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RESEARCH ARTICLE

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Status of Natural Regeneration of Mangroves in Southern Nigeria

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ABSTRACT

Mangroves of the Niger Delta in Nigeria have experienced increased degradation due to years of oil exploration/pollution, urbanization, and population explosion. However, studies on mangroves' natural recovery capacity and juvenile requirements are limited. Therefore, this study examined the relationship between natural mangrove regeneration and sediment parameters in the western Niger Delta. The study was conducted in four locations (Agge, Burutu, Opuama, and Kurutie) and a control location in Ifie. Twenty quadrats of 20 × 20 m were laid at each location. Juvenile species composition and density were obtained from sub-quadrats (10 × 10 m). Sediment samples, totaling 100, were taken from 0 to 30 cm depth within each quadrat. The sediment parameter concentrations were determined using standard laboratory procedures. Mangrove juveniles were classified, based on height, into seedlings (< 40 cm), saplings (40–150 cm), and young trees (1.5–<3m), with saplings forming a major proportion. Partial least squares regression was used to evaluate the effects of sediment parameters on mangrove juveniles. Calcium, magnesium, sand, organic carbon, electrical conductivity, total acidity, clay, effective cation exchange capacity, salinity, and bulk density were significant predictors of juvenile mangrove species abundance. A high potential for regeneration, particularly for *Rhizophora spp.* juveniles, has been established. The establishment of mangrove conservation and reforestation projects is therefore recommended.

Introduction

Mangroves are major storehouses of biodiversity that provide many products and services that benefit all ecosystem components, including humans. They are home to various animals at different developmental stages. For instance, they serve as nurseries for marine life, stopovers for migratory birds, and habitats for crabs, manatees, etc. The unique role of mangroves in moderating climate change through carbon sequestration is notable [1–3]. It also helps to moderate the effects of the characteristic climatic extremities of the coastal environment. Nigeria's mangrove forests are the largest in Africa and the third largest in the world [4].

Over time, however, environmental degradation has engulfed the global landscape due to increasing urbanization and population explosion. Corroborating this, Alongi [1] noted that mangrove forests globally have been reduced to approximately 50% of their original cover. Owing to the inherent deposits of oil and gas, oil pollution, gas flaring, and associated urban pollution are common in the Niger Delta of Nigeria, thereby constituting some of the drivers of degradation [5]. In most cases, sand mining and dredging operations have proven to have far-reaching destructive impacts on the mangrove ecosystem of the Niger Delta. These negative impacts further translate to ecosystem changes or outright mangrove forest clearance, destabilizing the balance of components within the natural environment [6]. The need to tackle the challenges of mangrove degradation through efficient management is important.

Several strategies adopted over time have achieved less-than-optimal success. Evidence of this is seen in several cases of increased deforestation and consequent colonization of the exotic Nypa palm [7,8]. To provide sustainable solutions, natural mangrove vegetation regeneration should be critically considered.

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Therefore, natural vegetation regeneration should be the central theme in the discourse on environmental sustainability as it serves as a foundation for vegetation growth and development. Natural regeneration involves primary vegetation growth conditioned by prevailing factors in the immediate environment. This can be determined mainly by the rate and occurrence of juvenile growth, hence, the preceding examination of juvenile mangrove vegetation. This is especially pertinent because mangroves are known to regenerate very slowly. In the case of a clear-felled area, it is estimated to be between 30 and 40 years [6].

The need for in-depth knowledge of the natural recovery processes of mangrove vegetation is underscored. Furthermore, the need for studies to identify mangrove regeneration requirements cannot be overemphasized [9,10]. Consequently, mangrove juveniles, being an indicator of natural regeneration in terms of their character, development, and requirements, ought to be focused on. Emphasis has been placed on other issues, such as adult mangrove species composition, structure, and relationship with the underlying soil, with limited focus on mangrove juvenile species composition, character, development, and relationships with other environmental factors. Some of these studies have focused on the internal workings of the environment itself, as it pertains to mangrove vegetation and its interaction with underlying soils. Several studies on mangrove regeneration have focused on the changes in mangrove area coverage. Others have focused on the nature and roles played by mangroves, specifically within the Niger Delta, among others [11–19]. Therefore, given its relationship with underlying sediments, this study examined the factors and status of the natural regeneration of mangroves in Southern Nigeria.

Materials and Methods

This research is based primarily on an exploratory research design. The study area was in Southern Nigeria, specifically within the western part of the Niger Delta area of Nigeria. The study area lies between latitudes $5^0 00'$ and $6^0 00'$ N and longitudes $5^0 00'$ and $6^0 00'$ E. A mean annual temperature of 31 °C and mean precipitation of 3,130 mm characterize the climate of the study area [20]. The study was carried out within the creeks of four major rivers within the region: Benin, Escravos, Forcados, and Ramos (Figure 1).

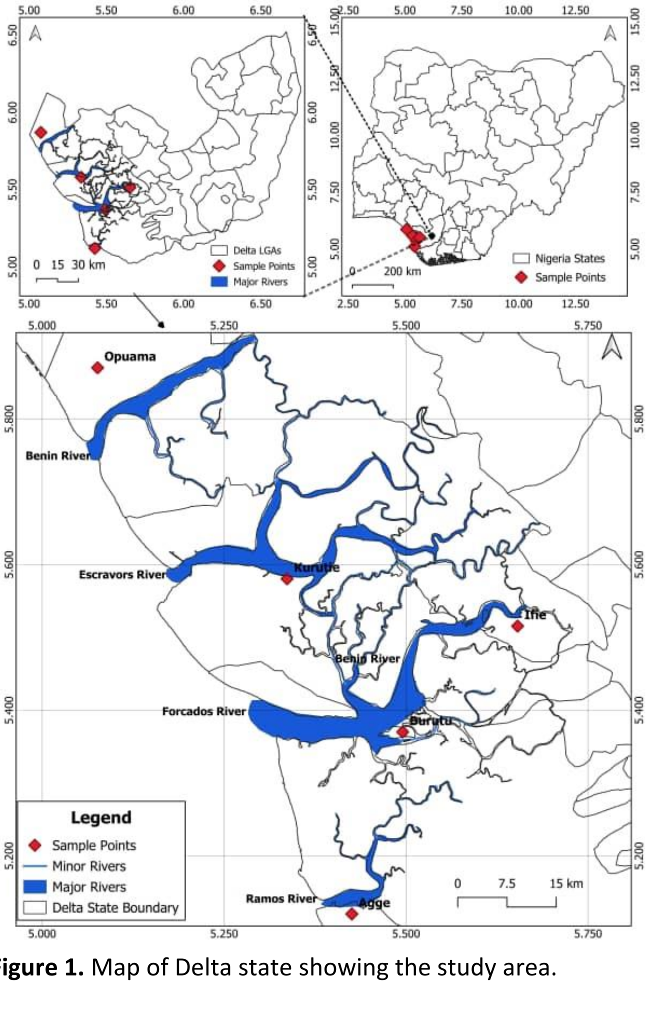

Figure 1. Map of Delta state showing the study area.

Twenty quadrats were sampled from each location. The control site was situated at the mangrove conservation site at Ifie. The control site was designated for the strict protection of the mangrove forest. Each site was delineated into 20 quadrats of 20 × 20 m, totalling 100 quadrats. Natural regeneration composition and distribution pattern information were obtained using a linear regeneration sampling method [21]. Juvenile mangrove measurements were obtained within 10 × 10 m sub-quadrats of the original 20 quadrats. Juvenile mangrove species were recorded, grouped, and counted according to their height. The species abundance and density were also calculated. Seedlings under 40 cm tall were classified as Regeneration Class I (RCI). Saplings between 40 and 150 cm in height were classified as RCII, while RCIII were all small trees with heights greater than 1.5 m but less than 3.0 m [21,22]. Species density and number for the various mangrove species were taken from each sub-quadrat. A core sampler was used to obtain 100 sediment samples at depths of 0 to 30 cm from each quadrat.

Samples were taken from different points and bulked together to form a composite sample for each quadrat. They were then placed in polythene bags and labelled. Laboratory analysis was carried out for the following parameters: particle size composition, effective cation exchangeable capacity (ECEC) (Summation Method), bulk density, total nitrogen (Kjeldahl Method), available phosphorus (Bray-P1 Method), exchangeable cations (flame photometer and atomic absorption spectrophotometer), exchangeable acidity (0.1 M $BaCl_2$), pH (pH meter), organic matter/carbon (walkley black), salinity/electrical conductivity. Multiple regression was used to test the relationship between the abundance of mangrove juveniles and underlying sediments at a significance level of 0.05. The sediments served as independent variables, while the various classes of mangrove juveniles were the dependent variables.

Results and Discussion

Result

Rhizophora spp. and *Avicennia germinans* juveniles were found within the study area. Most of the juveniles in all the locations across the study area belonged to the *Rhizophora* species. Juveniles of *Avicennia germinans* were observed only in Kurutie and Agge. Most of the mangrove juveniles of the various species fall into the RCII (sapling) class, as opposed to the other classes of RCI (seedlings) and RCIII (young trees). In the control, more young trees were observed than in the saplings (Figures 2 and 3). The general absence of seedlings depicted by species abundance is also characteristic of tree density values for various species. An exception, however, was observed in the mangrove forest in Opuama, where *Rhizophora* spp. seedlings were observed, with a mean tree density of 1,600 trees/ha. In addition, *Avicennia germinans* seedlings were observed in Agge, with a low mean tree density of 600 trees/ha. However, saplings had the highest mean tree density of all juvenile classes. This is particularly characteristic of mangroves in Burutu, with *Rhizophora* spp. saplings having a mean tree density of 5,789 trees/ha. The mean sapling density for the control, which was much lower, was 1,150 trees/ha.

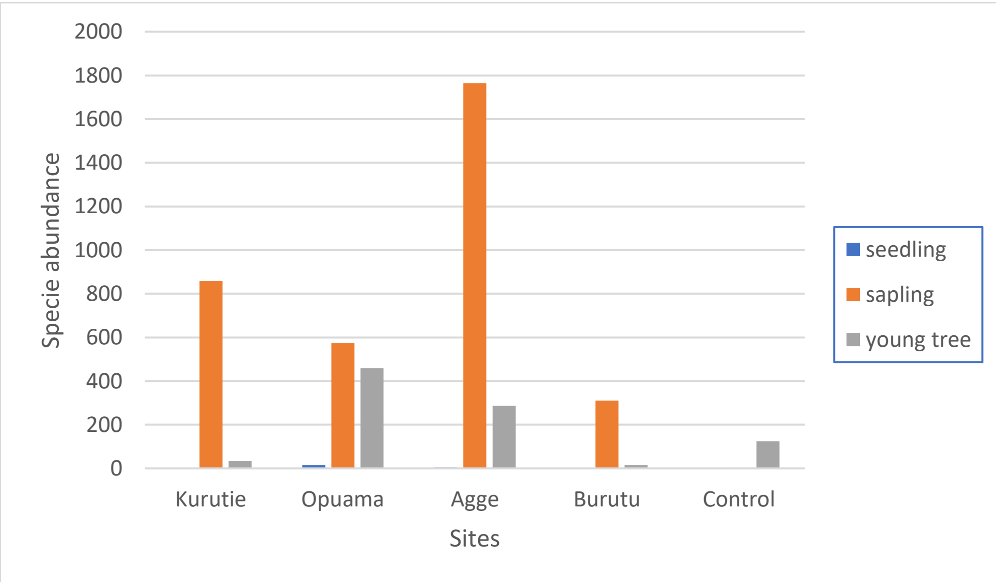

Figure 2. Mangrove juvenile abundance of seedlings, saplings, and young trees at various sites.

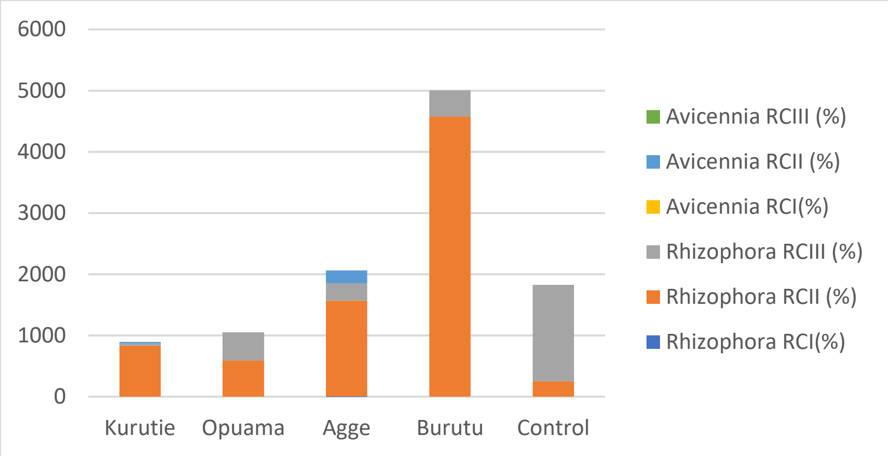

Figure 3. Mangrove juvenile abundance of *Avicennia* sp. and *Rhizophora* sp. at various sites.

The control had the highest mean tree density of 1,028 stems per hectare for young trees (RCIII). *Avicennia germinans* juveniles in the young tree class recorded the lowest tree density of 600 trees/ha in Agge. RCIII (young trees) had the highest tree density (1,028 trees/ha) for *Rhizophora* spp. The highest mean tree density for *A. germinans* occurred among saplings (2,886 trees/ha). The lowest mean density was observed in seedlings (RCI) (600 trees/ha). The mean tree density for *Rhizophora sp.* was lowest in Burutu (135 trees/ha) and highest in Opuama (778 trees/ha). The only juvenile species observed in the control were *Rhizophora spp.,* which occurred as saplings and young trees (Figure 3). Therefore, the disturbed site, which comprises the study sites, tends towards more diversity in structure and composition than the control site.

Table 1 shows the results of the soil laboratory analysis of the physical and chemical properties of the sediments in the study area. The pH values ranged from 3.66 to 4.82 and between 3.00 and 4.00 for pH ($CaCl_2$) and pH (H_20), signifying its acidic characteristic. The soil pH of the control group did not differ significantly from that of the study sites. The combination of sand, silt, and clay percentages implies that the underlying mangrove sediments in Opuama, Kurutie, and Burutu fall within a sandy clay loam texture. However, the sediments in Agge fall within the clay textural class. The sediments of the mangroves in the control, on the other hand, fell within the loam textural class. Bulk density differed minimally among sites, ranging from 0.71 to 1.09 g/cm^3. The organic matter content (30.32%) of the sediments in the control site differed significantly from that in the study sites. The potassium, sodium, calcium, ECEC, and total acidity contents in the study sites varied considerably from those of the control site (Table 1).

Table 1. Summary of mean sediment properties at the study sites (0–30 cm depth).

Parameters	Units	Agge	Burutu	Kurutie	Opuama	Control
1.1 Water	(pH)	4.82 ± 0.085	3.88 ± 0.17	4.99 ± 0.18	6.83 ± 0.09	3.52 ± 0.09
1:2 $CaCl_2$	(pH)	4.61 ± 0.080	3.61 ± 0.17	4.83 ± 0.18	6.59 ± 0.08	3.28 ± 0.07
Sand	(%)	26.85 ± 2.33	46.15 ± 4.33	51.60 ± 3.27	47.80 ± 4.33	52.4 ± 1.79
Silt	(%)	31.15 ± 2.58	21.85 ± 3.83	19.20 ± 2.74	21.15 ± 2.64	25.5 ± 1.74
Clay	(%)	42.0 ± 1.36	32.25 ± 3.17	29.00 ± 2.59	31.05 ± 3.32	22.1 ± 2.48
Bulk Density	(g/cm^3)	0.87 ± 0.03	0.72 ± 0.067	0.71 ± 0.03	1.09 ± 0.02	0.82 ± 0.03
O.C	(%)	7.86 ± 0.15	5.08 ± 0.52	4.48 ± 0.54	5.17 ± 0.38	17.65 ± 0.97
O.M	(%)	13.52 ± 0.26	8.72 ± 0.90	7.71 ± 0.92	9.34 ± 0.58	30.33 ± 1.66
Nitrogen	(%)	0.65 ± 0.03	0.56 ± 0.04	0.89 ± 0.06	0.54 ± 0.04	0.80 ± 0.08
Salinity	(g/L)	181.40 ± 21.2	117.06 ± 10.53	232.85 ± 11.68	44.11 ± 3.16	38.0 ± 5.88
Phosphorus	(ppm)	6.37 ± 0.59	4.87 ± 0.49	25.62 ± 4.22	11.59 ± 3.82	6.80 ± 0.48
Sodium	(cmol/kg)	26.2 ± 2.50	18.56 ± 2.64	36.92 ± 2.91	18.94 ± 1.39	0.89 ± 0.07
Potassium	(cmol/kg)	12.05 ± 0.01	11.49 ± 0.57	12.03 ± 0.01	12.04 ± 0.02	0.42 ± 0.05
Magnesium	(cmol/kg)	1.25 ± 0.09	1.21 ± 0.06	1.48 ± 0.02	1.89 ± 0.08	0.82 ± 0.01
Calcium	(cmol/kg)	46.30 ± 8.80	17.08 ± 1.32	25.42 ± 2.30	20.68 ± 1.55	3.94 ± 0.16
Total acidity	(cmol/kg)	1.66 ± 0.1	2.90 ± 0.43	2.97 ± 0.57	2.52 ± 0.46	6.35 ± 0.63
Electrial Conductivity	(µs/cm)	364.68 ± 42.48	212.34 ± 15.59	189.76 ± 17.95	88.12 ± 6.29	76.78 ± 11.80
ECEC	(cmol/kg)	87.5 ± 7.93	51.38 ± 3.84	78.8 ± 4.44	56.07 ± 2.56	12.41 ± 0.56

Partial least squares regression (PLS) was used in evaluating the relationship between mangrove juveniles and sediments. In the control site, the sediment parameters contributed approximately 42% and 0% to the abundance of *Rhizophora* spp. saplings and young trees respectively (Table 2). The significant predictors included calcium, magnesium, ECEC, salinity, sand, clay, bulk density, total acidity, and electrical conductivity (Figure 4). Across the study sites, the sediment parameters contributed approximately 18% and 3% to the abundance of *Rhizophora* spp. saplings, and young trees respectively. The contribution of the sediment parameters to the abundance of *Avicennia germinans* seedlings, saplings, and young trees was approximately 0%, 45%, and 1%, respectively, across the sites (Table 2).

Table 2. PLS results showing R-squared values for mangrove juveniles within the study area.

	Rhizophora spp.				*Avicennia germinans*					
	Sapling control	Young trees	Saplings sites	Young trees	Seedling control	Sapling	Young trees	Seedling sites	Sapling	Young trees
R^2	0.422	0.004	0.184	0.026	Nil	Nil	Nil	0.000	0.458	0.014

The significant predictors for *Rhizophora* spp. and *Avicennia germinans* juveniles across the study sites were ECEC, calcium, organic carbon, clay, sand, salinity, and electrical conductivity (Figure 5). In the control site, calcium, total acidity, sand, ECEC, magnesium, salinity, electrical conductivity, bulk density, and clay were significant contributors to the abundances of the juveniles of both mangrove species (Figure 4). Table 3 shows the model parameters for the dependent variables (*Rhizophora* spp. and *Avicennia germinans* juveniles) and the independent variables (sediment parameters) in the control and study sites.

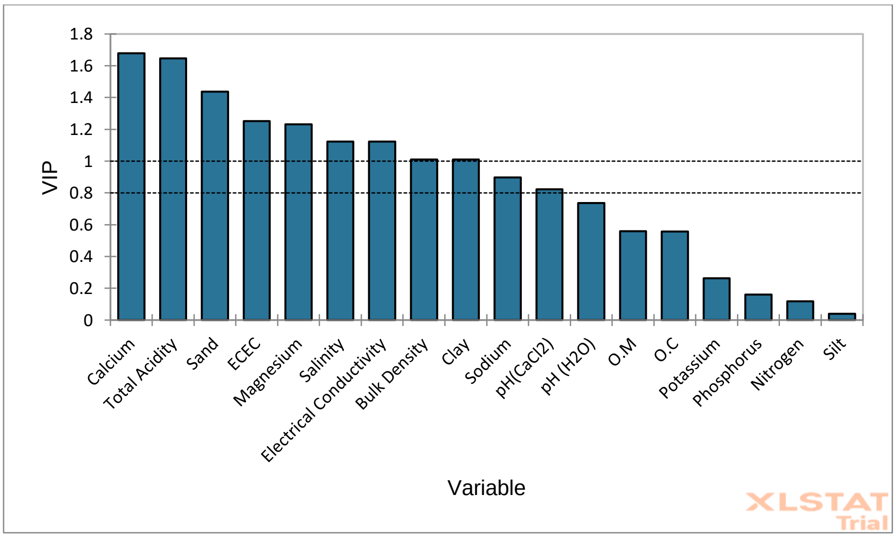

Figure 4. Chart showing the variable importance in the projection (VIP) for control.

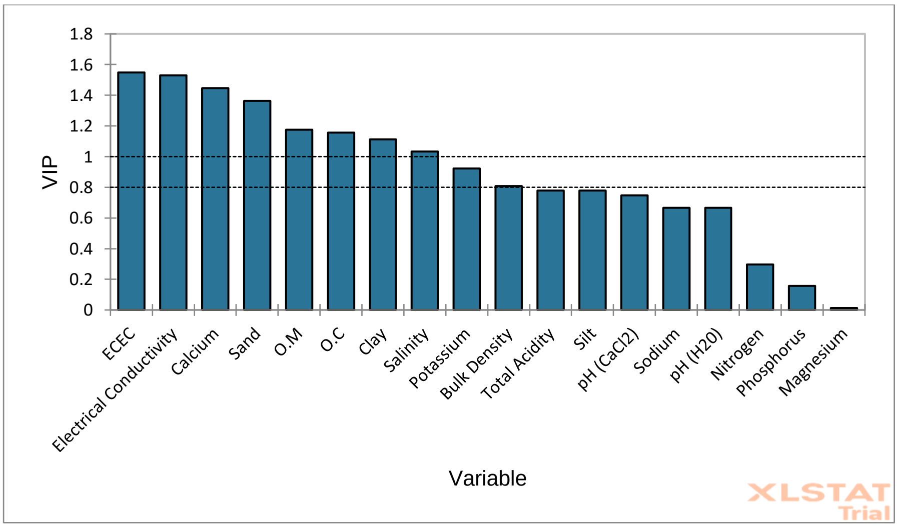

Figure 5. Chart showing variable importance in the projection (VIP) of study sites.

Table 3. PLS model and sediment parameters for juvenile mangrove species in the study area.

Variable	Control		Study sites				
	Rhizophora spp.		*Rhizophora* spp.		*Avicennia germinans*		
	Saplings (RCII)	Young tree (RCIII)	Saplings (RCII)	Young tree (RCIII)	Seedlings (RCI)	Saplings (RCII)	Young trees (RCIII)
Intercept	1.086	39.022	308.101	22.282	0.078	–95.718	–0.483
pH (H^2O)	0.041	–0.340	–3.562	–0.159	0.000	1.740	0.012
pH ($CACL^2$)	–0.055	0.457	–4.000	–0.178	0.000	1.954	0.013
Sand	–0.004	0.032	0.481	0.021	0.000	–0.235	–0.002
Silt	0.000	–0.001	–0.369	–0.016	0.000	0.180	0.001
Clay	0.002	–0.016	–0.567	–0.025	0.000	0.277	0.002
Bulk Density	0.143	-1.188	–22.922	–1.022	0.000	11.201	0.077
O.C	–0.003	0.023	–3.343	–0.149	0.000	1.633	0.011
O.M	–0.002	0.014	–2.015	–0.090	0.000	0.985	0.007
Nitrogen	–0.007	0.056	–8.403	–0.375	0.000	4.106	0.028
Salinity	–0.001	0.008	–0.074	–0.003	0.000	0.036	0.000
Total acidity	0.013	–0.105	2.644	0.118	0.000	–1.292	–0.009
Phosphorus	0.002	–0.013	0.069	0.003	0.000	–0.034	0.000
Electrical Conductivity	0.000	0.004	–0.069	–0.003	0.000	0.034	0.000
Sodium	–0.059	0.495	–0.337	–0.015	0.000	0.165	0.001
Potassium	0.025	–0.209	–4.753	–0.212	0.000	2.323	0.016
Magnesium	–0.937	7.800	–0.212	–0.009	0.000	0.104	0.001
Calcium	–0.050	0.419	–0.408	–0.018	0.000	0.199	0.001
ECEC	0.011	–0.089	–0.378	–0.017	0.000	0.185	0.001

Discussion

Juveniles of *Rhizophora* spp. formed the majority across all study sites. A similar result was reported in a study conducted in Ghana. However, researchers attributed this to the versatility of the species' tolerance to different salinity levels. The relatively higher percentage of mangrove saplings than that of the other juvenile classes (seedlings and young trees) corresponded with the findings of Asante et al. [23] for each of the various sites. They further noted that the thin or complete absence of the understory characterizes mangrove forests. The low abundance of mangrove juveniles could be due to predation stress, that is, propagule predation by crabs and squirrels. Predation stress owing to activities of crabs, results in delayed growth or, in most cases, death, particularly of *Rhizophora* propagules [24]. Mangrove juvenile growth is limited by intolerable levels of salt concentration in water, water inundation duration, and minimal solar illumination [25–26]. Seedling development is enhanced in canopy gaps [27]; however, an overbearing occurrence of an interlocking mangrove canopy could hinder the prevention of light and nutrients. Compared with hydrology, light has been observed to be more effective in seedling development than hydrology [28].

The trend in the control, whereby an increase in abundance from the sapling class to the young tree class is observed, indicates a growing/regenerating forest. This is not unconnected with the fact that the control site, being a conservation area, is characterized by a near absence of human disturbance and interference. In other study sites, the decline in the abundance of saplings relative to young trees suggests gradual degradation. This may be attributed to several factors, including logging and climate change. Climate change, characterized by an increase in the climatic variables of rainfall and temperature, is a common occurrence and a threat to mangrove forests [21]. Further confirmation of this finding included biotic agents as an additional factor. Conversely, the high sapling abundance observed, especially in Kurutie and Agge, for *Rhizophora* spp. and *Avicennia germinans*, indicates an inherently high potential for mangrove regeneration [29].

The increase further confirms this, characterizing the transition from saplings to young trees at the study sites. This is especially true for Kurutie, which has a relatively high sapling abundance compared with young trees. The implication is that the mangroves in Kurutie, although characterized by high regenerative potential, are declining at a higher magnitude than the other sites. However, the situation in the control indicated a gradual increase in the abundance of saplings to young trees, which aligns with the notion of the even-aged character of mangrove forests. The results of the PLS regression (Table 2) revealed that sediment parameters have a limited effect on the growth and abundance of the study area. This is depicted by the highest percentage contribution being within the 42 to 45% cohort for the *Rhizophora* spp. juveniles in the control and the *A. germinans* saplings in the study site, respectively. A contribution of 18% was observed for

Rhizophora spp. saplings abundance in the study sites. This suggests that sediment parameters influenced mangrove juvenile abundance more during the sapling stage for both mangrove species.

The relatively low percentage contribution of the sediment parameters implies the likely occurrence of other unknown contributory factors. These unknown factors may sometimes work in tandem with sediment parameters. However, further research is required to identify these factors. A study on habitat suitability modelling has lent credence to the interplay of several factors in mangrove forest sustainability, which are habitat/species-specific [30]. They are inclusive, but not limited to, soil, hydrological, and environmental characteristics [31]. It has also been observed that these factors demonstrate temporal and spatial variations which have a significant impact on the habitat in question [32]. Crab predation on mangroves has been shown to significantly impact natural regeneration and mangrove species zonation because of their status as the dominant herbivores in the mangrove ecosystem [33]. Other factors, such as hydrologic regimes and seed viability, also affect mangrove development [34]. Several studies have demonstrated the importance of particle size composition in the germination, growth, and adaptation of various mangrove species. This is not related to the physiology and morphology of the mangroves.

In this study, sand and clay content were common predictors of mangrove species in the study area. However, the sand content parameter was observed to negatively influence the *Rhizophora* spp. saplings in the control and A. *germinans* saplings in the study site (Table 3). This suggests that increasing sand content limits mangrove sapling abundance. Research has affirmed the limitation of mangrove juvenile growth in sandy soil [35], further confirming the findings of this study. Mangrove propagules have been discovered to perform less optimally in sandy soils because of root withering [36]. The salinity parameter had a negative influence on *Rhizophora* spp. juveniles in both the control and the study sites, suggesting a limitation to mangrove juvenile growth. This finding aligns with the assertion of Ahmed et al. and Devaney et al. [37,38], confirming the limitation of the salinity parameter as a factor in mangrove growth.

Conversely, an exception to the positive influence of salinity was observed in the young *Rhizophora* spp. trees at the control site. Salinity was also observed to positively influenced various juvenile classes of *A. germinans* at the study sites. Therefore, the findings of this study show that salinity significantly influences mangrove juvenile growth; however, this influence could either serve as a limitation or an improvement, depending on the juvenile stage or species. This aligns with the assertion of Devaney et al. [38], who noted that the response of juvenile root development to salinity varied in various mangrove species (Table 3). Calcium and magnesium were the only chemical sediment parameters significantly predictors of mangrove juvenile abundance across all sites (Figure 4 and 5). This aligns with the findings of Alongi [39], where calcium, magnesium, and sulphur were highlighted as being major contributors to mangrove growth. Organic carbon content significantly contributed to the abundance of juveniles of both *A. germinans* and *Rhizophora* spp. within the study sites (Figure 5). However, in the case of the control site, organic carbon was not a contributor (Figure 4).

The generally low or insignificant contribution of sediment parameters in the study area shows that mangrove juvenile growth is driven by several other factors that are likely to operate in collaboration with sediment parameters. Further research is required to discover such interlinkages and relationships to ensure efficient mangrove management. This further reveals the critical nature of the mangrove juvenile stage, underscoring the need for more studies to ensure a better understanding. The generally high values of the sapling class in all the locations are also suggestive of the inherent potential for development, if appropriate measures and interventions are adopted. This aligns with observations of Yun et al. [36], who noted that mangrove saplings had a significantly higher survival rate than seedlings owing to their ability to withstand coastal winds and waves of the adjoining oceans.

Conclusion

The mangrove forests of the Niger Delta in Nigeria show signs of degradation, as evidenced by the generally low abundance of young trees relative to sapling abundance. However, the high sapling abundance is indicative of high regenerative potential. The condition and growth of juveniles demonstrated at the control site suggest the interaction and interfacing of several other factors and functionalities, aside from sediment parameters, in operation. Therefore, the observed regeneration potential should be considered. Mangrove regrowth and afforestation, as well as the establishment of additional mangrove conservation sites throughout the region, are recommended.

Author Contributions

UEA: Conceptualisation, Investigation, Methodology, Writing: Original Draft - Review & Editing; **CTE**: Writing - Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

References

1. Alongi, D.M. Global Significance of Mangrove Blue Carbon in Climate Change Mitigation. *Sci* **2020**, *2*, 1–15.
2. Adame, M.F.; Connolly, R.M.; Turschwell, M.P.; Lovelock, C.E.; Fatoyinbo, T.; Lagomasino, D.; Brown, C.J. Future Carbon Emissions from Global Mangrove Forest Loss. *Glob. Change Biol.* **2021**, *27*, 2856–2866.
3. Nwankwo, C.; Tse, A.C.; Nwankwoala, H.O.; Giadom, F.D.; Acra, E.J. Below Ground Carbon Stock and Carbon Sequestration Potentials of Mangrove Sediments in Eastern Niger Delta, Nigeria: Implications for Climate Change. *Sci. Afr.* **2023**, *22*, e01898.
4. Ogbeibu, A.E.; Oribhabor, B.J. The niger delta mangrove ecosystem and its conservation challenges. In *Mangrove Biology, Ecosystem, and Conservation*; IntechOpen: London, UK, 2023;
5. Uche, I.; Gundlach, E.; Mbamalu, G. Survivability and growth performance of using Rhizophora mangrove life stages in the revegetation of mangrove forest. *Reg. Stud. Mar. Sci.* **2023**, *67*, 103228, doi:https://doi.org/10.1016/j.rsma.2023.103228.
6. Nababa, I.I.; Symeonakis, E.; Koukoulas, S.; Higginbottom, T.P.; Cavan, G.; Marsden, S. Land Cover Dynamics and Mangrove Degradation in the Niger Delta Region. *Remote Sens.* **2020**, *12*, 1–22, doi:https://doi.org/10.3390/rs12213619.
7. Numbere, A.O. The Impact of Landscape Reclamation on Mangrove Forest and Coastal Areas in the Niger Delta, Nigeria. In *Landscape Reclamation—Rising from What's Left*; IntechOpen: London, UK, 2020;
8. Nwobi, C.J.; Williams, M. Natural and Anthropogenic Variation of Stand Structure and Aboveground Biomass in Niger Delta Mangrove Forests. *Front. For. Glob. Change* **2021**, *4*, 746671.
9. Nwobi, C.; Williams, M.; Mitchard, E.T. Rapid Mangrove Forest Loss and Nipa Palm (*Nypa fruticans*) Expansion in the Niger Delta, 2007–2017. *Remote Sens.* **2020**, *12*, 23–34.
10. Ferreira, A.C.; Borges, R.; de Lacerda, L.D. Can Sustainable Development Save Mangroves? *Sustainability* **2022**, *14*, 1–27, doi:https://doi.org/10.3390/su14031263.
11. Ellison, A.M.; Felson, A.J.; Friess, D.A. Mangrove Rehabilitation and Restoration as Experimental Adaptive Management. *Front. Mar. Sci.* **2020**, *7*, 1–19.
12. Dewiyanti, I.; Darmawi, D.; Muchlisin, Z.A.; Helmi, T.Z.; Imelda, I.; Defira, C.N. Physical and Chemical Characteristics of Soil in Mangrove Ecosystem Based on Differences Habitat in Banda Aceh and Aceh Besar. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *674*, 012092.
13. Cooray, P.L.; Jayawardana, D.T.; Gunathilake, B.M.; Pupulewatte, P.G. Characteristics of Tropical Mangrove Soils and Relationships with Forest Structural Attributes in the Northern Coast of Sri Lanka. *Reg. Stud. Mar. Sci.* **2021**, *44*, 101741.
14. Hossain, M.D.; Nuruddin, A.A. Soil and Mangrove: A Review. *J. Environ. Sci. Technol.* **2016**, *9*, 198–207.
15. Banerjee, K.; Bal, G.; Mitra, A. How soil texture affects the organic carbon load in the mangrove ecosystem? a case study from Bhitarkanika, Odisha. In *Environmental Pollution: Select Proceedings of ICWEES-2016*; Springer: Singapore, 2018; pp. 329–341, ISBN 978-981-10-5791-5.
16. Ita, R.E.; Ogbemudia, F.O.; Kekere, O.; Udo, E.D. Plant species as influenced by soil relations in a mangrove ecosystem of lower IMO river estuary, Niger Delta, Nigeria. *MOJ Ecology & Environmental Sciences* **2019**, *4*, 92–98.
17. Ngongolo, K.; Mtoka, S.; Makulu, A. Challenges and Opportunities for Restoring the Threatened Mangroves. *Journal of Scientific Research and Reports* **2015**, *5*, 352–360.

18. Ferreira, A.C.; Alencar, C.E.; Bezerra, L.E. Interrelationships among ecological factors of brachyuran crabs, trees, and soil in mangrove community assemblage in Northeast Brazil. *Community Ecology* **2019**, *20*, 277–290, doi:https://doi.org/10.1556/168.2019.20.3.8.
19. Nwosu, F.M.; Holzlohner, S. Suggestions for the Conservation and Rehabilitation of Nigeria's Mangrove Ecosystem. *Journal of Ecosystem and Ecography* **2016**, *6*, 1–3.
20. Akpovwovwo, U.E.; Gbadegesin, A.S. Species composition and distribution patterns of the Mangrove forests of the Western Niger Delta, Nigeria. *African Geographical Review* **2022**, *41*, 468–482, doi:https://doi.org/10.1080/19376812.2022.2046013.
21. Raganas, A.F.; Hadsall, A.S.; Pampolina, N.M.; Hotes, S.; Magcale-Macandog, D.B. Regeneration capacity and threats to mangrove areas on the southern coast of Oriental Mindoro, Philippines: Implications to mangrove ecosystem rehabilitation. *Biodiversitas* **2020**, *21*, 3625–3636.
22. Alemayehu, F.; Chemuku, W. Structure and natural regeneration of mangroves in areas exposed to different agents of degradation in Kenya. *Journal of Global Biosciences* **2017**, *6*, 4695–4707.
23. Asante, F.; Huge, J.; Asare, N.K.; Dahdouh-Guebas, F. Does mangrove vegetation structure reflect human utilization of ecosystem goods and services? *iScience* **2023**, *26*, 106850, doi:https://doi.org/10.1016/j.isci.2023.106850.
24. Langston, A.K.; Kaplan, D.A. Modelling the effects of climate, predation, and dispersal on the poleward range expansion of black mangrove (*Avicennia germinans*). *Ecological Modelling* **2020**, *434*, 109245, doi:https://doi.org/10.1016/j.ecolmodel.2020.109245.
25. Numbere, A.O. Mangrove restoration under different disturbance regimes in the Niger Delta, Nigeria. In *Mangrove Ecosystem Restoration*; Intechopen: London, UK, 2021; pp. 51–68, ISBN 978-1-83962-800-9.
26. Auni, A.H.; Bachtiar, B.; Paembonan, S.A.; Larekeng, S.H. Growth analysis of mangrove (*Rhizophora apiculata* Bl) propagule toward differences in types of water and planting media at Makassar mangrove center. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *575*, 012137, doi:https://doi.org/10.1088/1755-1315/575/1/012137.
27. Azad, M.S.; Kamruzzaman, M.; Kanzaki, M. Canopy gaps influence regeneration dynamics in cyclone-affected mangrove stands in medium saline zone of the Sundarbans, Bangladesh. *Acta Ecol. Sin.* **2021**, *41*, 296–303, doi:https://doi.org/10.1016/j.chnaes.2020.07.003.
28. Sloey, T.M.; Lim, K.E.; Moore, J.; Heng, J.M.; van Breugel, M. Influence of abiotic drivers on 1-year seedling survival of six mangrove species in Southeast Asia. *Restor. Ecol.* **2022**, *30*, e13694, doi:https://doi.org/10.1111/rec.13694.
29. Erasto, D.A.; Okeyo, B.; Dharani, N. Assessment of structure and natural regeneration capacity of Avicennia marina and Bruguiera gymnorrhiza species of mangroves in Mida Creek, Kilifi County, Kenya. *Int. J. Plant Anim. Environ. Sci.* **2021**, *11*, 262–294.
30. Shih, S.S. Spatial habitat suitability models of mangroves with Kandelia obovata. *Forests* **2020**, *11*, 1–19, doi:https://doi.org/10.3390/f11040477.
31. Gorman, D.; Vanderklift, M.A.; Lafratta, A. Quantitative analysis of methodological and environmental influences on survival of planted mangroves in restoration and afforestation. *Forests* **2022**, *13*, 1–16, doi:https://doi.org/10.3390/f13030404.
32. Sahana, M.; Areendran, G.; Sajjad, H. Assessment of suitable habitat of mangrove species for prioritizing restoration in the coastal ecosystem of Sundarban Biosphere Reserve, India. *Sci. Rep.* **2022**, *12*, 20997, doi:https://doi.org/10.1038/s41598-022-25425-3.
33. Numbere, A.O.; Camilo, G.R. Mangrove Leaf Herbivory along a Hydrocarbon Pollution Gradient in a Mangrove Forest (*Rhizophora racemosa*) in the Niger River Delta, Nigeria. *J. Pet. Environ. Biotechnol.* **2019**, *10*, 1–16.
34. Numbere, A.O. Natural seedling recruitment and regeneration in deforested and sand-filled mangrove forest at Eagle Island, Niger Delta, Nigeria. *Ecology and Evolution* **2021**, *11*, 3148–3158, doi:https://doi.org/10.1002/ece3.7264.
35. Dookie, S.; Jaikishun, S.; Ansari, A.A. Soil and water relations in mangrove ecosystems in Guyana. *Geol. Ecol. Landsc.* **2024**, *8*, 445–469, doi:https://doi.org/10.1080/24749508.2024.11910240.

36. Yun, W.Y.; Yeok, S.; Youshao, W.; Lu, D.; Limi, M.; Lai, G.T. Spatiotemporal dispersal study of mangrove Avicennia marina and Rhizophora apiculata propagules. *Sains Malaysiana* **2022**, *51*, 2351–2364, doi:https://doi.org/10.17576/jsm-2022-5109-10.
37. Ahmed, S.; Sarker, S.K.; Friess, D.A.; Kamruzzaman, M.; Jacobs, M.; Islam, M.A.; Alam, M.A.; Suvo, M.J.; Sani, M.N.; Dey, T.; et al. Salinity reduces site quality and mangrove forest functions: From monitoring to understanding. *Sci. Total Environ.* **2022**, *853*, 158662.
38. Devaney, J.L.; Marone, D.; McElwain, J.C. Impact of soil salinity on mangrove restoration in a semiarid region: A case study from the Saloum Delta, Senegal. *Restor. Ecol.* **2021**, *29*, e13186, doi:https://doi.org/10.1111/rec.13186.
39. Alongi, D.M. Macro- and Micronutrient Cycling and Crucial Linkages to Geochemical Processes in Mangrove Ecosystems. *J. Mar. Sci. Eng.* **2021**, *9*, 1–26, doi:https://doi.org/10.3390/jmse9050456.

