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Impacts of Solid Wastes on Physicochemical Characteristics and Habitats of Fiddler Crabs (*Uca tangeri*) on the Intertidal Sediments of Part of the Bonny Estuary, in Rivers State, Nigeria

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ABSTRACT: The objective of this paper was to evaluate the impacts of solid wastes on physicochemical characteristics and habitats of fiddler crabs (*Uca tangeri*) on the intertidal sediments of Part of the Bonny Estuary, in Rivers State, Nigeria using appropriate standard methods. Results obtained show that the physiochemical characteristic in the study are were pH (4.9 - 6.3); conductivity (780.0 – 6290 µS/cm) sulphate (34.4 – 190.0 mg/kg); phosphate (0.6 – 6.8mg/kg); nitrate (1.2 – 4.5mg/kg); sand (32 – 87%); silt (0.2 - 14%) clay (3 - 54%). Solid wastes observed were plastics, wood/plank, bottles, Styrofoam, tyres, nylon/polyethene, clothes and ropes while fiddler crabs holes ranged from 3 -38 .in the study area. Physico-chemical characteristics of sediment varied between intertidal stations however, changes in pH, phosphate, nitrate and silt particles caused significant ($p<0.05$) changes in the number of fiddler crab holes. The amount of solid wastes observed at the mid intertidal level also impacted significantly on the number of crab holes but the observation was different at the low and the high intertidal zones. In conclusion, the interplay of physicochemical characteristics of the sediment with solid wastes contributed to the fragmentation and loss of fiddler crab habitats but varied from one intertidal coast to another. It is therefore, important to assess each intertidal coast in order to conserve fiddler crabs and their habitats.

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Keyword: Solid Wastes; Fiddler crabs; intertidal habitat fragmentation.

The constant increase in human populations and its associated activities has become a stress factor for ecological communities of the aquatic ecosystem/environment particularly, the intertidal zones, mangrove forests and wetland ecosystems that serve as a refuge for a diversity of organisms including fiddler crabs- *Uca tangeri* (Moslen *et al*., 2022), with habitation and protection often coming in the form of extensive mudflats/sandy beaches and dense vegetations. The rising population of humans in congested towns and cities is rapidly putting pressure on coastal areas of the Niger Delta with the conversion of numerous mangrove forests into built up areas like houses, roads and industrial estates (Numbere, 2020), which impact on intertidal habitats. The intertidal zone is a very interesting and unique ecosystem housing diversity of flora and fauna. The physico-chemical characteristics of the sediments and the overlying water determine to a great extent the biology and biodiversity of this unique environment. Construction activities over time had changed the formation of the coastal system, which has a lot of organisms such as

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the dexterous fiddler crabs (*Uca tangeri*) that live in burrows along the shore (Numbere, 2020). This unique ecosystem is subject to rapid or gradual changes in view of the prevailing hydrodynamic conditions of the area. The intertidal zone is a very important coastal zone where the sea water meets the land. It is exposed at low tide and submerged at high tide with heavy influence from the nearby seas and oceans, in the case of this study, the Atlantic Ocean in the southern Niger Delt Belts of Nigeria. The immersion and emersion of the flora and fauna of the intertidal zones enable special adaptation of the organisms for them to be able to dwell in this habitat due to their peculiar challenges. The intertidal zone of the coast is a very critical link between the land and the sea in terms of food chain and ecosystem services. Fiddler crab (*Uca tangeri*) is one of the common crabs inhabiting the intertidal zones along the shoreline areas of tropical and subtropical coastal zones. Fiddler crabs perform important functions within the coastal intertidal, such as recycling of nutrient and energy in mangrove forest (Banerjee *et al*., 2020; Otero *et al.,* 2020), and also has filter feeding habit, that enable consumption of microphytobenthos and plant litter from substrates (Horn *et al.,* 2019). This crab plays important ecological roles with regards to prey-predator relationships that sustain the ecosystem. Fiddler crabs also play important roles of sediment aeration via bioturbation and mud balling and organic matter degradation (Moslen *et al.,* 2022). According to Morouf and Ojetay, (2017) *Uca tangeri* is an ecologically important species in our marsh lands hence, mangrove ecosystem should be effectively monitored for the conservation of this species. Fiddler crab burrows increase oxygen dispersion in anoxic mangrove sediment and promote iron reduction and nitrification process over sulphate reduction in subsurface sediment. Therefore, it is expected to accelerate decomposition rate under oxic and suboxic conditions (Mokhtari *et al*., 2013), but they concluded in their research that oxidation created by burrowing activity of *U. forcipata* was not efficient to change physical properties of mangrove sediments. Fiddler crabs clean the sediment surface via picking up litter at low tides and move seeds from one part of the mangrove forest to another causing formation of zonation patterns in mangrove forests (Liu *et al*., 2018). Crabs influence sediment formation through their bioturbation activities (Kristensen, 2008), which include re-design of burrows, carving of ventilation outlets, creation of flow channels and construction of protective walls against external intruders. Fiddler crabs represent a rich model system for examinations of sensory processes and behaviour. Their stereotypical displays, specific visual tasks, relatively simple environment and dynamic social interactions have made them an ideal system for identifying the sensory system contribution to many behaviours such as tracking conspecifics (Land and Layne, 1995), finding burrows (Hemmi and Zeil, 2003), neighbour and species recognition (Detto *et al*., 2006) and attracting mates (Christy, 1995). The intertidal environment housing abundance and diversity of fiddler crabs and other organisms is now subject to contamination, pollution, habitat fragmentation and destruction especially with regards to solid wastes. Moslen *et al.,* (2015) reported that the generation of solid wastes is on the rise due to increase in population, urbanization, industrialization and change in consumption pattern. The ultimate end for most of these wastes is the creeks and Rivers around the metropolis. Moslen *et al*., (2022) had reported that solid wastes generated from municipal, urban development and industrial processes eventually find their way into the aquatic environment especially, the intertidal areas which provide habitats for diversity of organisms including fiddler crabs. Moslen *et al*., (2015) had observed the dominant wastes made up of xenobiotic and non-biodegradable substances such as plastics, cans/bottles of different industrial products and 'pure water' sachets/poly-ethylene bags generated around city center that eventually find their way to the intertidal zones and coastal regions. Clogging of the water ways, reduction of flow rate, siltation, destruction and alteration of aquatic habitat, impairment of fishing activities and loss of aesthetic value of adorable recreational sites were noticeable significant negative effects of solid wastes (Moslen *et al*., 2015). The domination of solid wastes on the intertidal zones of our estuaries and coastal system had caused serious habitat degradation and loss for fiddler crabs and other organisms by blocking fiddler crab burrows and occupation of available shoreline space, dislodging the crabs from their habitats and eventual reduction of their population (Moslen *et al*., 2022). The objective of this paper was to evaluate the impacts of solid wastes on physicochemical characteristics and habitats of fiddler crabs (*Uca tangeri*) on the intertidal sediments of Part of the Bonny Estuary, in Rivers State, Nigeria

MATERIALS AND METHODS

Site Description: The study area is within the southern part of Nigeria. South-South Nigeria is bordered by the Atlantic Ocean which drains the numerous rivers and creeks around Port Harcourt where the study was done. Port Harcourt falls within the limits of the humid tropics, influenced by land and sea breezes and the two major pressure and wind system namely the South-West (S-W) and the North-East (N-E) trade winds (Austine and Ukpere, 2022). There were few existing mangrove vegetations, shrubs and grasses where others are lost to urbanization by invasion of lands and reclamation of low/wet lands. The study area characterized by sandy beaches, stretches of mudflats and poorly drained chikoko soil of high plasticity is now laden with different types of solid wastes. Five intertidal coastal fronts (five stations) of creeks bordering Choba (CHO), Eagle Island (EI), Eastern By-pass (EBP), Ogbunabali (OGB) and Elelenwo (ELE) in the southern part of Nigeria were assessed (Fig. 1). The intertidal zones of the study area generally have a gentle slope and marshy terrain with different types of solid wastes (plastics, nylons, packaging bags, forms, fabrics) interspersed with fiddler crab holes.

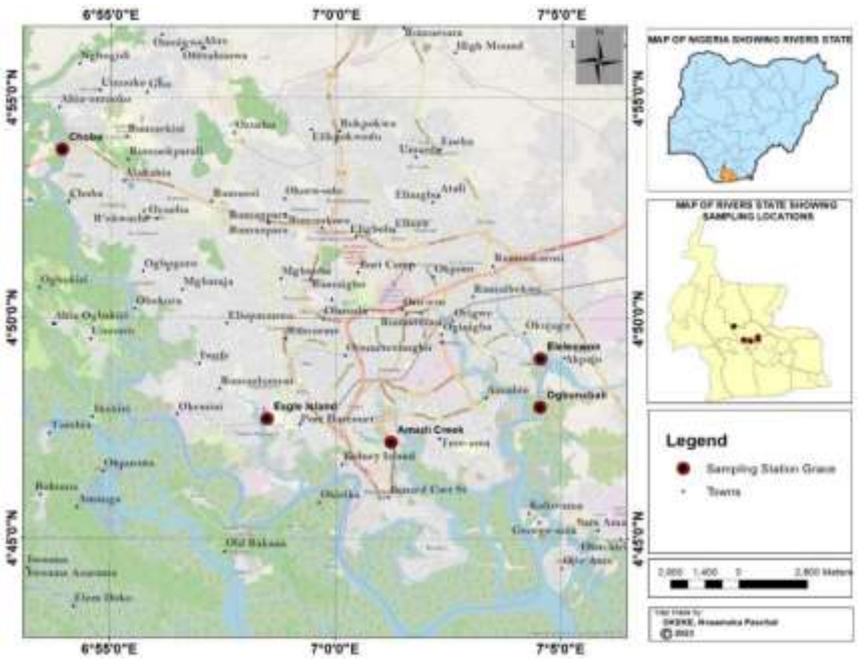


Fig. 1: Map of Study Area/locations

Sampling Design: Five stations of different intertidal/coastal zones (Choba, Eagle Island, Eastern By-pass, Ogbunabali and Elelenwo) where identified for assessment. Each station was further divided into subzones of high intertidal (HIT), mid intertidal (MIT) and low intertidal (LIT) zones for purposes of solid wastes examination vis-a-vis crab holes. Tidal exposure and submergence periods were key in the determination of the subzones. Sampling was done on a monthly regularity for six months (July – December 2022).

Sediment Sample collection and Analysis: A small spade was used to collect composite surface sediments (0 – 15cm) from each intertidal station for evaluation of sediment characteristics. The sediment was put into a labelled polythene bag and taken to the laboratory for analysis.

Solid Wastes Assessment: One meter square ($1m^2$) quadrat was used in the solid waste assessment and standardization. Three different random throws of the quadrat in each of the intertidal subzones was done and the different types of solid wastes within each quadrat were sorted and counted in addition to the number of crab holes within the quadrat.

Sample Analysis: In the laboratory, the sediment samples were opened (air-dried) at room temperature before grounded into uniform fine particles using laboratory mortar and pestle. The pH, conductivity, nitrate, sulphate and phosphate content of the sediment were analysed as described in APHA, (2017) while grain size analysis of sediment was by hydrometer method (IITA, 1979).

Statistical Analysis: Microsoft Excel was used to plot graphs and mean determination while analysis of variance (ANOVA), post hoc and regression analysis were done using Minitab R16.

RESULTS AND DISCUSSION

Sediment Characteristics: Spatio-temporal variations in sediment characteristics is presented in Figs. 2 – 9. The pH of the study area indicated weak acidity with spatio-temporal differences across the different intertidal stations assessed. The lowest value of 4.9 was recorded in July at Ogbunabali (OGB) while the highest value of 6.3 was observed at Choba (CHO) in September and December. The spatial variation was significantly different (P<0.001) between the intertidal sediments at CHO and the other stations. Variation in physicochemical characteristics of sediments could have also affected the number of crab holes observed on a station-by-station basis. The pH is quite characteristic of the sediments of the southern Niger Delta region of Nigeria. Several researchers had reported similar pH ranges in the study area similar to that of the current study; Daka and Moslen, (2013) 4.6 – 6.7; (Moslen and Miebaka, (2017) 6.3 – 6.7; (Okolocha *et al*., 2020) 6.5 – 6.8; (Kalio *et al*., 2021) 5.5; (Wosu *et al*., 2022) 5.5 – 6.2. The regression output indicated that the p-value (0.003) rejected Null hypothesis which means changes in the predictor variable (pH) caused changes in the response variable (number of holes) in the study area. The electrical conductivity of the different intertidal sediments (Fig. 3) was also significantly different (P<0.001). Post hoc analysis indicated that the conductivity of the sediments of the intertidal areas of Eagle Island (EI), Eastern By-Pass (EBP) and Elelenwo (ELE) were similar but significantly different from those of Ogbunabali and Choba (EI=EBP=ELE<GBU<CHO). The conductivity differential between stations could be due to freshwater inputs particularly from the Choba intertidal axis. The conductivity of the sediments in the current study was also in consonant with values (900.0 – 4133.0 S/cm; 7.5 – 21.6 mS/cm) reported by other researchers (Daka *et al*., (2007; Daka *et al*., 2018) within the study region. This also implies that such conductivity values observed favoured the survival of fiddler crabs within the study region. The concentration of sulphate (Fig. 4), phosphate (Fig. 5) and nitrate (Fig. 6) were also analyzed in the various intertidal sediments with variations observed. Sulphate concentration ranged from 34.4 (CHO) – 190.0 mg/kg (OGB) in July, phosphate concentration varied from 0.6 mg/kg at CHO in December to 6.8 mg/kg at ELE in July while Nitrate varied from 1.2mg/kg at CHO in August to 4.5 mg/kg at OGB in July. The concentration of sulphate varied significantly (P<0.001) between the intertidal stations such that EI<CHO<EBP=ELE<OGB. Significant difference (P<0.05) was also observed in the concentration of phosphate in space and time. The significant difference between the intertidal zones occurred thus: EI<EPB=CHO=ELE<OGB while that in time occurred between July and the rest of the months. Nitrate concentration in the sediments of the intertidal zones differed significantly in space (P<0.001) and time (P<0.01). The difference in space occurred between OGB and the rest of the zones while the difference in time took place between July and rest of the months. Variation in nutrient parameters is also expected to influence abundance and distribution of fiddler crabs in addition to other environmental factors such as temperature as reported by Tiralongo *et al*., (2020). Regression output of nitrate and phosphate indicated significant relationship and interaction with crab holes implying that changes in the concentration of these nutrients also caused changes in the number of crab holes. Elevated values of nitrate and phosphate corroborated with higher number of crab holes observed at stations Ogbunabali, Eagle Island and Elelenwo, affirming more fiddler crabs in sediment with improved nutrient quality. Nitrate and phosphate values of the current study accords with those earlier reported by other researchers in the study region (Daka *et al*., 2007; Daka and Moslen, 2013; Agamini *et al*., 2018). Inter station variation was also noticed in the grainsize composition of the sediments. Sand particles ranged from 32 % at OGB to 87% at OGB and EBP (Fig. 7) while silt particles ranged from 0.2% at EBP to 14% at OGB (Fig. 8) and clay particles varied from 3% at CHO to 54% at OGB (Fig. 9). ANOVA showed significant difference (P<0.01) between periods/time of sample for sandy particles while silt particles showed significant difference (P<0.001) in space and time. The significant difference in time for sand particles occurred between July and other months but that of silt occurred thus (EI=CHO<OGB=EBP=ELE) and time (July<Aug=Sep=Oct=Nov=Dec). Grain/particle size is also another major factor that influence sediment characteristics and determine sediment dwellers such as fiddler crab abundance and distribution. Ocypodid crabs distribution have also been correlated with characteristics of sediment such as median grain size and organic content (Geist *et al*., 2012). In the current study, sandy particles dominated the sediments of the study area followed by clay and silt. The regression analysis affirmed a significant (p<0.001) relationship between the percentage silt content of the sediment and the number of crab holes observed in the study area. Higher number of crab holes were associated with increased silt content of the sediment particularly, at stations OGB, ELE and CHO but with exception at EI probably due to other factors. The grain size component (%) of the current study is also in accordance with values reported by other researchers in the study area (Anyanwu et al 2018; Daka *et al*., 2018; Agamini *et al*., 2018). However, Daka and Moslen, (2013) reported sediments that were generally sandy-mud in nature with higher proportions of clay. The burrowing of fiddler crabs has been reported to impact soil chemistry by altering the pH, oxygen, heavy metal, nutrient and dinitrogen oxide content of the sediment (Sarker *et al*., 2020), therefore, Hanim *et al*., (2020) described fiddler crabs as keystone species due to their high impact on mangrove

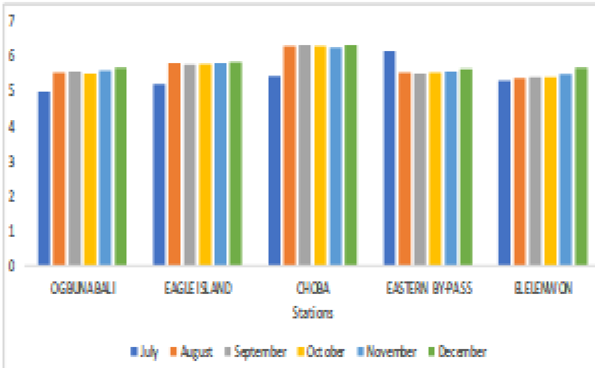


Fig. 2: Variation in pH of sediment from the study area

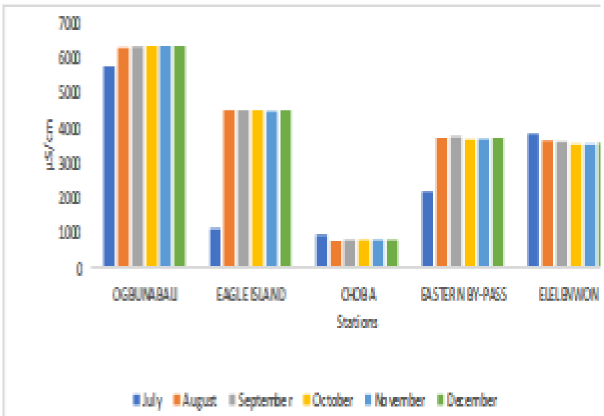


Fig. 3: Variation in Electrical Conductivity of sediment from the study area.

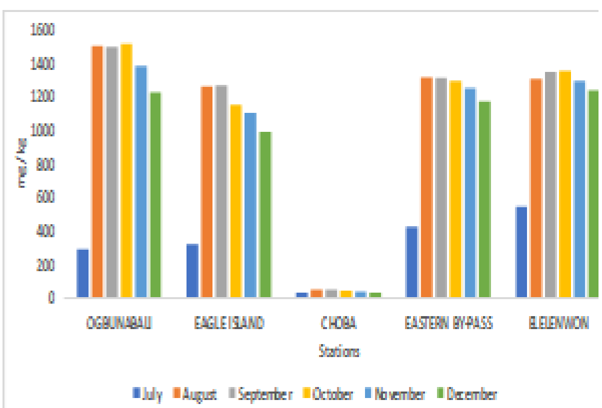


Fig.4: Variation in Sulphate concentration of sediment from the study area.

Solid Wastes: Evaluation of solid wastes was carefully done comparing wastes between different intertidal zones (High intertidal – HIT, Mid intertidal– MIT and Low intertidal – LIT) of each station. The variations in mean count of wastes within the different zones of the intertidal areas is shown in Figs. 10 – 14. Within the HIT zone of Eagle Island (EI) wood/plank wastes dominated with mean count of 28, followed by bottles (6) and the least was tyres and Styrofoam with mean counts of 2. Nylon/polyethene wastes dominated the MIT zone of EI with mean count of 3 followed by bottles while the LIT regions of EI was dominated by wood with mean counts reaching 4. Ropes (7), plastics (6) and nylons/polythene (6) dominated the HIT of EBP, the MIT of EBP also had similar wastes dominance but lower values while the LIT region had more of nylon/polythene wastes, ropes and plastic but with lower counts.

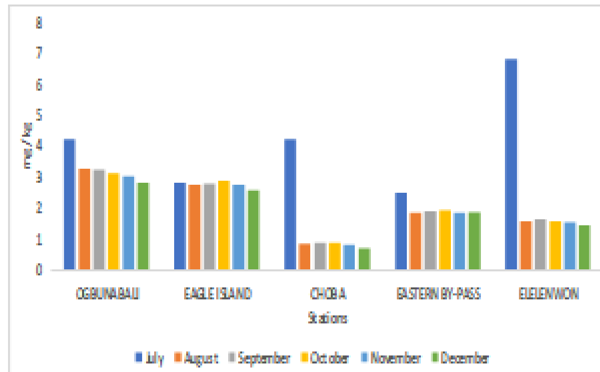


Fig. 5: Variation in phosphate concentration of sediment from the study area.

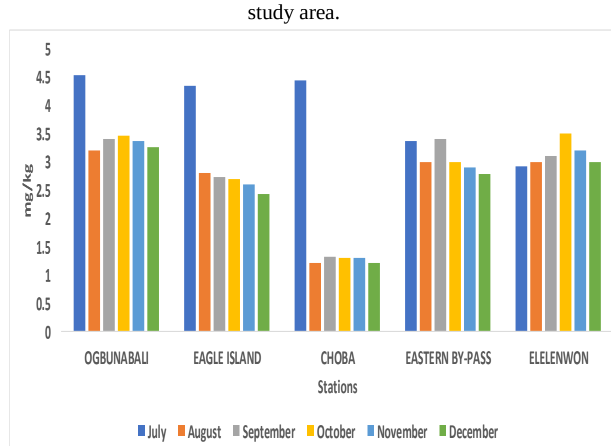


Fig.: **6:** Variation in Nitrate concentration of sediment from the study area.

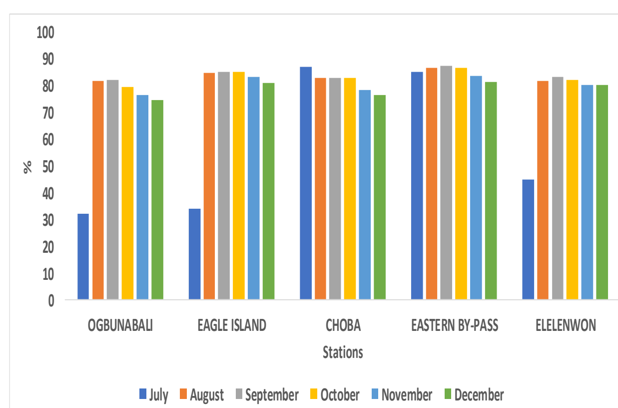


Fig. 7: Variation in Sand of sediment from the study area.

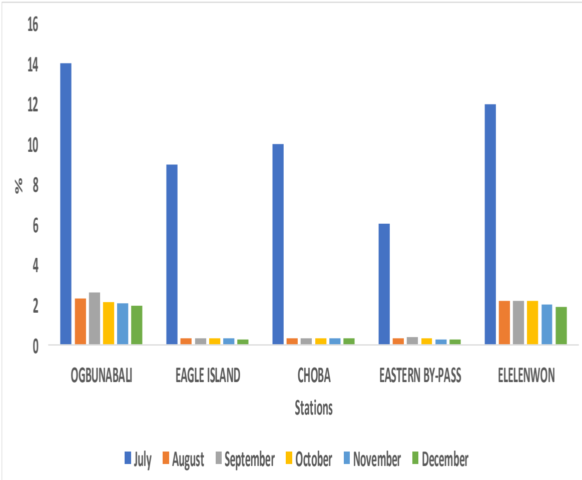


Fig. 8: Variation in Silt of sediment from the study area.

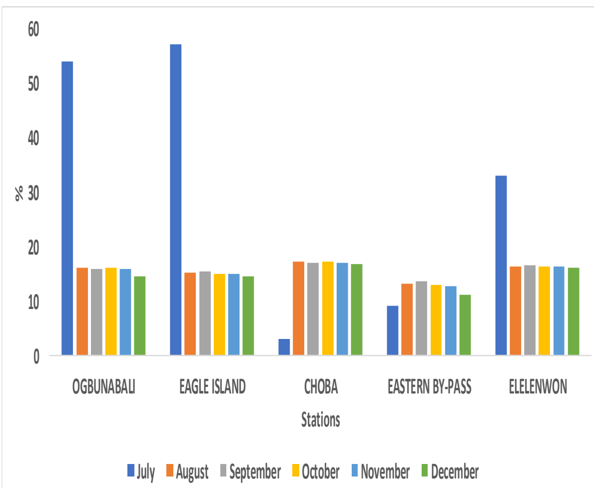


Fig. 9: Variation in Clay of sediment from the study area.

Mean counts of solid wastes in the HIT region of OGB were nylon/polythenes (7), ropes (5), and plastics (4) while that of the MIT was nylon/polythene (5), wood (4), plastic and ropes (3) and the LIT region had nylon/polythene (6), plastics (4) and ropes (4). Mean counts of wastes at the intertidal area of ELE showed that HIT region had more of plastics (5), nylon/polythene (4) and bottles (3) while the MIT region had plastics (5), nylons/polythene (3) and bottles (3) and LIT region had more of nylons/polythenes (4) and plastics (3). Mean counts at the HIT of CHO showed ropes (6), bottles 4 and nylon/polythenes (4) but at the MIT, wood/planks (7) followed by ropes (5), nylons and bottles while at the LIT area of CHO, ropes, nylons/polythenes and bottles dominated.

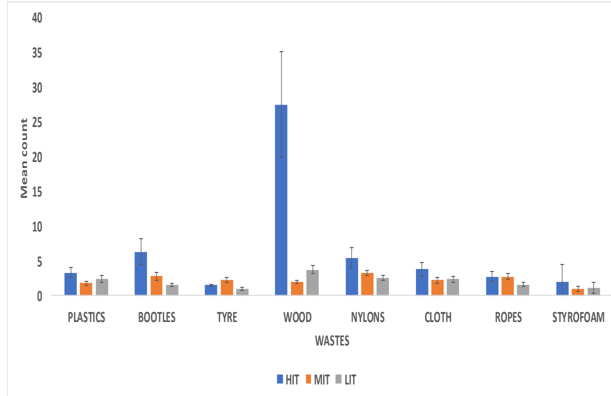


Fig. 10: Mean variation in solid wastes count at Eagle Island intertidal zones of the study

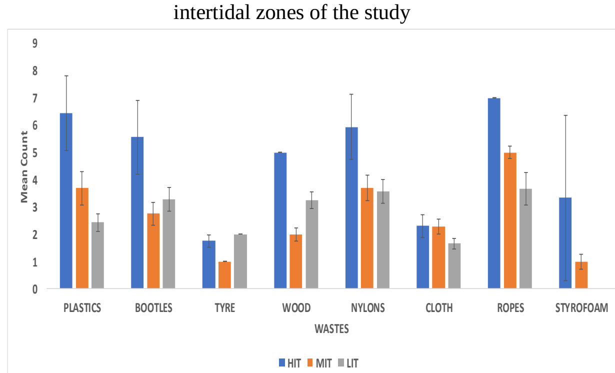


Fig. 11: Mean variation in solid wastes count at Eastern ByPass intertidal zones of the study

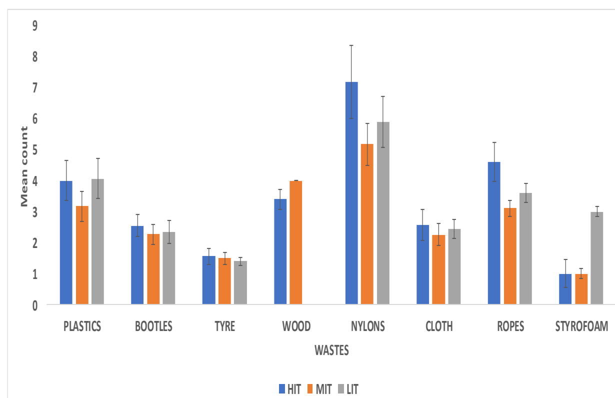


Fig. 12: Mean variation in solid wastes count at Eagle Island intertidal zones of the study

Relationship between Number of Fiddler Crab holes and Total wastes counted: The relationship between the number of holes (response variable) and the total number of wastes counted (predictor variable) at the different zones of the intertidal environment is expressed in Figs.15 – 17. At the HIT and the LIT, there were no significant difference (P>0.05) between the response variable (number of holes) and the predictor variable (total wastes counted) but at the MIT, there was significant difference ($P<0.05$) between the predictor and the response variables implying a relationship and interplay between the two variables.

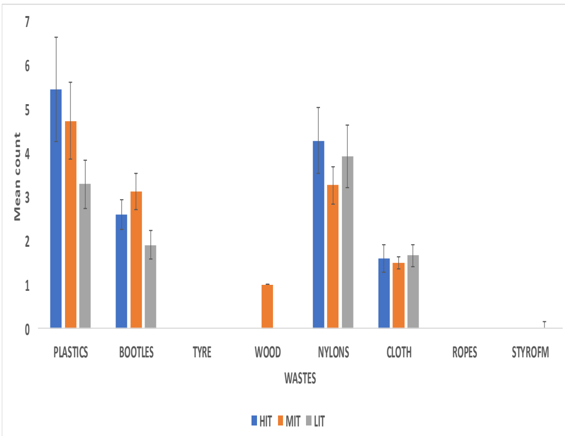
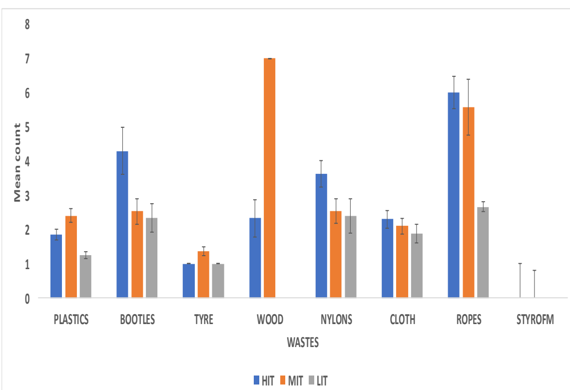


Fig. 13: Mean variation in solid wastes count at Eagle Island intertidal zones of the study



Where: HIT = high intertidal; MIT = mid intertidal and LIT = low intertidal

Fig. 14: Mean variation in solid wastes count at Eagle Island intertidal zones of the study

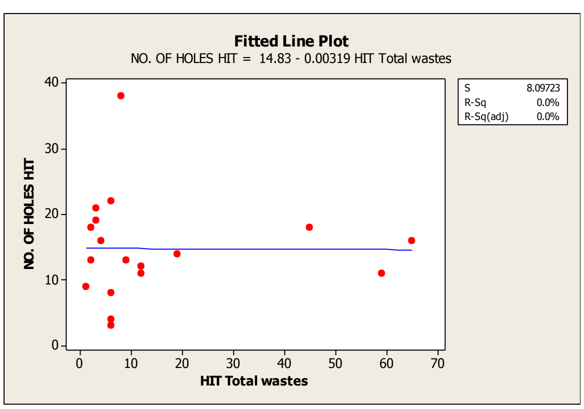


Fig. 15: Relationship between Number of holes and Total wastes counted at High Intertidal

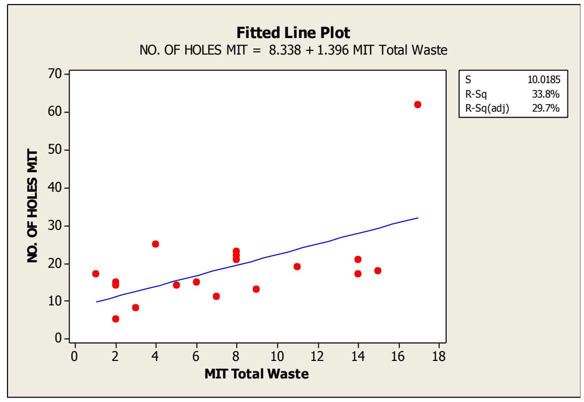


Fig. 16: Relationship between Number of holes and Total wastes counted at Mid Intertidal

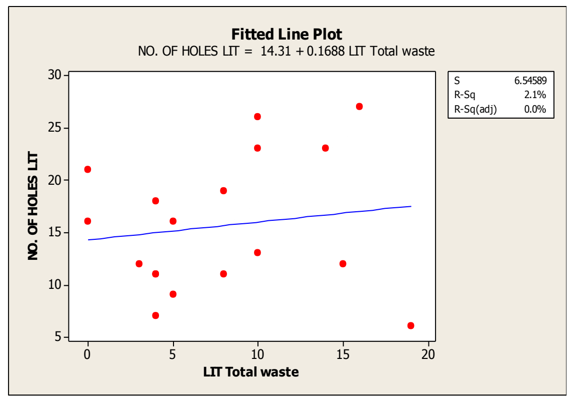


Fig. 17: Relationship between Number of holes and Total wastes counted at Low Intertidal

Relationship between Number of holes and Sediment characteristics: The relationship between number of holes and sediment characteristics is expressed in the regression outputs (Table 1)

Table 1: Regression output showing relationship between number of holes and sediment characteristics

Term	Coef	SE Coef	T	P
Constant	-114.357	40.0205	-2.85746	0.01
Total Waste	0.134	0.1036	1.29198	0.211
pH	17.455	5.1397	3.39609	0.003
EC	0.000	0.001	-0.36497	0.719
Sulphate	-0.028	0.0514	-0.54098	0.594
Phosphate	5.102	1.2771	3.99473	0.001
Nitrate	9.366	2.1543	4.34763	0.000
Sand	-0.156	0.2691	-0.58032	0.568
Silt	-2.644	0.6667	-3.96613	0.001
Clay	0.381	0.2886	1.32143	0.201

S = 3.84444 R-Sq = 67.2% R-Sq(adj) = 54.7%

Total waste count in the entire study area did not significantly impact ($P>0.05$) the number of crab holes in the sediment but there was significant relationship ($p<0.05$) between sediment pH and number of crab holes with mean variation of about 17.5 crab holes for a unit change in pH. The regression output for electrical conductivity and sulphate of the sediment indicated no significant difference ($P>0.05$). The other two nutrient parameters (phosphate and nitrate) had significant difference ($P<0.05$) indicating relationship with the number of crab holes in the sediment. The silt content of the sediment had significant difference ($P<0.05$) indicating influence on the number of crab holes in the sediment. In the entirety of the study area, about 67% of the variation observed in the number of crab holes in sediment was caused by the different predictor variables measured. The regression model shows that there was no significant relationship ($p>0.05$) between number of waste and number of holes at the HIT. This is because the correlation coefficient indicated that a unit increase in the number of wastes could only yield an average of 0.00319 rise in the number of crab holes. The R^2 value (0.0%) confirms that variation in the number of holes was not accounted for by the presence of wastes at the HIT in the study area. On the contrary, there was significant relationship ($p<0.05$) between the amount of wastes and the number of fiddler crab holes at the mid intertidal (MIT) zones of the study area. The correlation coefficient which measured the strength of the linear relationship between the predictor variables and the response variable was far above zero. The regression coefficient indicated that unit rise in the number of wastes produced an average of 1.396 rise in the number of crab holes at the MIT. The R^2 value (33.8%) in the regression output confirms that about 34% of the predictor variable (number of wastes) accounted for the variation in the number of holes observed at the mid intertidal of the study area. This accords with Numbere, (2020) who reported that anthropogenically impacted areas of the Niger Delta intertidal had fewer burrows. Barakali, *et al*., (2020) had also reported the impact of human activities on crab burrows. The low intertidal area shared similar characteristic with the high intertidal, in terms of the relationship between the amount of wastes and number of fiddler crab holes. At the low intertidal, the regression equation showed no significant ($p>0.05$) relationship between the predictor variable and the response variable. The regression coefficient showed that unit increase in the number of wastes could only give an average of 0.168 rise in the number of fiddler crab holes. The coefficient of determination (R^2) which explains the proportion of the variance in the response variable that can be explained by the predictor variable was 2.1%. This implies that the variance in the number of holes was only accounted for by 2.1% of the number of wastes present at the low intertidal. However, Gul and Griffen, (2018) reported that crabs in extremely disturbed areas restrict themselves to the edges of the intertidal zone or beaches. Steib, (2020) has also established that anthropogenic factors influence the number of crab burrows within a given area.

Conclusion: The study characterized the intertidal sediments of the southern Niger Delta region of Nigeria using sediment parameters such as pH, electrical conductivity, sulphate, nitrate, phosphate, sand, silt and clay, vis-à-vis the effect of solid wastes on fiddler crab habitats at different intertidal zones. The values of the physicochemical characteristics of this study corroborated with those of other researchers in terms of sediment characteristics that favoured the survival of fiddler crabs. However, variables such as pH, phosphate, nitrate and silt had significant effects that caused changes in number of fiddler crab holes. The number of solid wastes at the high intertidal and low intertidal did not significantly affect number of crab holes but at the mid intertidal zone, changes in the number of wastes significantly affected the number of fiddler crab holes. In conclusion, fragmentation and destruction of fiddler crab habitat was due to solid wastes in combination with other sediment characteristics which could vary from one intertidal region to another.

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Data Availability Statement: Data are available upon request from the first author or corresponding author.

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