number of fish species and diversity during the night period stated that the influence of abiotic components in shaping fish communities (salinity, turbidity) has been equally well studied in different aquatic ecosystems all over the world [6-12]. Although many fish species of the estuarine can be considered euryhaline, therefore Whitfield, et al., reported that, in estuarine systems a strong relationship between fish community composition and salinity has been found. Castellanos-Galindo and Krumme reported that changes in salinity are ultimately a consequence of the seasonality of the rainfall, precipitation regime, and size of the drainage system at each study site. Most study investigated the relationship between salinity and fish assemblage structures in the main channels of estuaries [13-15]. A few studies have investigated how intertidal mangrove creek fish assemblages and fish tidal migrations are affected by precipitation and/or salinity change [16-18].

Knowledge on the ecological habit of juvenile marine fishes could provide fundamental importance for the effective management of the fishery but in Ghana, there is a dearth of information.

Little information is documented on the diversity of brackish water fisheries in Ghana. However, the species composition has been reported in a few cases [19]. In understanding the ongoing change that occurred in environmental conditions and the continual utilization of brackish water resources in the country, periodic monitoring of the biodiversity of these ecosystems requires to be vigorously pursued to assess their status. Based on the result of the assessments, an adaptation of management strategies will be necessary. This present study describes the status of species diversity, similarity, richness, and size distribution of marine fishes entering Kakum River Estuary in the Central Region of Ghana and their possible relationship with some environmental factors. This study will help understand estuarine fish assemblage dynamics in this area.

MATERIALS AND METHODS

Study site

The study was conducted in Kakum River Estuary (Figure 1). The Kakum River Estuary is formed by a twin river system, the Kakum River, and the Sweet River, fringed by a mangrove system that is pristine in some areas and highly degraded in other areas. The estuary (1˚19' W, 5˚05' N) is located near Elmina and about 5 km West of Cape Coast (the regional capital) [20].

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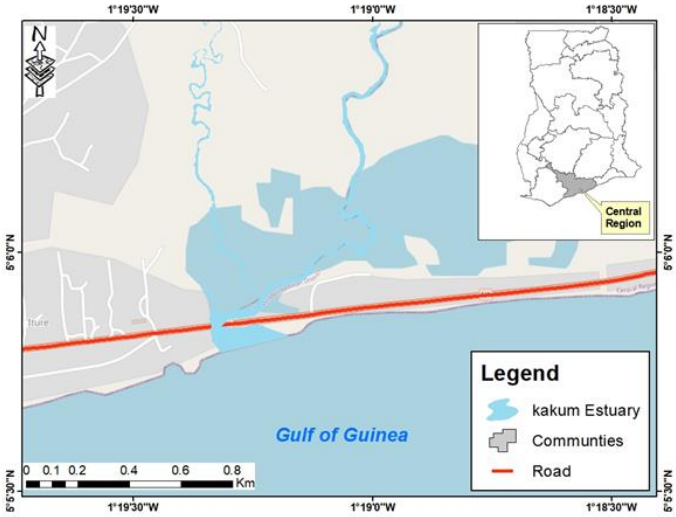
Figure 1. Map of Ghana and plate of Kakum River Estuary.



Sampling design

Diel measurements of temperature and salinity: Measurements of temperature and salinity were taken on each sampling date from November 2016 to April 2017 at 06:00, 10:00, 14:00, 18:00, 22:00, 02:00 and 06:00. Surface temperature and salinity were measured simultaneously using a HANNA multi parameter probe. Three replicates of each parameter were taken at different points of the water body during sampling and the average value was calculated [21].

Diel fish sampling and data collection: The fish from Kakum River Estuary were sampled at the same time temperature and salinity was taken. The fish sampling was carried out monthly from November/2016 to April/2017 by using one mini boat of 9 m with a distant less than 1.5 m during diurnal (06:00, 10:00, 14:00, 18:00, 06:00 h) and nocturnal (22:00, 02:00 h) periods using a medium-mesh cast net of 20 mm stretched. Sampling was done within thirty (30) minutes on all sampling occasions. Each sampling covered 100 m in order to control the sampling effort. Casting was done parallel to the water according to the tidal level to identify the variation during low and high tide. Ten casting were made during both day and night on each sampling date for a total of twenty casting each month. Fish were identified using protocols used by Schneider, Kwei and Ofori-Adu,. The Total Length (TL, cm) and body weight (BW, g) were recorded for each specimen [22].

All fishes sampled were preserved in 10% formalin immediately after capture to avoid post-mortem digestion of stomach contents. Fish were sorted into freshwater species, brackish water species and marine species and subsequently identified to them into family and species level using taxonomic keys, measured (Total Length, TL) and wet weighed (g ± 0.1). Fish species were then allocated to spatial and Trophic Guild (TG) groups according to Elliott, et al. and Froese and Pauly [23].

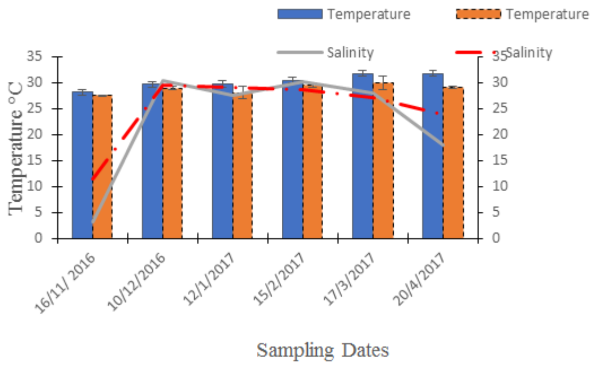
Data analysis: The variability in species abundance, number of fish (individuals/haul) and body weight (grams/haul) was evaluated using Catch Per Unit Effort (CPUE). The variation in fish composition and community structure was investigated using Margalef's richness index, Shannon's diversity (number of individuals), and Simpson's dominance (number of individuals) [24]. The differences in fish assemblages' during day and night periods was determined using Student t–test. Average monthly values were previously log-transformed and tested for familiarity.

RESULTS

Diel variations in temperature and salinity

At Kakum River Estuary, the surface water temperature recorded during both diurnal and nocturnal periods respectively ranged from 27.5 to 31.8˚C with higher values recorded during the day (31.8˚C) on 17/3/2017 and 20/4/2017 and lower ones recorded at night (27.5˚C). Salinity periods ranged from 3.3 to 30.4‰ during the study period Figure 2. There was not much variation in salinity between 10/12/2016, 12/01/2017, 15/02/2017, and 17/03/2017 with exception of 16/11/2016 where low salinity of 3.3 %o was recorded during the day and 11.4%o at night respectively [25].

Figure 2. Diel Variation of temperature and salinity (Error bars: +/- 1 SE) in the Kakum River Estuary on Nov 2016- April 2017.



Tide, diel and salinity related patterns, taxonomic and estuarine use composition

At Kakum River Estuary, a total number of 1,223 fish belonging to 25 species, and 16 families, with biomass of 10,832.8 grams were recorded during the entire sampling period from November/2016 to April/2017 [26]. While the brackish water species *Sarotherodon melanotheron* (*Cichlidae*) and *Aplocheilichthys spihauchen* (*Cyprinodontidae*) and the freshwater fish *P. leonensis* occurred in both day and night capture, the freshwater *Coptodon zilli* (*Cichlidae*) fish was recorded during the day and the remaining 23 species belonging to 15 families were of marine origin.

The most occurring families were *Mugilidae* (6 species), and *Lutjanidae* (3 species). *Mugil curema* (*Mugilidae*) were the abundant species representing 18% of all the individual fishes collected during the diurnal and nocturnal periods. *Liza dumerillii* (*Mugilidae), Mugil bananensis* (*Mugilidae*), *Caranx hippos* (*Carangidae*), and *Eucinostomus melanopterus (Gerreidae)* accounted for 14%, 13%10%, and 7% of the total catch respectively during both diurnal and nocturnal periods. In terms of catch weight for both diurnal and the nocturnal periods, *Liza falcipinnis*, *Liza dumerillii*, *Mugil curema*, *Lutjanus agennes*, and *Caranx hippos* represented 28% of the total catch *weight*. The family *Mugilidae* (grey mullet) contributed to 54% of the total catch weight of the estuary fish assemblage followed by *Lutjenidae* (13%). The diurnal catches had 24 species, contributing to 52% of the individuals and 45% biomass. The nocturnal catches had 19 species, contributing to 48% of the total catch and 55% biomass. *Mugil curema*, *Liza dumerillii*, *Eucinostomus melanopterus*, *Lutjanus agennes*, and *Pellonulla leonensis*, representing 23%, 20%, 10%, 4%, and 3% respectively were higher during the nocturnal period (Table 1) [27].

The fish assemblage was dominated by herbivore-phytoplankton, and detritivores with a minimal level of omnivores representing 56% of the total fish species (eg. *Coptodo zilli*, *Liza falcipinnis*, *Mugil curema*, and *Elops lacerta*). Piscivores were very abundant and were consumed by 6 fish species namely *Citharichthys stamflii*, *Lutjanus fulgens*, *Lutjanus agnnes, Lutjanus goreensis Pseudotolithus typus*, and *Caranx hipos*, and their weights were especially high during the diurnal periods [28]. Most herbivore-phytoplankton species had higher catch weights during both day and night periods (*i.e., Liza falcipinnis, Mugil curema, Elops lacerta*). Catch weights of the most abundant species in the estuary, the herbivore-phytoplankton *Mugil curema*, were highest only during the night (Table 1).

Table 1. Composition of fish species in Kakum River Estuary.

Family	Species	Density/Biomass (g)	SG	TG	Size Range

		D (n)	D (g)	N(n)	N (g)			TL (cm)	Max-TL (cm)
Cichlidae	*Sarotherodon melanotheron*	8	105.85	3	58.19	D	HP, D	8.3-18.6	
	Coptodon zilli	25	121.75			D	HP, D	3.2-5.6	
Cyprinodontidae	*Aplocheilichthys spilauchen*	4	11.41	3	4.65		HP	4.1-12.5	
Clupeidae	*Pellonulla leonensis*	1	4.03	20	86.69	P	HP	2.1-5.2	9.0
	Sardinella aurita	3	282.97	11	43.54	P	BP,D	7.1-17.6	35.0
Bothidae	*Citharichthys stamflii*	37	329.64	15	148.93		PV	4.1-15.3	15.0
Mugilidae	*Liza falcipinnis*	86	700.37	41	310.21	BP	HP, D	5.1-16.6	35.0
	Liza dumerillii	63	550.9	114	1560.96	BP	HP, D	2.2-20.9	35.0
	Mugil bananensis	92	87.57	63	401.16	BP	HP, D	4.4-15.5	40.0
	Mugil curema	90	355.56	133	1774.95	BP	HP, D	4 - 29.8	35.0
	Mugil cephalus	5	72.93	4	64.62	BP	HP, D	9.6-12.4	120.0
	Liza grandisquamis	8	107.76			BP	HP, D	4.2-14.1	40,0
Lutjanidae	*Lutjanus fulgens*	20	122.83	14	149.83	D	P	5.1 - 16	60.0
	Lutjanus goreensis	31	225.55	18	234	D	P	5.1-15.8	80.0
	Lutjanus agennes	14	461.53	22	192.93	D	P	6.2-26.6	75.0
Gobiidae	*Bothygobius soporator*	25	219.14	7	91.45	D	Z	4.1-12.4	36.0
Carangidae	*Caranx hippos*	88	659.09	36	50.8	PB	P	4.3-15.3	75.0
Sciaenidae	*Pseudotolithus typus*	1	89.36			D	P	9.3	285.0
Elopidae	*Elops lacerta*			1	73.47		O	9 .6-10.2	90.0
Gerreidae	*Eucinostomus melanopterus*	25	156.83	59	327.62	D	Z	4.6-18.5	30.0
Serranidae	*Epinephelus aeneus*	1	7.09			RA		8.4	
Ariidae	*Arius gigas*	3	170.9	17	306.57	D	HP	7.9-21.8	120.0
Haemulidae	*Plectorhynchus*	2	10.49			BP		4.9 -	45.0

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	macrolepis							7.6	
Acanthuridae	*Acanthurus monroviae*	6	26.57	3	71.04	D		5.2-11.5	50.0
Scombridae	*Scomberomorus tritor*	1	1.04				HP	5	
Total		639	4881.16	584	5951.61				

Note: Number of individual's fishes (n), Trophic Guilds (TG), Number of diurnal catch (D (n)), Number of nocturnal catch (N (n)), Spatial guilds (SG), mean and range total length (TL cm), Biomass of day (D (g)), Biomass at night (N(g)), maximum lengths reported in the literature (Max-TL) (FAO, 1990).
Trophic Guilds (TG) include: Detritivore (D), Herbivore-Phytoplankton (HP), Piscivore (P), Zoobenthivore (Z), and Omnivore (O).
Spatial Guilds (SG) includes; Pelagic (P), Benthopelagic (BP), Demersal (D), Reef-associated (RA), and Freshwater (F).

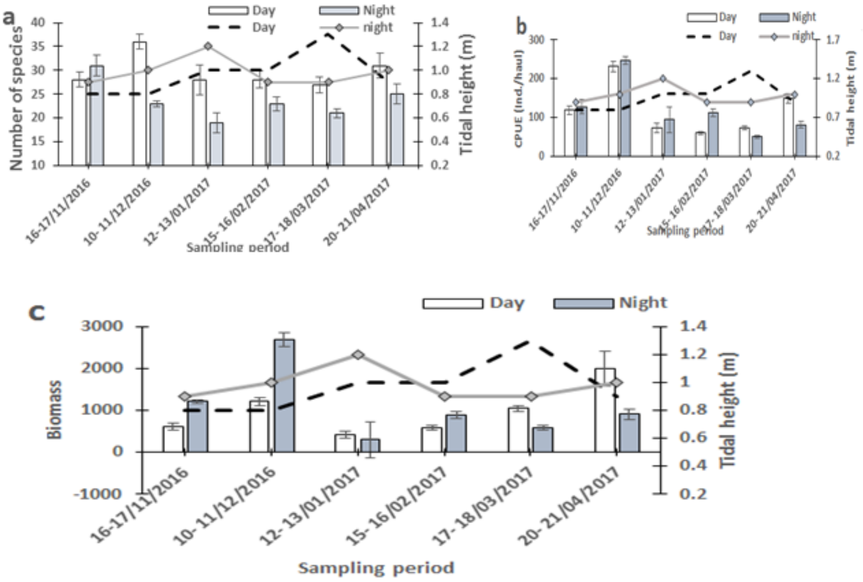
Tidal fluctuation over species, individuals, and biomass

The number of species caught at different times from the estuary varied from 19 to 11 in January/ 12 and December/10 respectively during the six (6) month study period. During the diurnal tides, fish species increased from 28 in November/16 to 36 in December/16 and from 27 in March/17 to 31 in April/20 during the day period.

Mean species richness did not differ significantly between day and night ($F_{1,10}$=7.59, p=0.02043) or between months ($F_{5,10}$ = 1.04431, p = 0.40696). Mean fish species were significantly different between tide-time of day and night ($F_{3,20}$ = 187.789, p=7.3764) with the highest species values (36) recorded at low tide (Medium salinity) on 10/01/2016 during the day and lowest species of (19 on 12/01/2017 and 21 species on 17/03/2017) were recorded at the peak tide during the nocturnal period (Figure 3a).

While mean overall fish density (ind.m^{-2}) ranged from 60 on 15/02/2017 to 232 on 10/11/2017 during the day and from 51 to 247 on 17/03/2017 and 10/12/2017 during the night respectively, mean overall fish biomass ranged from 416.27 to 1999.35 on 12/01/2017 and 20/04/2017 respectively during the diurnal sample and from 297.27 on 12/01/2017 to 2686.49 10/12/2016 during the nocturnal period. Both fish density (p=0.9272997) and biomass (p=0790128) were significantly higher in low tide than in higher tide during both day and night (Figure 3b and 3c). These differences were statistically significant.

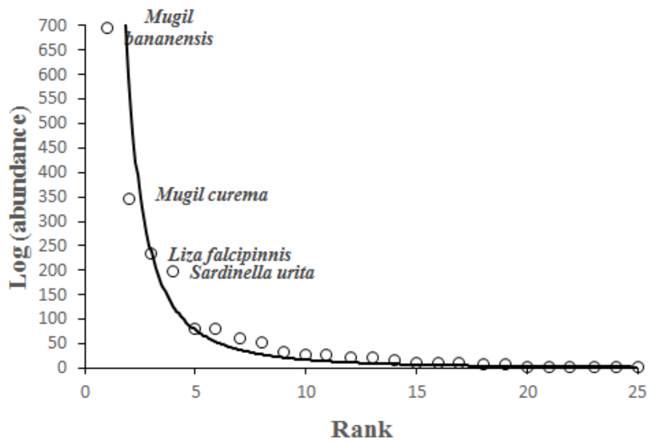
Figure 3. Tidal variation over number of fish species (a) CPUE ((individuals/haul); (b) CPUE (grams/haul); (c) during diurnal (- -) and nocturnal (-) capture at Kakum River Estuary (November/16 to April/20).



Rank abundance distribution curve

A relatively even fish assemblage was found in Kakum River Estuary. The shape of the SAD using individual abundance as a currency resembled that of a log-normal distribution (Figure 4).

Figure 4. Rank-abundance plot of Kakum River Estuary fishes captured from November 2016 to April 2017.



Box plot distribution of fish number and biomass

Mean overall fish density ranged from 27 to 169 at low salinity and 18 to 146 at mid-rise salinity. Mean overall fish biomass ranged between 297.2 g to 1114.3 g. Both fish density and biomass were significantly higher in low salinity than midrise salinity period (Figure 5).

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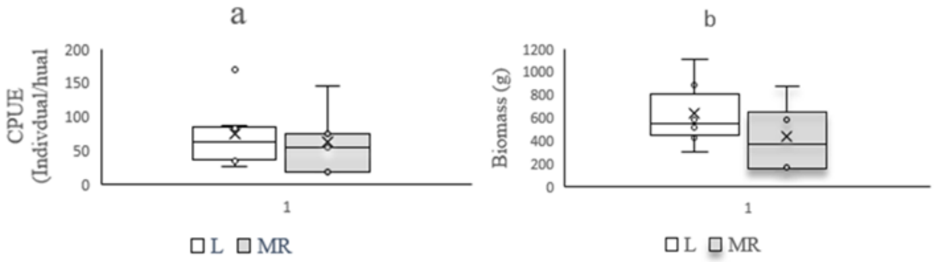
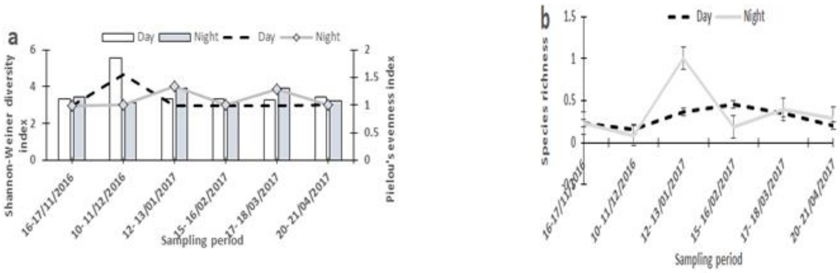
Figure 5. Boxplots representing differences in density (a) and catch-weight (b) of fishes collected from Kakum River Estuary during low and mid-rise salinity.



Diversity and Evenness between samples

The biodiversity did not vary greatly during sampling time as well as sampling dates throughout the sampling (Figure 6a and 6b). Species evenness and Shannon diversity index were very similar for both day and night, with higher values recorded during the night period in January/2017 and in March/2017 except for December 2016 where high levels did occur with a peak of 5.58 diversity and 0.99 evenness during the day period (Fig. 6). The richness index was calculated. The values varied from 0.09 to 1 for both day and night. The distribution of the number of individuals among the various species was more even in Kakum River Estuary. Diversity (H'), evenness (J), and richness showed significant differences between day and night periods (p< 0.5) or were they correlated (p< 0.5).

Figure 6. Temporal variation of Shannon's diversity and Pielou's dominance (d), Margalef's richness (b), in diurnal (- -) and nocturnal (-) periods at Kakum River Estuary (November/16 to April/20).



DISCUSSION

The study provides an indication that fish populating the Kakum River Estuary establish their niches along a temporal scale and interacts with the tide as well as the diel cycles. The study also provides evidence of the significant role of salinity on fish assemblage structure in the estuary.

The range of diel variation of surface temperature was 27.5˚C to 31.8˚C. There was no clear pattern in temperature. The temperature measured from the estuary followed a similar pattern during day and night periods.

Nielsen reported that, there is no tidal influence on salinity. Long has stated that, tides intensely influence the differences of salinity in the estuaries. During the present study, it was identified that the influence of tides on the surface salinity of the estuary was considerable, and the values of salinity showed a modal distribution with peaks (29.6%o) in 10/12/2016 during the high tide, and the lowest salinity recorded were 3.3%o during the day and 11.4%o during the night in 16/11/2016. Indicating that fluctuations in salinity values are controlled by the tides and tidal surface currents.

The fish community occurred in the estuary at different times during sampling and the abundance of fish changed on an irregular basis. This suggests that temperature might play an important role in defining the behavior of marine migrants species. Wang, et al. reported that the occurrence of the fish larvae and juveniles in the coastal waters of the Tanshui estuary could be related to temperature of the water body.

Variation in salinity was also greater in the current study. As a result, although a large proportion of the individuals recorded from the estuary were marine migrants and estuarine species which have a wide tolerance to salinity [29].

Marine fish resources that were attained from the estuary during the study period were diverse in nature. These fishes include species belonging to the families Clupeidae, Mugilidae, Lutjanidae, Gobiidae, Bothidae, Carangidae, Sciaenidae, Elopidae, Gerreidae, Serranidae, Ariidae, Haemulidae, Acanthuridae, Scombridae, and Cynoglossidae. Most of the species recorded in this current study were similar to that of Oribhabor and Ogbeibu in a study of the Niger Delta Mangrove Creek in Nigeria, and Blay in Kakum River Estuary and Benya lagoon, Ghana. The current study recorded 25 marine species belonging to 16 families in the Kakum River Estuary. Comparing the species number recorded in the present study with Blay, Blay recorded greater number of fish species (28 species of 14 families) than what those of this present study. The differences might be attributed to the interaction among fish and its environment (biological, as well as physical characteristics) which might be factored in predicting changes in breeding population size, overall abundance, and other aspects of population structure [30].

Salinity is an essential factor that influences the community structure of brackish systems in both the tropics and subtropics due to species differences in salinity tolerance [31]. This might account for the presence or absence of some fish species in the estuary despite the proximity of the brackish systems.

Similarly, fish assemblages in the macro-tidal areas of northern Brazil are dominated in catch weight by Tetraodontidae and Ariidae according to Barletta, *et al*. The result from the estuary showed a high diversity of the fish community with most of the fish biota being dominated by marine species. These marine species include *Mugil curema, Liza falcipinnis, Mugil bananensis, Liza dumerilii, Sardinella aurita, Caranx hippos,* among others. This indicates that marine fishes migrate largely to utilize the estuary as feeding and spawning grounds by the adult and spend their life at sea while the juvenile fishes are nurtured in the brackish water systems before they move to the marine environment in their adult stage. This agrees with Albaret and Lae in Ebrie Lagoon in West Africa and Blay in Kakum River Estuary and Benya Lagoon [32]. According to Emmanuel and Oyenma, marine fish species (*Caranx hipos, Liza falcipinnis, Mugil cephalus,* and *Penaeus notialis)* occur in nearly freshwater to hypersaline waters. These indicate that species have the ability to adapt and cope with the variable conditions of the brackish water environment. Zander, *et al.* stated that, many fishes have evolved specialized physiological, and an adoptable behavior and increasing their ability to adapt and cope with these localized conditions may be a strategy to exist as a permanent brackish system resident. The observation of high diversity of the fish species recorded in the current study may also be attributable to good environmental conditions that are ideal and favorable for good growth and fish survival.

Effects of salinity on fish composition

The current study indicates that fish biomass of the estuary can be considerably affected by salinity. Cyrus and Blaber mentioned that salinity has been confirmed to be one of the major elements of the dynamics of estuarine fish assemblages. Greatly, when high precipitation producing high runoff through the sub tidal channels is the main driver of salinity changes in the estuary. The lower the salinity of an estuary, the higher the number of fish densities and biomass than the mid-rise salinity period and this is because of the higher biomass of marine fish species (*Mugil curema, Liza dumerilli, Liza falcipinis, and sardinella aurita*) [33]. This is similar to a study conducted in the Caeté River in North Brazil by Barletta, *et al.,* They reported the highest number of species with the greatest biomasses of fish in the lower salinities period. This pattern confirms higher biomasses of a single estuarine species (Sciaenidae), with a significant contribution of freshwater-related catfishes (*i.e.,* Aspredinidae, Auchenipteridae, Pimelodidae) which were identified in a region where the freshwater fish fauna is rich and abundant [34-36]. Therefore, the low numbers of fish and biomass of species recorded in the upper estuaries in different parts of the world might be attributed to the lack of intolerance of most marine and estuarine fish species to long-term low salinity values, as well as occurrence of fresh water fish fauna of these regions [37,38].

Tide related patterns: The overall patterns of distribution of fish species, abundance, and biomass are not fixed, however, following dissimilar patterns. The dissimilarity in the distribution of species, and biomass are because of migration pattern of individual fish species the estuary at a variety of time scales. Several marine fish species migrate according to the tidal cycle. The absence of such pattern is indicated by the lack of species in the catches made over the intertidal zone during high tide. Although pelagic species were caught during low tide periods, therefore, the presence of fishes in the intertidal zone may likely be the result of random movement than a direct shoreward movement. Abou-Seedo, *et al.* stated that tidal migrations may or may not be modified by a superimposed diel movement pattern.

Diel fluctuations in fish species: Concerning the community structure, a diel pattern occurred in number of species, abundance, and biomass was identified, however, the species caught were neither diurnal nor nocturnal in Kakum River Estuary. This variation in species number and abundance identified in the present study over the diel cycles may be due to visual stimulus and the avoidance capacity of the fish to the fishing nets, cryptic behavior, and migration chances between day and night which are essential factors in capture success. Wardle studied the behavior of fish species reported that many fishes are primarily active at night then search for shelter during the day from inaccessible places to the fishing net or to other protected areas; therefore, these fishes are hardly caught in diurnal samplings. In the Kakum River Estuary, the highest density and biomass (g) of fish sampled respectively occurred in the night period. This occurrence of high abundance and biomass values during the nocturnal period in the estuary may attribute to an increase in catch ability at night or a movement of these individuals into the area at dusk and leaving at dawn or a combination of both. According to Clark *et al.,* the occurrence of great biomass at night is considered a common pattern in different environments of the coastal zones. Wardle pointed out that the main factor that contributes to the high abundance in biomass of fish is the protection of fish against predators due to the absence of sunlight, which would make the visualization of the prey difficult [39].

The fish community occurred in the estuary at different times during sampling and the abundance of fish changed on an irregular basis. This suggests that temperature might play an important role in determining the behavior of marine migrants and this agrees with Wang, et al., who reported that the occurrence of fish larvae and juveniles in the coastal waters was in relation to water temperature of the estuary.

Variation in salinity was also greater in the current study. As a result, although a large proportion of the individuals recorded from the estuary were marine migrants and estuarine species which have a wide tolerance to salinity.

CONCLUSION

This study proves the complexity that can be encountered in the composition of estuarine fish assemblages. Despite the similarities that occurred among the species, fish assemblages separate along the tide and diel related patterns between macrotidal regions and specific patterns can change according to local environmental characteristics. The structural setting of the estuary also plays an important role in influencing how fish utilize the estuary according to the tidal cycles. These factors can explain the distribution of fishes along salinity gradients in the estuary and helps understand the differences in the productivity of the estuary.

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