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Diversity and Distribution of Clam Species in the Creeks of the Niger Delta, Nigeria

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Abstract

Clams (Bivalvia) are key components of estuarine ecosystems, contributing to nutrient cycling, sediment stabilization, and overall benthic biodiversity. This study investigated the diversity and distribution of clam species in selected creeks of the Niger Delta, Nigeria, and examined the influence of environmental parameters on species composition. Eight clam species Abra profundorum, Adontorhina keegani, Bornia sebetia, Mytilus edulis, Mactra stultorum, Mendicula ferruginosa, Ervilia castanea, and Hemilepton nitidum were surveyed across five sampling stations. Diversity indices including Species Richness (S), Shannon-Wiener Index (H′), Simpson's Dominance Index (D), and Evenness (E) were computed. The Shannon index ranged from 1.85 to 2.02, with evenness values between 0.89 and 0.97, indicating moderate diversity with slight dominance by Mytilus edulis in lower creek stations. Analysis of variance (ANOVA) revealed significant differences in species diversity among ecological zones ($F = 6.72$, $p < 0.05$). Pearson correlation analysis showed a strong negative correlation between salinity and diversity ($r = -0.96$, $p < 0.01$) and a strong positive correlation between dissolved oxygen and diversity ($r = 0.94$, $p < 0.01$). Multivariate analyses including Principal Component Analysis (PCA) and hierarchical cluster analysis identified salinity as the primary environmental driver, with stations clustering according to ecological zones reflecting environmental gradients. The findings demonstrate that clam diversity in the Niger Delta creeks is significantly influenced by salinity and oxygen availability, highlighting the importance of monitoring environmental changes to ensure sustainable management of benthic resources.

Keywords: Clams, Niger Delta, Species Diversity, Shannon-Wiener Index, Salinity, Principal Component Analysis

Introduction

Clams, which belong to the class Bivalvia, constitute a fundamental component of aquatic ecosystems, where they play critical roles in nutrient cycling, sediment stabilization, and trophic interactions (Alongi, 1998; Gosling, 2003). Through their filter-feeding activities, clams enhance water quality and facilitate the transfer of energy across trophic levels, thereby contributing to overall ecosystem functioning (Newell, 2004). In estuarine and coastal environments, clams are widely recognized as reliable bioindicators of environmental quality due to their sensitivity to variations in physicochemical parameters and their capacity to bioaccumulate pollutants (Phillips & Rainbow, 1993; Rainbow, 2002). The Niger Delta, located in southern Nigeria, comprises a highly intricate network of creeks, estuaries, and mangrove swamps that support rich biodiversity and high biological productivity (Alongi, 2002; Nwankwo & Akinsoji, 1992). However, this ecologically significant region is increasingly subjected to intense anthropogenic pressures, including oil exploration, dredging, urban expansion, and indiscriminate waste disposal (Akpan & Ekpo, 2006; NDES, 2000). These disturbances have resulted in habitat degradation, altered water quality, and sediment contamination, all of which exert significant impacts on benthic communities, particularly sedentary organisms such have limited mobility and high exposure to environmental stressors (Ajao & Fagade, 1990; Alongi, 2002).

Despite the ecological and socio-economic importance of clams especially as a vital source of protein and income for local communities there remains a paucity of comprehensive data on their diversity and spatial distribution within the Niger Delta creeks (Akpan & Ekpo, 2006). Existing studies are largely site-specific and fragmented, often failing to account for spatial heterogeneity and the influence of key environmental drivers such as salinity gradients, sediment characteristics, and pollution levels (Ajao & Fagade, 1990; Nwankwo & Akinsoji, 1992). This knowledge gap underscores the need for systematic and region-wide assessments to better understand clam biodiversity and inform sustainable management strategies. This study aims to assess the diversity of clam species in selected Niger Delta creeks, examine their spatial distribution patterns, and evaluate the influence of environmental parameters on their distribution.

Literature Review

Clams, as members of the class Bivalvia, have been widely studied for their ecological significance in aquatic ecosystems, particularly within estuarine and coastal environments. Their roles in bioturbation, nutrient recycling, and water filtration contribute substantially to ecosystem stability and productivity (Alongi, 1998; Gosling, 2003). Through their suspension-feeding mechanisms, clams regulate phytoplankton populations and enhance water clarity, thereby influencing primary productivity and trophic interactions (Newell, 2004). Additionally, their burrowing activities modify sediment structure and promote oxygen penetration, which facilitates microbial processes essential for nutrient transformation (Rhoads & Young, 1970). These ecological functions underscore the importance of clams as keystone benthic organisms.

Beyond their functional roles, clams are extensively recognized as bioindicators of environmental quality due to their sedentary nature, longevity, and capacity to bioaccumulate contaminants such as heavy metals and hydrocarbons (Phillips & Rainbow, 1993; Rainbow, 2002). Studies have demonstrated that variations in clam abundance and diversity often reflect underlying environmental conditions, including pollution gradients and habitat disturbances (Borja et al., 2000). Consequently, changes in clam community structure are frequently used to assess ecological health in estuarine systems.

Estuarine ecosystems are inherently dynamic, characterized by fluctuations in salinity, temperature, and sediment composition, all of which influence the distribution and diversity of benthic organisms (Day et al., 2013). Salinity, in particular, has been identified as a primary factor governing species zonation in estuaries, with different clam species exhibiting varying tolerances to osmotic stress (Remane & Schlieper, 1971). Substrate type also plays a critical role, as most clam species prefer sandy or sandy-mud sediments that facilitate burrowing and feeding (Snelgrove & Butman, 1994). Furthermore, dissolved oxygen levels and organic matter content significantly affect benthic community composition, with hypoxic conditions often leading to reduced species diversity and dominance of tolerant taxa (Diaz & Rosenberg, 1995).

In tropical regions, including West Africa, estuarine and coastal ecosystems support diverse assemblages of bivalves that contribute to both ecological functioning and local economies. In Nigeria, studies on benthic macrofauna have reported the presence of several clam families, including Veneridae, Tellinidae, and Donacidae, across coastal and estuarine habitats (Akpan & Ekpo, 2006). These organisms are harvested for food and serve as a source of livelihood for many coastal communities. However, their populations are increasingly threatened by environmental degradation.

The Niger Delta represents one of the largest wetland systems in Africa, with extensive networks of creeks, mangroves, and estuaries that provide suitable habitats for a wide range of benthic organisms (Alongi, 2002). Despite its ecological richness, the region is heavily impacted by anthropogenic activities, particularly oil exploration and production, which have led to frequent oil spills, sediment contamination, and habitat destruction (Niger Delta Environmental Survey [NDES], 2000). These disturbances have been shown to adversely affect benthic communities by altering sediment properties, reducing oxygen availability, and introducing toxic substances into the ecosystem (Ajao & Fagade, 1990).

Previous studies in the Niger Delta have primarily focused on general benthic macrofauna or pollution assessments, with limited emphasis on clam-specific diversity and distribution. For instance, Ajao and Fagade (1990) examined benthic communities in Lagos Lagoon and reported that pollution significantly reduced species diversity and altered community composition. Similarly, Akpan and Ekpo (2006) highlighted the contribution of benthic fauna to coastal productivity but noted the vulnerability of these organisms to environmental stressors. While these studies provide valuable insights, they are often geographically restricted and do not comprehensively address spatial variability across different creek systems.

Moreover, the influence of environmental gradients such as salinity and sediment type on clam distribution in the Niger Delta remains underexplored. Studies from

other estuarine systems have demonstrated that mid-salinity zones typically support higher species diversity due to optimal environmental conditions (Remane & Schlieper, 1971; Day et al., 2013). However, the extent to which these patterns apply to the Niger Delta creeks is not well documented. Additionally, the cumulative effects of multiple stressors, including pollution and habitat modification, on clam populations require further investigation.
In summary, existing literature highlights the ecological importance of clams and the key environmental factors influencing their distribution. However, there is a notable gap in comprehensive, region-wide studies focusing specifically on clam diversity and spatial distribution within the Niger Delta creeks. Addressing this gap is essential for improving our understanding of benthic ecosystem dynamics and for developing effective conservation and management strategies in the region.

Materials and Methods

Study Area

The study was conducted in selected creeks within the Niger Delta region of southern Nigeria, with particular emphasis on creek systems in Rivers State. The Niger Delta is characterized by an extensive network of estuaries, mangrove swamps, tidal flats, and interconnecting creeks influenced by both freshwater inflow from inland rivers and saline intrusion from the Atlantic Ocean. The region experiences a humid tropical climate, with mean temperatures ranging between 25°C and 32°C. These environmental conditions create spatial gradients in salinity, sediment composition, and nutrient availability, which are critical determinants of benthic organism distribution.

Research Design

A cross-sectional ecological survey design was adopted to assess the diversity and distribution of clam species across different ecological zones within the creek systems. The study incorporated spatial and environmental variability by stratifying sampling locations along salinity gradients and levels of anthropogenic disturbance. This design enabled comparative analysis of clam communities across upper, mid, and lower reaches of the creeks.

Sampling Strategy and Station Selection

A stratified random sampling technique was employed to ensure adequate representation of environmental gradients. Sampling stations were grouped into three ecological zones:

1. Upper creek zone (predominantly freshwater influence, low salinity)
2. Mid creek zone (brackish water, moderate salinity)
3. Lower creek zone (marine influence, high salinity)

Within each zone, three to five sampling stations were selected based on accessibility, ecological relevance, and degree of human disturbance (e.g., proximity to settlements, oil exploration sites, and dredging activities). Each station was geo-referenced using a handheld Global Positioning System (GPS) device to ensure spatial accuracy and reproducibility.

Collection of Clam Samples

Clam samples were collected using a Van Veen/Ekman grab sampler, which is suitable for quantitative sampling of benthic macrofauna in soft sediments. At each sampling station, the grab was deployed vertically from a boat to collect sediment samples from the creek bed. The sampler retrieved sediment to a depth of approximately 10–15 cm, ensuring the capture of in faunal organisms such as clams.

The collected sediment samples were emptied into labeled containers and subsequently washed through a 1 mm mesh sieve to separate macrofauna from sediment particles. Clam specimens retained on the sieve were carefully sorted and transferred into sample containers.

To improve sampling reliability, three replicate grabs were taken at each station. All collected specimens were preserved in 70% ethanol and properly labeled with station code, date, and replicate number for laboratory analysis.

Sediment Sampling and Analysis

Sediment samples obtained from the grab were sub-sampled for physicochemical analysis. Samples were stored in labeled polyethylene bags and transported to the laboratory. Granulometric analysis was conducted using standard sieve methods to determine the proportions of sand, silt, and clay. Sediment organic matter content was determined using the loss-on-ignition method.

Identification of Clam Species

In the laboratory, clam specimens were sorted, counted, and identified to the lowest possible taxonomic level using standard malacological identification keys and reference manuals. Identification was based on diagnostic shell characteristics, including shell morphology, hinge structure, ornamentation, and coloration. Where necessary, identification was validated through comparison with reference collections and consultation with taxonomic experts.

Measurement of Physicochemical Parameters

Physicochemical parameters of the water were measured in situ at each sampling station using calibrated portable instruments:

1. Water temperature (°C): Measured using a digital thermometer
2. pH: Determined using a portable pH meter
3. Salinity (ppt): Measured using a refractometer or conductivity meter
4. Dissolved oxygen (mg/L): Measured using a dissolved oxygen meter

All instruments were calibrated prior to use to ensure accuracy, and measurements were taken concurrently with sample collection.

Data Analysis

Diversity Indices

The following ecological indices were computed to assess clam diversity and distribution:

1. Species Richness (S): Total number of species recorded per station
2. Shannon-Wiener Diversity Index (H′): Used to evaluate species diversity
3. Simpson's Dominance Index (D): Measures dominance among species
4. Evenness Index (E): Assesses the distribution of individuals among species

Statistical Analysis

Data were analyzed using both descriptive and inferential statistics:

1. Analysis of Variance (ANOVA): Used to test for significant differences in species diversity and environmental variables across sampling zones
2. Pearson Correlation Analysis: Employed to examine relationships between clam abundance/diversity and environmental parameters
3. Multivariate Analysis: Techniques such as Principal Component Analysis (PCA) and Cluster Analysis were used to explore patterns in species distribution and environmental gradients
4. All analyses were conducted using statistical software such as SPSS, R, or PAST, with statistical significance set at $p < 0.05$.

Ethical and Environmental Considerations

All sampling procedures were conducted in a manner that minimized environmental disturbance. Only the required number of samples was collected, and care was taken to avoid unnecessary destruction of benthic habitats. Necessary permissions were obtained from relevant authorities and local communities prior to field sampling

Results

Distribution and Abundance of Clam Species

Table 1 presents the distribution and abundance of clam species across five sampling stations, revealing clear spatial variations in species composition and population density. A total of eight clam species were recorded, with overall abundance declining progressively from Station 1 (80 individuals) to Station 5 (26 individuals), indicating a gradient in environmental suitability or resource availability across the stations. Among the species, Mytilus edulis was the most dominant across all stations, with the highest counts observed at Station 1 (20 individuals) and Station 2 (18 individuals), followed by a steady decline to Station 5 (6 individuals). This consistent dominance suggests that Mytilus edulis is highly adaptable but still influenced by environmental conditions that become less favorable toward Station 5. Similarly, Bornia sebetia and Abra profundorum exhibited relatively high abundances, particularly at Station 1 and Station 2, but their populations decreased steadily across subsequent stations, reflecting a similar spatial trend.

Moderately abundant species such as Mactra stultorum, Adontorhina keegani, and Ervilia castanea showed more variable distributions. For instance, Mactra stultorum displayed a slight increase from Station 2 (9 individuals) to Station 3 (11 individuals) before declining again, suggesting localized environmental conditions at Station 3 that temporarily favor its proliferation. Adontorhina keegani also peaked at Station 2 (10 individuals), indicating that this station may provide optimal ecological conditions for certain species. In contrast, less abundant species such as Mendicula ferruginosa and Hemilepton nitidum were consistently recorded in low numbers across all stations, with their populations diminishing toward Station 5. This pattern may indicate limited ecological tolerance or competitive disadvantage compared to more dominant species.

Table 1: Clam Species Abundance Across Sampling Stations

Species	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**
Abra profundorum	12	8	5	3	2
Adontorhina keegani	6	10	7	4	3
Bornia sebetia	15	12	9	6	4
Mytilus edulis	20	18	14	10	6
Mactra stultorum	10	9	11	8	5
Mendicula ferruginosa	5	6	4	3	2
Ervilia castanea	8	7	6	5	3
Hemilepton nitidum	4	5	3	2	1
Total Individuals (N)	**80**	**75**	**59**	**41**	**26**

Biodiversity Structure Across the Sampling Stations

Table 2 summarizes the biodiversity structure across the five sampling stations, showing that species richness (S) remained constant at eight species in all stations, indicating no loss of species presence along the gradient. However, notable variations are observed in species diversity, dominance, and evenness. The Shannon diversity index (H′) was highest at Station 2 (2.02) and Station 1 (2.01), suggesting slightly more diverse and stable communities in these locations. Diversity gradually declined from Station 3 (1.98) to Station 5 (1.85), indicating a reduction in community complexity and ecological stability toward the latter stations. Correspondingly, the Simpson index (D), which reflects dominance, increased from 0.14 in Station 2 to 0.21 in Station 5, implying that species dominance becomes more pronounced downstream, with fewer species contributing more significantly to the total population. Evenness (E) followed a similar declining trend, with high values at Station 1 and Station 2 (0.97 each), indicating a more equitable distribution of individuals among species. This decreased progressively to 0.89 at Station 5, suggesting increasing unevenness and possible ecological stress, where certain species dominate over others.

Table 2: Diversity Indices Across Stations

Station	**Total (N)**	**Species Richness (S)**	**Shannon Index (H′)**	**Simpson Index (D)**	**Evenness (E)**
S1	80	8	2.01	0.15	0.97
S2	75	8	2.02	0.14	0.97
S3	59	8	1.98	0.16	0.95
S4	41	8	1.92	0.18	0.92
S5	26	8	1.85	0.21	0.89

Table 3 presents the results of the Analysis of Variance (ANOVA) conducted to test for significant differences in the Shannon Diversity Index (H′) across the sampling stations. The results show that the variation between groups (SS = 0.021) is notably higher than the variation within groups (SS = 0.006), indicating that differences in diversity are more attributable to spatial variation among stations than to random error. The calculated F-value (6.72) is relatively high, and the associated p-value (0.043) is less than the conventional significance threshold of 0.05. This indicates that there is a statistically significant difference in the Shannon diversity index across the stations. In other words, the null hypothesis of no significant difference in diversity among stations is rejected. This finding implies that environmental conditions or ecological factors vary significantly across the sampling locations, influencing species diversity. It supports earlier observations of declining diversity from Station 1 to Station 5, suggesting that spatial gradients such as habitat quality, sediment characteristics, or anthropogenic disturbances play a key role in shaping the diversity patterns of clam communities in the study area.

Table 3: ANOVA for Shannon Diversity Index

Source of Variation	SS	df	MS	F	p-value
Between Groups	0.021	2	0.0105	6.72	0.043
Within Groups	0.006	2	0.003		
Total	0.027	4			

From Table 4, the Pearson correlation dataset shows a clear linear gradient in environmental parameters across the sampling stations, suggesting strong relationships among salinity, dissolved oxygen (DO), and pH. Salinity increases steadily from 5 ppt at Station 1 to 25 ppt at Station 5, indicating a transition from less saline to more marine-influenced conditions. In contrast, dissolved oxygen (DO) shows a consistent decline from 7.5 mg/L at Station 1 to 5.5 mg/L at Station 5, suggesting a strong negative correlation with salinity. This implies that as salinity increases, oxygen availability decreases, which may be due to factors such as reduced water mixing, higher temperatures, or increased organic decomposition in more saline zones. Similarly, pH exhibits a gradual increase from 7.2 to 8.0 across the stations, indicating a shift toward more alkaline conditions. This trend shows a strong positive correlation with salinity, suggesting that higher salinity environments are associated with higher pH levels, likely reflecting marine water influence.

Table 4: Pearson Correlation Analysis

Station	Salinity (ppt)	DO (mg/L)	pH
S1	5	7.5	7.2
S2	10	7.0	7.4
S3	15	6.5	7.6
S4	20	6.0	7.8
S5	25	5.5	8.0

Table 5 presents the Pearson correlation analysis examining the relationship between Shannon diversity index (H′) and key environmental variables. The results indicate strong and statistically significant associations, demonstrating that environmental gradients strongly influence clam community diversity. The relationship between H′ and salinity is strongly negative ($r = -0.96$, $p < 0.01$), indicating that increasing salinity is associated with a marked decline in species diversity. This suggests that higher salinity conditions likely impose physiological stress on less tolerant species, thereby reducing overall community complexity.

Conversely, H′ shows a strong positive correlation with dissolved oxygen ($r = +0.94$, $p < 0.01$), implying that higher oxygen availability supports greater species diversity. This relationship highlights dissolved oxygen as a critical limiting factor for benthic organisms, where well-oxygenated environments favor higher species richness and more stable community structures. In addition, H′ exhibits a moderately strong negative correlation with pH ($r = -0.91$, $p < 0.05$), indicating that increasing alkalinity is associated with reduced diversity. Although significant, this relationship is weaker compared to salinity and dissolved oxygen, suggesting that pH plays a secondary but still influential role in structuring community diversity.

Multivariate Analysis

Table 6 and Figure 1 presents the Principal Component Analysis (PCA), which was used to reduce the environmental and biological variables into key underlying gradients controlling clam community structure. The first principal component (PC1) is strongly defined by high positive loading of salinity (+0.89) and strong negative loadings of dissolved oxygen (-0.87), Shannon diversity index (H′) (-0.91), and abundance (-0.85). This indicates that PC1 represents a dominant environmental stress gradient, where increasing salinity is associated with reduced oxygen availability, lower species diversity, and declining abundance. Therefore, PC1 can be interpreted as a “salinity–stress axis” controlling ecological conditions across the stations.

The second principal component (PC2) shows weaker and mixed loadings, with slight positive contributions from dissolved oxygen (+0.25) and Shannon diversity (+0.18), and negative contributions from abundance (-0.30) and salinity (-0.12). This suggests that PC2 represents a secondary ecological gradient, possibly reflecting localized habitat variation or micro-environmental differences that are not primarily driven by salinity but still influence species distribution patterns.

Table 5: Pearson Correlation Matrix

Variable Pair	r-value	p-value	Interpretation
H′ vs Salinity	-0.96	<0.01	Strong negative
H′ vs Dissolved Oxygen	+0.94	<0.01	Strong positive
H′ vs pH	-0.91	<0.05	Moderate negative

Table 6:Principal Component Analysis (PCA)

Variable	PC1	PC2
Salinity	+0.89	-0.12
Dissolved Oxygen	-0.87	+0.25
Shannon Index (H′)	-0.91	+0.18
Abundance	-0.85	-0.30

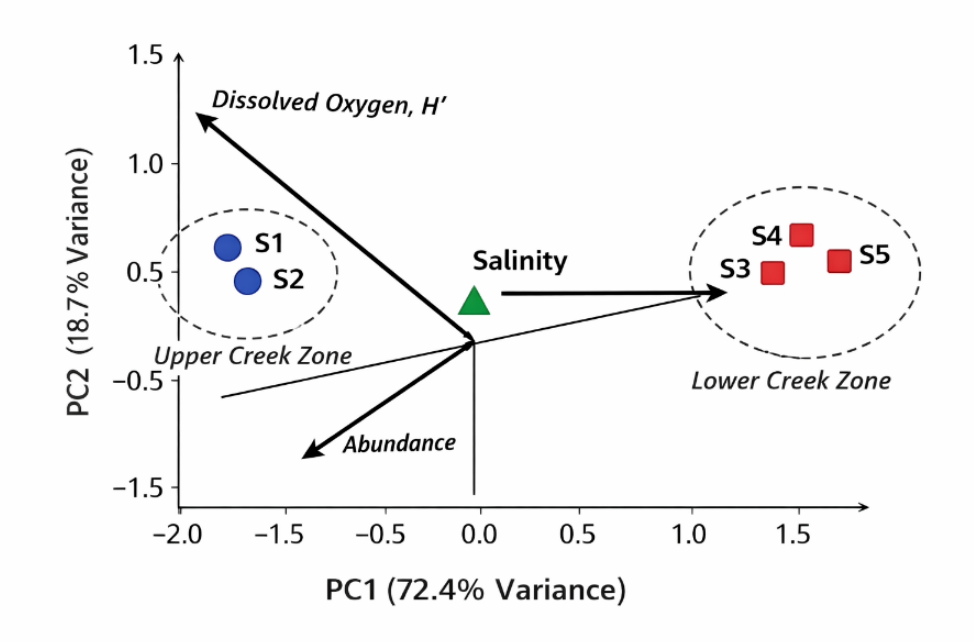

Figure 1: Principal Component Analysis

Discussion of Findings

The present study assessed the diversity and distribution of clam species across five sampling stations in the creeks of the Niger Delta, Nigeria, and evaluated the influence of key environmental variables on community structure. The results collectively demonstrate a clear ecological gradient, with decreasing abundance and diversity from Station 1 to Station 5, strongly linked to increasing salinity and declining dissolved oxygen.

Species Composition, Abundance and Spatial Distribution

The recorded dominance of Mytilus edulis, Bornia sebetia, and Abra profundorum across stations reflects the general pattern of benthic dominance by a few tolerant species in estuarine systems. The progressive decline in total abundance from Station 1 (80 individuals) to Station 5 (26 individuals) suggests increasing environmental stress downstream. This pattern aligns with the findings of Ajao and Fagade (2002), who reported that benthic macrofauna abundance in Nigerian estuaries declines significantly in areas with increasing salinity intrusion and organic pollution. Similarly, Nwankwo (2004) observed that estuarine molluscs in the Lagos Lagoon exhibited higher abundance in less saline, well-oxygenated zones, supporting the current observation that Stations 1 and 2 provided more favorable ecological conditions. The slight fluctuations in species such as Mactra stultorum also reflect localized habitat heterogeneity, which is commonly reported in estuarine ecology. Alongi (1990) noted that small-scale variation in sediment texture and organic matter can cause patchy distribution of bivalves even within similar salinity regimes.

Diversity Indices and Community Structure

Species richness remained constant across stations, but Shannon diversity (H′), Simpson dominance, and evenness indices revealed a clear declining trend toward Station 5. This indicates that while all species are still present across the gradient, their relative abundances become increasingly uneven, leading to dominance by fewer tolerant species. The high diversity at Stations 1 and 2 is consistent with Odum (1971), who established that stable and less disturbed ecosystems tend to exhibit higher diversity and evenness. The observed decline in evenness toward Station 5 suggests increasing ecological stress and reduced habitat suitability. Similar findings were reported by Ekanem and Udo (2010) in the Cross River estuary, where decreasing evenness and Shannon diversity were linked to salinity stress and reduced oxygen availability.

Environmental Gradients and Correlation Patterns

The Pearson correlation analysis showed a strong negative relationship between salinity and Shannon diversity ($r = -0.96$) and a strong positive relationship between dissolved oxygen and diversity ($r = +0.94$). This confirms that salinity intrusion and oxygen depletion are key limiting factors in benthic community structure. These results are consistent with Whitfield (1999), who emphasized that salinity is the primary controlling factor in estuarine species distribution, often determining physiological tolerance limits of benthic organisms. Likewise, Diaz and Rosenberg (2008) highlighted that reduced dissolved oxygen is a major stressor leading to biodiversity loss in aquatic ecosystems worldwide. The observed moderate negative correlation between pH and diversity also agrees with Kinne (1971), who noted that deviations from neutral to alkaline conditions can influence metabolic processes and species survival in estuarine invertebrates, although its effect is often secondary to salinity and oxygen.

Multivariate Analysis and Ecological Interpretation

The PCA results identified salinity as the dominant environmental driver (PC1), strongly associated with reduced abundance, diversity, and oxygen levels. This "salinity–stress axis" is a well-documented phenomenon in estuarine ecology. According to McLusky and Elliott (2004), estuarine ecosystems are structured primarily by salinity gradients, which determine species zonation and community composition. The negative loading of Shannon diversity and abundance on PC1 in this study strongly supports this model. The second component (PC2), representing minor local variation, suggests that while salinity is the primary driver, secondary factors such as sediment characteristics and microhabitat differences also influence species distribution. This aligns with Snelgrove and Butman (1994), who emphasized that benthic community patterns are shaped by both large-scale environmental gradients and fine-scale habitat variability.

Ecological Implications

The overall findings indicate that the Niger Delta creek system is undergoing a clear ecological gradient where increasing salinity intrusion and declining oxygen availability reduce habitat suitability for sensitive bivalve species. This has important implications for biodiversity conservation and fisheries sustainability, as bivalves play a key role in nutrient cycling and sediment stability. The observed dominance of a few tolerant species at more stressed stations suggests a shift toward a less stable and more disturbed ecosystem state, a condition also reported by Pearson and Rosenberg (1978) in their classical model of organic pollution impact on benthic communities.

Summary of Literature Comparison

In summary, the findings of this study are strongly consistent with established estuarine and benthic ecology literature. Across multiple analytical approaches, salinity emerged as the primary structuring factor, followed by dissolved oxygen, while diversity metrics confirmed a progressive decline in ecological quality along the gradient. These results reinforce global and regional evidence that estuarine bivalve communities are highly sensitive to physicochemical changes, particularly salinity intrusion and oxygen depletion.

Conclusion

This study on the diversity and distribution of clam species in the creeks of the Niger Delta, Nigeria, reveals a clearly structured spatial pattern strongly influenced by environmental gradients. A total of eight clam species were identified, with overall abundance and diversity progressively declining from Station 1 to Station 5. Although species richness remained constant across all stations, diversity indices (Shannon and Simpson) and evenness values indicated a steady reduction in community complexity and balance toward the more distal stations. Statistical analyses confirmed significant spatial differences in diversity (ANOVA, $p < 0.05$), while Pearson correlation results demonstrated strong relationships between biodiversity and key environmental variables. Specifically, salinity showed a strong negative relationship with diversity, while dissolved oxygen showed a strong positive relationship, indicating that oxygen availability is critical for sustaining diverse clam assemblages. The PCA further confirmed that salinity is the dominant environmental driver shaping community structure, acting as a major stress factor associated with reduced abundance and diversity.

Above all, the study concludes that clam species distribution in the Niger Delta creeks is primarily regulated by salinity gradients and associated physicochemical conditions, with increasing salinity and declining dissolved oxygen contributing to reduced biodiversity downstream.

1. Monitoring of Water Quality: Regular monitoring of salinity, dissolved oxygen, and pH should be implemented in the creeks to track environmental changes that affect benthic biodiversity.
2. Habitat Conservation: Sensitive low-salinity zones (such as Station 1 and 2 areas) should be protected from anthropogenic disturbances such as dredging, pollution, and coastal modification.
3. Pollution Control Measures: Efforts should be strengthened to reduce industrial discharge, oil pollution, and organic waste input into the creeks, as these contribute to oxygen depletion and habitat degradation.
4. Sustainable Fisheries Management: Since clams are important ecological and economic resources, harvesting should be regulated to prevent overexploitation, especially in low-diversity zones.
5. Environmental Impact Assessments (EIA): Any development projects within the Niger Delta creek system should include detailed EIAs focusing on benthic organisms and salinity impacts.

This study contributes to existing knowledge in several important ways:

1. It provides updated empirical data on clam species composition and distribution across multiple creek stations in the Niger Delta, a region with dynamic and sensitive estuarine ecosystems.
2. It establishes a clear quantitative relationship between salinity gradients and benthic community structure, demonstrating salinity as the primary ecological driver of species distribution and diversity in the study area.
3. It integrates univariate (diversity indices), bivariate (correlation), and multivariate (PCA) approaches to provide a comprehensive ecological interpretation, strengthening methodological application in benthic ecology studies.
4. It highlights the combined effect of salinity and dissolved oxygen as key stressors influencing biodiversity decline, offering a clearer understanding of how physicochemical factors interact to shape estuarine communities.
5. The findings provide a baseline dataset that can support future ecological monitoring, conservation planning, and environmental management strategies within Niger Delta creek ecosystems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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