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SALINITY-DRIVEN PATTERNS IN BENTHIC MACROINVERTEBRATE COMMUNITIES: AN ENVIRONMENTAL MANAGEMENT PERSPECTIVE FOR A COASTAL LAGOON

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ABSTRACT

This study investigated the response of benthic macroinvertebrate communities to salinity variations along the stretch of a coastal lagoon in Nigeria. 576 samples collected using a van Veen grab of 0.1 m^2 size from eight investigation stations were used for this study. Benthic macrofauna population of 177,120 m^2 from 45 species was recorded. Molluscs were the main group, making up 98.43% of the population, followed by anelids, arthropods, and several other macroinvertebrate groups. Although seasonal changes had a minor effect on fauna abundance, the richness, diversity, and evenness of species were not significantly impacted. Salinity gradients played a crucial role in determining the distribution and abundance of benthic macrofauna. Locations with elevated salinity levels (> 0.34‰) exhibited greater abundance.

RÉSUMÉ: Modèles de communautés de macroinvertébrés benthiques influencés par la salinité: une perspective de gestion environnementale pour les lagunes côtières.

Cette étude a examiné la réponse des communautés de macroinvertébrés benthiques aux variations de salinité le long d'une lagune côtière au Nigéria. 576 échantillons prélevés à l'aide d'une benne Van Veen de 0,1 m^2 dans huit stations d'investigation ont été utilisés pour cette étude. Une population de macrofaune benthique de 177 120 m^2, composée de 45 espèces, a été recensée. Les mollusques constituaient le groupe prédominant, représentant 98,43% de la population, suivis des annélides, des arthropodes et de plusieurs autres groupes de macroinvertébrés. Bien que les variations saisonnières aient eu un effet mineur sur l'abondance de la faune, la richesse, la diversité et la régularité des espèces n'ont pas été significativement affectées. Les gradients de salinité ont joué un rôle crucial dans la détermination de la répartition et de l'abondance de la macrofaune benthique. Les sites présentant des niveaux de salinité élevés (> 0,34‰) présentaient une plus grande abondance.

REZUMAT: Modele bazate pe salinitate în comunitățile de macronevertebrate bentonice: o perspectivă de management de mediu pentru o lagună costieră.

Acest studiu a investigat răspunsul comunităților de macronevertebrate bentonice la variațiile de salinitate de-a lungul unei lagune de coastă din Nigeria. Pentru acest studiu au fost utilizate 576 de eșantioane colectate cu ajutorul unui dispozitiv van Veen grab de 0,1 m^2, din opt stații de investigație. Populația de macronevertebrate bentonice a 45 de specii, a fost înregistrată pe o suprafață de 177.120 m^2. Moluștele au fost grupul predominant, reprezentând 98,43% din populație, urmate de anelide, artropode și alte câteva grupuri de macronevertebrate. Deși schimbările sezoniere au avut un efect minor asupra abundenței faunei, bogăția, diversitatea și uniformitatea speciilor nu au fost afectate semnificativ. Gradienții de salinitate au jucat un rol crucial în determinarea distribuției și a abundenței macronevertebratelor bentonice. Locațiile cu niveluri ridicate de salinitate (> 0,34 ‰) au prezentat o abundență mai mare.

INTRODUCTION

Coastal lagoons are complex and dynamic ecosystems that support a rich diversity of plant and animal species (Borja and Tunberg, 2011; Elliott and Quintino, 2007). These ecosystems provide essential services, including shoreline stabilization, water filtration, and habitat for numerous aquatic organisms. Benthic macroinvertebrates, such as molluscs, annelids, and arthropods, play a vital role in maintaining the health and function of coastal lagoons by contributing to nutrient cycling, sediment stabilization, and food webs (Fischer et al., 2006). Salinity is a critical environmental factor that shapes the structure and function of benthic macrofauna communities in coastal lagoons (Folke et al., 2004). Changes in salinity can significantly impact the distribution, abundance, and diversity of these communities, potentially altering ecosystem functions and services. For instance, shifts in salinity can lead to changes in species composition, altered ecosystem functions, and impacts on biodiversity. These changes can make ecosystems more vulnerable to disturbances and reduce their overall resilience (Layman et al., 2014; Clark and Frid, 2001).

From an environmental management perspective, it is crucial to consider the salinity-driven patterns in benthic macroinvertebrate communities when developing conservation and management plans for coastal lagoons (Jayaraj et al., 2007). This involves understanding the relationships between salinity and benthic macroinvertebrate communities, developing effective conservation strategies, and managing salinity levels to maintain healthy and diverse ecosystems. By taking a proactive approach to managing salinity-driven patterns, we can help protect and conserve benthic macroinvertebrate communities and the ecosystem services they provide (Jennerjahn and Mitchell, 2013).

In West Africa, a lot of benthological studies have been undertaken in coastal lagoons (Uwadiae et al., 2020), however, not much attention has been given to the salinity-driven patterns in benthic macroinvertebrate communities with a view to examining the environmental management implications for coastal lagoons. Therefore, the aims of this research are to: ascertain the relationship between salinity and benthic macroinvertebrates communities; examine how fluctuations in salinity impact the distribution, abundance, and diversity of benthic macroinvertebrates in the studied coastal lagoons; and identify salinity-driven patterns and trends in benthic macroinvertebrate communities in response to varying salinity levels, in order to determine the best environmental management principles and practices to be adopted for the effective environmental management and conservation of coastal lagoons.

MATERIAL AND METHODS

Study area

Epe Lagoon (Fig. 1) is located between latitudes 30°50'-40°10' N and longitudes 50°30'-50°40' E. Covering an approximate surface area of 243 km² (Kusemiju, 1988) it is positioned between two other lagoons: the Lekki Lagoon (freshwater) to the east and the Lagos Lagoon (brackish water) to the west. Nestled in Nigeria's rainforest region, it undergoes prolonged rainy seasons and dry seasons.

The area's flora predominantly features raphia palms (*Raphia sudanica*) and oil palms (*Elaeis guineensis*), while coconut palms (*Cocos nucifera*) are prevalent in nearby villages. Mats of floating aquatic macrophytes can be found along the edges and occasionally in the central parts of the lagoon. Among these species are water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), *Ipomoea aquatica*, *Salvinia nymphellula*, *Lemna* sp., and *Hydrocharis morsus-ranae* (Uwadiae, 2009).

In the lagoon system housing the study stretch, the lagoon's water leans towards freshwater during the wet season but takes on a higher salinity level during the dry season. The intrusion of seawater remains relatively low, as the influx of freshwater from streams and surface runoff is significantly higher. The observed salinity variation in the lagoon mirrors its unique interposed location with salinity levels within the lagoon ecosystem typically higher during the dry months from January through May (Uwadiae, 2017). In June and July, salinity tends to drop, only to surge again in August and September before declining once more in October and November. The arrival of rainfall in the wet months generally does not lead to a noticeable decrease in salinity until roughly eight to ten weeks later, however, in August, the return of rainy weather after a brief dry spell results in a salinity reduction within just two to four weeks, while the end of rainfall is reflected in a salinity increase after two weeks. It is evident that, once the ground is saturated, rainwater from the drainage basin takes an average of two to four weeks to reach the lagoon. After the dry season, a significant portion of the initial rains is absorbed by the soil and seldom makes it to the lagoons. Only after sufficient rain has fallen to cause appreciable runoff do the rivers start to flow, thereby impacting the salinity of the lagoon. This phenomenon extends the duration in which marine conditions dominate the harbor, with salinity remaining notably high for five months, from mid-December to mid-May, as opposed to a dry season lasting just three months.

Throughout November, December, and January, salinity increases, reaching levels comparable to that of the open sea by February, where it may sustain for a period until mid-April. In certain areas of the lagoon, as the dry season nears its end and the wet season begins, salinity drops swiftly at low tide. Although the daily fluctuation in salinity within the lagoon is minimal, there can be substantial variations in the harbor and its surroundings that may persist throughout the rainy season, except when freshwater inflow is so significant that it prevents the influx of saline or brackish water from the sea during high tide. Expectedly, salinity levels and their fluctuations decrease with increasing distance from the harbor entrance, with lagoon waters typically remaining fresh even 32,000 m away from the ocean.

Besides tidal and freshwater influences, alterations in salinity within the Lagos Lagoon systems have also been associated with effluents occasionally washing over the beach, resulting in saltwater flowing into the lagoon and consequently elevating the salinity during high tide under tumultuous weather conditions. Infiltration of salty water into the lagoon from the sea through beach sand is another probable contributor to the increase in water salinity. Additionally, evaporation from the lagoon's surface has been identified as another significant factor raising water salinity levels. The drainage of rainwater from local storms is recognized as significantly contributing to lower salinity levels in the lagoon throughout all the wet season.

In the harbor, the seasonal salinity trends form a simple cycle dictated by rainfall patterns. The peak salinity values occur in March, at the peak of the dry season, while the lowest salinity is recorded at the end of the wet season, between August and September. The seasonal variations in salinity within the Lagos Lagoon system correlate positively with the volume of water draining into the lagoon from rivers. It has been noted that salinity levels and their variations in the Lagos Lagoon complex decrease progressively with distance from the sea and suggested that the values observed at the harbor are the highest at any moment (Uwadiae, 2017).

Local human activities encompass fishing, sand extraction, and also boat transportation. Eight research stations (Fig. 1) were chosen based on their accessibility for this investigation.

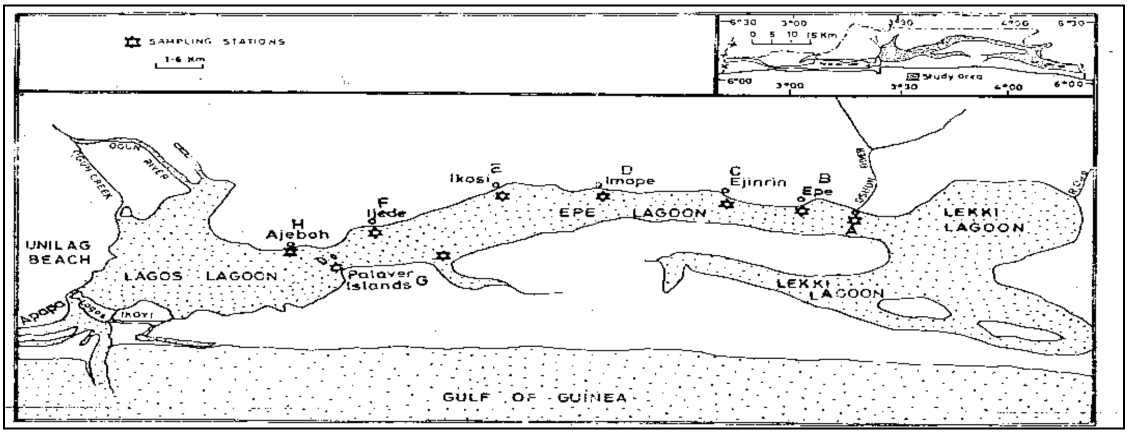

Figure 1: Map showing Lagos,
Epe and Lekki lagoons.

Field investigation

Salinity measurements were performed from each of the eight stations between 09:00 and 15:00 h on each sampling day between September and August during the study periods. Benthic macroinvertebrates samples were collected using van Veen grab of 0.1 m^2. Three successful hauls of the grab were washed through a 0.5 mm mesh sieve, and the retained materials preserved in 10% formalin solution for further laboratory processing.

Laboratory analyses

Benthic samples were washed with tap water to eliminate any preservatives and residual sediment, facilitating easier sorting. The organisms were classified into various taxonomic groups using methods employed by Uwadiae et al. (2020). The number of species and individuals for each station were enumerated and recorded. The biomass of all sorted organisms was determined by wet method as used by Uwadiae (2018). This involves direct weighing of all the sorted animals of each phylum. The organisms were allowed to dry for one minute after puncturing the shells with a fine needle and the mantle cavity water sucked up with filter paper (in the case of molluscs) and all the organisms were drained on a fine sieve until liquid was no longer noticeable. The organisms were then weighed using an electronic scale of 0.001g sensitivity and values approximated to the nearest weight in grams (g) and converted to gm^{-2}.

Data analysis

All statistical evaluations were conducted using the Statistical Package for Social Sciences (SPSS). A One-Way analysis of variance (ANOVA) was used to identify significant differences ($P < 0.05$) among the study stations for salinity. Upon detecting significant variations, a post hoc analysis using Duncan's New Multiple Range Test (DMRT) was performed to determine the locations of significant differences. A simple linear regression model was applied to investigate the relationship between macrofauna metrics (Y) and salinity (X). Margalef's index of taxa richness (d), Shannon-Weiner's index (H) of overall diversity, and Equitability index (E) were utilized to evaluate taxa richness, species diversity, and evenness respectively. Sorenson's index of similarity was computed to assess the overlap of species between each pair of study locations using the formula 2C / (SA + B); where: A = number of species in sample A; B = number of species in sample B; C = number of species common to both samples.

RESULTS AND DISCUSSION

Salinity

The study found significant differences in salinity values, with higher values downstream. The salinity at the upstream stations A to F were similar (DMRT, $P < 0.05$) and significantly lower than those at downstream stations (G and H) which had similar (DMRT, $P < 0.05$) salinity values. Values recorded for salinity in the investigated stations were in the following order; H > G > F > E > D > C > B > A. The study's findings on salinity levels have several implications and raise important questions about the water body's salinity dynamics. The higher salinity levels at downstream stations G and H could be due to the influence of tidal waters from the Lagos Lagoon which introduces saltwater into the water body. Changes in water flow or mixing patterns along the water body's gradient could also contribute to the observed differences in salinity levels (Dubois et al., 2016).

Other important factors responsible for salinity variation in estuaries include precipitation, evaporation, and water flow. The distance between stations has also been reported to impact salinity variation in several ways, this is because, spatial gradients resulting in varied salinity levels can change gradually or abruptly along a spatial gradient (Sánchez-Moyano and García-Asencio, 2010), with distance between stations influencing the magnitude and pattern of these changes. Freshwater input can make stations closer to have lower salinity levels, while those farther away may have higher salinity levels due to mixing with seawater. Also, tidal influences can cause stations closer to the ocean to experience greater tidal fluctuations in salinity, values, while those farther inland may have more stable salinity levels. In the same vein, water circulation may result in distance and difference between stations and can affect water circulation patterns, which in turn influence salinity levels through transport of freshwater or saltwater.

Benthic macroinvertebrates' abundance and diversity

Table 1 shows the summary of benthic macroinvertebrates' metrics at the investigated stations. The total population density of macroinvertebrates at the stations ranged from 87 individuals/m^{-2} (Station C) to a maximum density of 3855 $indm^{-2}$ (station H). The remaining six stations recorded densities > 1,000 ind./m^{-2}. Abundance of benthic macroinvertebrates were mainly controlled by the molluscan population which constituted 98.23% of the total population. Molluscan population was influenced majorly by the gastropod *Pachymelania aurita* which accounted for 44.33% and the bivalve *Macoma cumana* which recorded 28.89%. Patterns in benthic macroinvertebrates' metrics in the lagoon were closely linked with variation in salinity during the study period (Fig. 2). Arthropods constituted 35.6% 27% were Molluscs, 22.2% were Annelids, 4.44% were Nemertina and 2.2% of the population belong to Porifera, Chordate, and Ehinodermata constituted 2.2% each. Molluscs were present in all the study stations, *P. aurita* and *M. cumana* had the widest distribution with representations in all the stations investigated.

The mean number of species per sampling station remained relatively constant in the upstream and downstream stations, but clearly declined in the middle area. The same pattern was shown by the diversity index. Upstream stations recorded majorly freshwater species, while in downstream stations brackish and marine species were observed. Monthly diversity and species richness were significantly different (ANOVA, $P < 0.05$). Similarity (DMRT, $P > 0.05$) existed among the investigated stations except in station three which was significantly lower. Regressions among abundance, species richness, diversity, Margalef's index of species richness and salinity were significant ($P < 0.05$), indicating that salinity of water was a very strong determinant of the pattern in benthic macroinvertebrate characteristics in the lagoon. Distributional analysis also showed a pattern closely linked to variations in salinity levels. The widespread distribution of *P. aurita* and *M. cumana* across all the stations confirms the euryhaline nature of the two subspecies (Uwadiae, 2017). The positive correlations among benthic macroinvertebrate species richness, abundance, and diversity with salinity is also indicative of the cardinal role of salinity in benthic macroinvertebrate community structure.

These findings have implications for understanding the ecological dynamics of the lagoon and the potential impacts of environmental changes on the macroinvertebrate communities. The species composition of the benthic macroinvertebrates was diverse, with 45 species observed across different taxonomic groups. Molluscs were the most dominant group, followed by arthropods, annelids, and other phyla. The results highlight the importance of considering the complex relationships between environmental factors and biological communities in coastal aquatic ecosystems.

Table 1: Summary of the benthic macroinvertebrates' metrics at the study stations in Epe Lagoon (September 2004 – August 2006). Lower case alphabets indicate no significant difference ($P > 0.05$) * DMRT ($P < 0.05$).

	Study Station							
	1	2	3	4	5	6	7	8
Number of samples	72	72	72	72	72	72	72	72
Number of taxa	23	23m	11	12j	18k	12m	32k	18j
Number of individuals	191h	1045h	87h	3312i	3611i	3120i	2489i	3855i
Margalef's Index of species richness (*d*)	4.37d	3.30c	2.46c	1.60d	2.32d	1.37c	4.09	2.18d
Shannon-wiener diversity index (H')	1.06f	0.34f	0.77	0.61g	0.60g	0.62f	0.60	0.66g
Evenness (E)	0.33a	0.10a	0.31	0.24a	0.19a	0.25a	0.20a	0.22a

Change along the estuarine gradient

The values (Fig. 2) of similarity between stations during sampling months as computed using Sorensen index indicate the following ranges; 0 – 1 (1 versus 2), 0 – 0.67 (2 versus 3), 0 – 0.90 (3 versus 4), 0.22 – 0.94 (4 versus 5), 0.40 – 0.92 (5 versus 6), 0.33 – 1.00 (6 versus 7), 0.40 – 1.00 (7 versus 2), 0 –0. 67 (8 versus 1), 0 – 0.86 (8 versus 2) and 0.22 – 1.00 (8 versus 5). It was observed that higher fauna similarity existed between stations close to each other. It was clear that, there was an abrupt change along the study stretch especially towards the oligohaline zone. The similarity pattern observed shows a more or less gradual and continual change in assemblage along the estuarine gradient. The rate of change in the benthic coenocline of the lagoon was mainly determined by differences in salinity.

The greater fauna similarity that existed between stations closer to each other highlights the importance of spatial proximity in shaping benthic community composition. The abrupt change in benthic community composition towards the oligohaline zone suggests a significant shift in environmental conditions, likely driven by changes in salinity. The oligohaline zone, characterized by low salinity levels, appears to support a distinct community of benthic organisms that are adapted to these conditions. The study's findings suggest that spatial proximity plays a crucial role in shaping the composition of benthic communities. The observation that greater fauna similarity exists between stations close to each other implies that benthic communities in nearby areas tend to have similar characteristics especially species compositions. This similarity can be attributed to the shared environmental conditions and ecological processes that occur in these areas (Stevens et al., 2014; Thuiller, 2004).

The findings have implications for understanding the ecological dynamics of benthic communities and the factors that shape their composition. The study suggests that changes in salinity levels can have significant impacts on benthic community composition, potentially leading to shifts in species distributions and abundances. This knowledge can sustain conservation and management efforts aimed at protecting and restoring benthic commuities and the potential impacts of changes in salinity levels on ecosystem function and biodiversity.

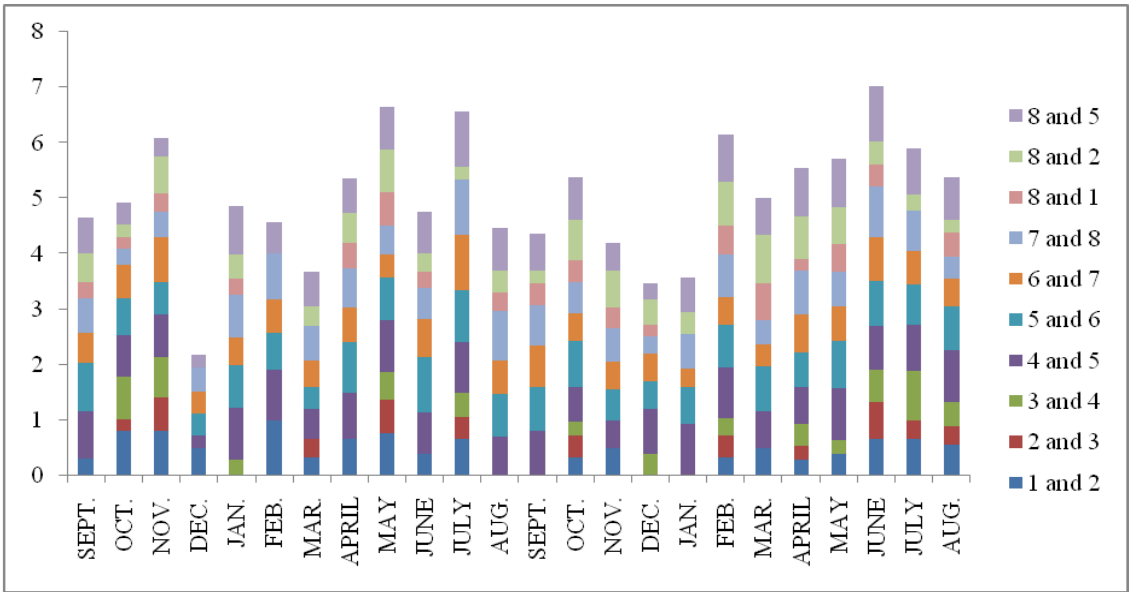

Figure 2: Variation in fauna similarity between study stations during the study period.

Community structure

Analysis of benthic macroinvertebrates' communities structure reveals that the three utmost upstream stations, located in the freshwater (oligohaline) zone, were characterized by a severely impoverished benthic macroinvertebrate communities, with a single taxon (*M. cumana*) being the predominant species. The organisms documented in this area primarily comprised arthropods, including; *Gammarus fasciatus*, *Gomphus vulgatissimus*, *Libellula luctosa*, and *Beatis muticus*. The mid and downstream stations (D, E, F, G, and H) included brackish water species capable of enduring mesohaline conditions. At station G, organisms adapted to low polyhaline environments were also noted.

The total species count per sampling station were markedly greater for the brackish water stations when compared to those of freshwater stations. Mollusc dominance was a key characteristic of the brackish water species community. Notable species in this group included *M. cumana, Aloides trigona, Neritina glabarata, Tellina nymphalis, P. aurita, N. kuramoensis, Tympanotonus fusatus*, and *T. fuscatus* var *radula*. *Pachymelania aurita* constituted a significant portion of the overall population within the brackish water area. With an average density of 15,668 indm^{-2}, it penetrated into the lagoon's freshwater zone, although only a few individuals were recorded here. *Macoma cumana* was another prevalent species that exhibited a wide distribution. Its peak density (13,470 indm^{-2}) was observed at station H, yet it was poorly represented in stations F and H. Within this group, arthropod was represented by crabs species including *Ocypoda cursor, O. africana, Uca tangeri, Penaeus notialis, Clibanarius africana, C. senegalensis, C. chapini*, and *Sersema huzardi*, which were exclusively found in station H.

Several species identified in this study thrived in both freshwater and brackish water categories but were found in minimal quantities, notably *Heteromastus filiformis, Nereis diversicolor, N. succinea, N. lamellosa*, and *Chironomus plumosus*. Certain species such as *Notomastus hemipodus*, *Lumbrinerides cingulata*, and *Lumbrineriopsis paradoxa* were also prevalent in both the freshwater and brackish zones, but were less abundant than the earlier mentioned species. Notably polyhaline species, including *Brachiostoma nigeriense*, *Cucumaria conicospermium*, *Adocia cinerea*, and *Tetilla monodii* were recorded solely at station G.

From the gathered data in this study, it can be inferred that the stations formed clusters closely associated with the lagoon's salinity gradient. Nonetheless, many species were observed in both the freshwater and brackish regions, these distinct groups are likely variations of a singular community type, rather than a remarkable distinction between two entirely separate benthic communities. The species distribution observed in this investigation aligns with established theories on species reactions to salinity gradients. Each estuary possesses distinct physical and ecological characteristics (Warwick et al., 1991). For example, the extent to which a marine species can advance into an estuary is largely influenced by the volume and variability of freshwater inflow compared to the tidal influx of seawater. The oligohaline region, serving as both a physical and biological buffer, typically exhibits the lowest species diversity within estuaries. This is evident in the study area, where only a limited number (12 to 24) of species and individuals (87 to 1045) were observed in oligohaline and mesohaline regions, whereas station G, characterized by higher salinity conditions, recorded 33 species and over 2000 individuals.

Regression analysis

Figs. 3 and 4 depict the patterns shown by regression computation for abundance, species richness, diversity, Margalef's index, and salinity, which were significant ($P < 0.05$), indicating salinity's strong predictive power for macrobenthic invertebrate characteristics. Regression analysis highlights the significant relationships between salinity and various characteristics of macrobenthic invertebrates, including abundance, species richness, and diversity. The regression analysis reveals that salinity is a strong predictor of these characteristics, with significant correlations ($P < 0.05$) observed between salinity and each of these variables. The findings have important implications for understanding the ecological dynamics of estuarine and coastal ecosystems, where salinity levels can fluctuate significantly due to various natural and anthropogenic factors.

The predictive power of salinity for macroinvertebrate characteristics highlights the need to consider salinity as a key factor in conservation efforts aimed at protecting and restoring these ecosystems. The findings suggest that changes in salinity levels, such as those caused by climate change, sea level rise, or freshwater diversions, can have significant impacts on macrobenthic invertebrate communities. Therefore, it is essential to monitor and manage salinity levels in these ecosystems to maintain their ecological integrity and biodiversity.

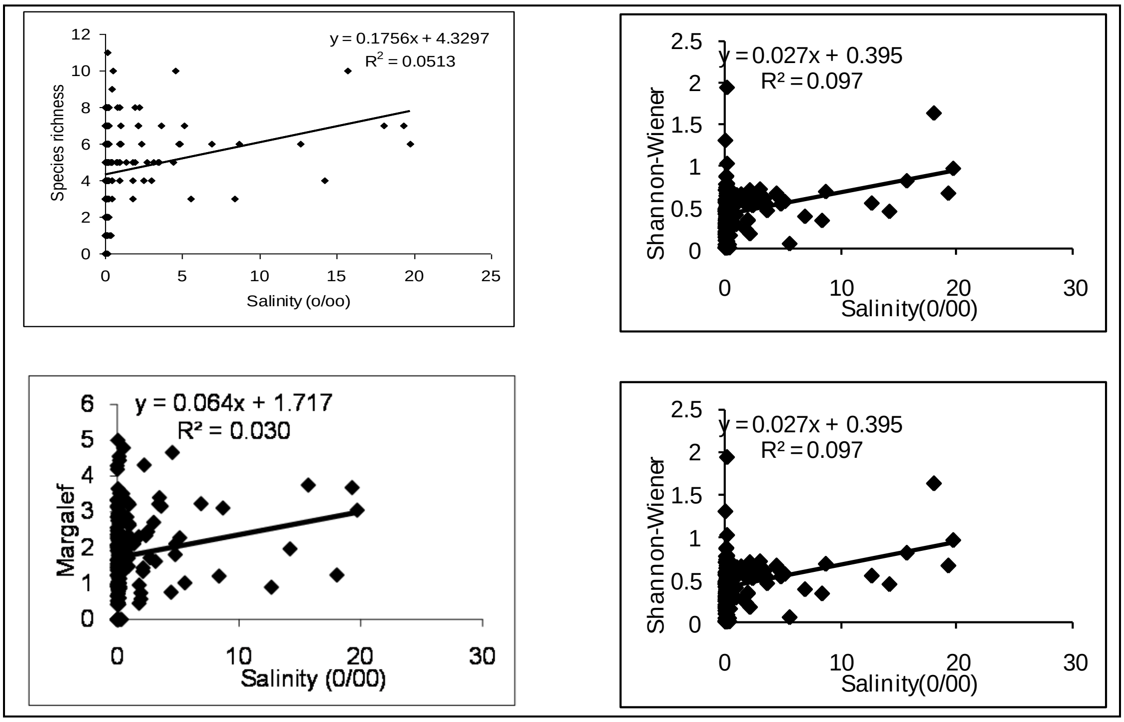

Figure 3. Relationships between macrobenthic invertebrates' metrics and salinity.

Meta-assessment of impact of salinity changes on diversity and stability of benthic macoinvertebrates community

Estuaries and the adjacent coastal areas are marked by significant gradients in chemical, physical, and biological characteristics. In North American estuaries, the oligohaline and freshwater tidal zones are typically characterized by lower species richness, with Oligochaeta and Chironomidae dominating, along with, to a lesser extent, amphipods and molluscs (Buhl-Mortensen et al,. 2010; Odiete, 1999). A decrease in species diversity due to salinity fluctuations is attributed to osmotic stress that organisms encounter in estuarine esosytems (Dubois et al,. 2016). Changes in external salinity often lead to corresponding shifts in the concentration of internal fluids, as organisms adjust through osmotic adjustment to maintain osmotic balance. These alterations are frequently associated with changes in the levels of ions in internal fluids. For many species, deviations from normal concentrations and compositions of internal substances can lead to metabolic disruptions and eventual mortality. This limitation imposed by the extensive salinity variations in estuarine environments significantly contributes to their low biodiversity (Fig. 5). Only those species capable of withstanding substantial salinity fluctuations can flourish in estuaries.

This study found the presence of *P. aurita* and *M. cumana* across all study stations but reported sparse populations at stations A to C. These species have been recognized as genuinely euryhaline organisms (Egonmwan, 2007), potentially explaining their widespread occurrence in the research area. Numerous benthic organisms depend on stable salinity conditions for their survival and reproduction. Terebelid polychaetes and sipunculids were shown to be negatively impacted by salinity changes (Ferraris et al., 1994). The growth and development of the marine polychaete *Arenicola cristata* and the gastropod *Ilyanassa obsolata* were adversely affected by periodic drops in ambient salinity (Richmond and Woodin, 1999). Populations of the soft clam *Mulinia lateralis* decreased, and the amphipod *Ampelisca abdita* vacated the area following a three-week exposure to freshwater discharges that reduced salinities in St. Lucie Estuary from 18-30 ppt to 0.5-5.0 ppt (Haunert and Startzman, 1985)

The species distribution observed in this investigation aligns with established theories on species reactions to salinity gradients (Uwadiae, 2017). Each estuary possesses distinct physical and ecological characteristics (Jennerjahn and Mitchell, 2013; Gaudêncio and Cabral, 2007). For example, the extent to which a marine species can advance into an estuary is largely influenced by the volume and variability of freshwater inflow compared to the tidal influx of seawater. The oligohaline region, serving as both a physical and biological buffer, typically exhibits the lowest species diversity within estuaries. This is evident in the study area, where only a limited number (12 to 24) of species and individuals (87 to 1,045) were observed in oligohaline and mesohaline regions, whereas station G, characterized by higher salinity conditions, recorded 33 species and over 2,000 individuals.

Implications of findings for environmental management

The study highlights the importance of considering the unique characteristics of different salinity zones in estuaries when developing environmental management strategies in coastal aquatic ecosystems. The oligohaline region, with its limited species diversity, requires special attention and management to protect the specific species that inhabit this zone. The findings suggest that management efforts should focus on the followings.

Protecting habitat diversity – preserving the unique habitats found in oligohaline and mesohaline regions is crucial for maintaining the species that depend on these areas.

Managing the peculiar salinity gradient – alterations to salinity levels, such as those caused by freshwater diversions or climate change, can have significant impacts on species diversity and abundance in estuarine regions.

Conservation of species – efforts should be made to conserve species that are specifically adapted to the oligohaline and mesohaline regions, as these species may be more vulnerable to changes in their environment.

Monitoring and assessment – Regular monitoring and assessment of these regions are necessary to understand the impacts of environmental changes which may determine the relevant management decisions.

By taking a targeted approach to managing these unique ecosystems, environmental managers can help protect the biodiversity and ecological integrity of estuaries. In addition, the findings have significant implications for environmental management in coastal ecosystems, particularly in understanding.

Salinity-driven community change – the rate of change in the benthic coenocline is mainly determined by differences in salinity, emphasizing the critical role of salinity in shaping community composition (Pinto et al, 2009).

Spatial heterogeneity – The gradual and continual change in assemblage along the estuarine gradient highlights the importance of spatial heterogeneity in coastal ecosystems.

The need for targeted management – Understanding the relationship between salinity and benthic community composition can inform targeted management strategies to conserve and protect specific ecosystems or species.

Ecosystem-based management – adopting an ecosystem-based approach to management can help balance human activities with environmental protection and conservation goals (Wildsmith et al., 2011; Nunes et al., 2008).

Environmental stressors – the impoverished studied benthic macroinvertebrates population may indicate the presence of environmental stressors, such as pollution, habitat degradation, or altered hydrological regimes, which can impact the ecosystem's health and function.

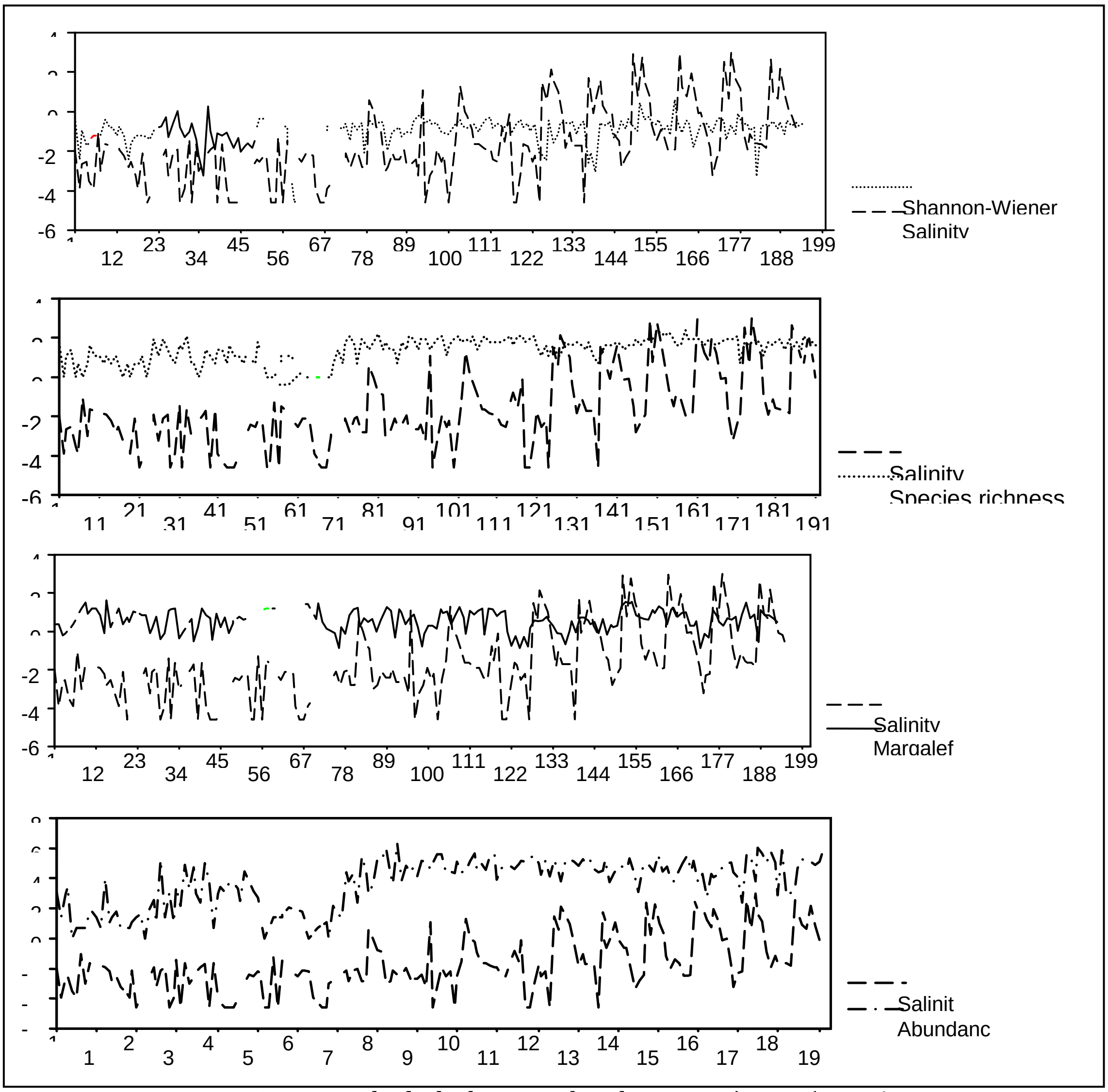

Figure 4: The links between benthic macroinvertebrates' metrics and salinity.

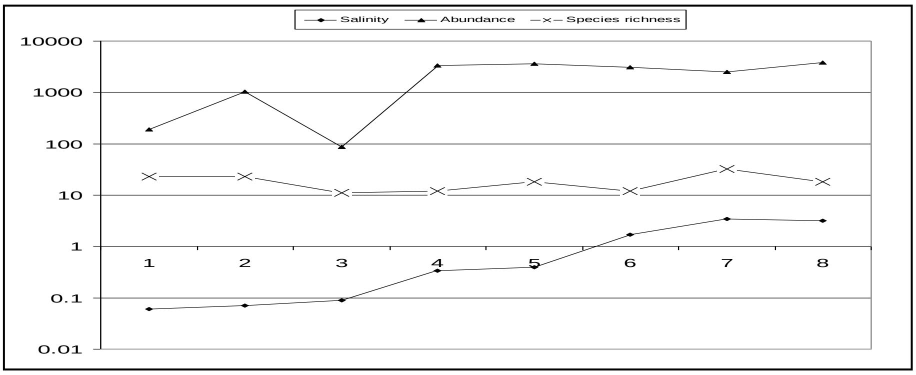

Figure 5: Variations in mean species richness, abundance and salinity in the study stations.

CONCLUSIONS

Regular monitoring of salinity levels and other water quality parameters would be essential to understand the dynamics of the water body and necessary informed management decisions. Additional research would be necessary to determine the underlying causes of the observed salinity patterns and to identify potential mitigation strategies to address any negative impacts on the aquatic ecosystem or water quality. Further research could investigate the specific mechanisms by which salinity influences the distribution and abundance of benthic macroinvertebrates in the lagoon, as well as the potential impacts of changes in salinity levels on the ecosystem's health and biodiversity.

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