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Research Article

Distribution of Mangrove Species Diversity Along Environmental Variables Using Canonical Correspondence Analysis in Brgy. Penaplata, Samal City, Philippines

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Abstract

The main objective of this study is to assess the mangrove biodiversity in response to environmental changes, specifically its relationship between environmental variables and mangrove species biodiversity by evaluating the indicators in terms of abundance, richness, and evenness, alongside an analysis using Canonical Correspondence Analysis. Mangrove forest plays a significant role that caters to potential services like reductions of atmospheric carbon and has been the center for conservation due to its high importance to marine ecology. Based on the findings of the study, it was revealed that the area located in Brgy. Pe ñaplata, Samal City, Philippines, seven mangrove species were identified, classified into four families: *Avicennia alba*, *Avicennia marina*, and *Avicennia rumphiana* in the Avicenniaceae family; *Rhizophora apiculata*, *Rhizophora mucronata*, and *Rhizophora stylosa* in the Rhizophoraceae family; and *Sonneratia alba* in the Lythraceae family. *Rhizophora mucronata* emerged as the most abundant species, comprising 35.5% of total individuals. Moreover, the area determined to have low diversity due to the dominance of *Rhizophora mucronate* and *Avicennia alba*, leading to an unbalanced ecosystem, except in plot 3, which showed a more balanced and diverse mangrove ecosystem. Overall, significant correlations with the use of CCA were found, highlighting the positive influence of pH, temperature, TDS, and conductivity on mangrove species patterns and distribution. The findings of this study could support shape strategies for conserving and safeguarding mangrove ecosystems in Samal City, and maybe throughout the Philippines.

Keywords

Mangrove Species Diversity, Environmental Variables, Canonical Correspondence Analysis, Brgy. Penaplata, Samal City, Philippines

1. Introduction

Blue-carbon habitats, like mangroves, play an important role in providing active ecological services including carbon sequestration and coastal protection. Because of its relevance in carbon reduction, the potential of mangrove ecosystems as one of nature's solutions to climate change has become the primary priority for biodiversity conservation and protection.

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However, mangrove ecosystems confront significant environmental risks such as pollution and habitat loss, as noted in the study by Akram et al. [2], emphasizing the urgency of monitoring and management. Aside from the risks indicated, environmental conditions have been shown to influence mangrove vegetation (Peters et al., [11]) and structure (Rodda et al., [13]), limiting the growth toward exponential distribution and diversity of mangroves.

In connection, mangrove forest is the most widespread land cover in Malaysia, notably in Sabah, and has been classified as a mangrove forest reserve class V; yet, 9.8% of the total area is threatened by deforestation (Wah et al., [19]), and one of the main threats of mangrove forest degradation is due to the increase of population and rapid industrialization (Sharma et al., [15]). Knowingly, the ecological importance of mangroves to marine life has been vital, especially to spawning and nursery grounds for different marine organisms. The significant factors influenced by mangrove forests are not only as habitats for diverse marine species but also as support for coastal erosion (Pennings et al., [10]) and storm damage (Temmerman et al., [18]).

Meanwhile in the Philippines, which has been continually noted as one of the top biodiversity hot spots of the world. The mangrove forest is currently experiencing diversity loss (Suman, [17]), a national struggle from active construction of infrastructure towards the needs of the increasing population. As part of the management strategy for the conservation and protection of the mangroves, several studies have shown the importance of monitoring the environmental parameters that reciprocate the abundance and richness of mangroves and provide sufficient expansion in terms of distribution to specific species of mangroves. For example, Sreelekshmi et al. [16] found that pH and salinity were essential components in the proliferation and growth of mangroves, while Saifullah et al. [14] confirmed that even specific species of mangrove diversity has a relative effect on temperature and conductivity. These become a concern considering the exponential increase of temperature and fluctuation of climate conditions due to global warming.

Samal City, located in the southern portion of the Philippines, is home to an extensive variety of mangrove species that contribute significantly to the region's ecological resilience and socioeconomic prosperity. Understanding the distribution of mangrove species in Samal City is essential for effective management and protection, considering that only a few extensive studies have been recognized in the city. Furthermore, understanding the biological processes that drive these systems requires knowledge of the environmental conditions that influence mangrove species distribution. Accordingly, Canonical correspondence analysis (CCA) is a multivariate statistical approach commonly employed in ecological studies to identify correlations between species distributions and environmental factors (Nguyen et al., [8]). CCA incorporates both biotic and abiotic elements, disentangling the fundamental environmental gradients that influence species assemblages and giving insights into ecosystem dynamics and function.

This research aims to assess the distribution patterns of mangrove species along environmental assemblages in Samal City, Philippines, using Canonical Correspondence Analysis. Moreover, this study provides and gives upshot linkage to the existing gaps in knowledge on mangrove ecology and formulates an evidence-based management strategy that will be tailored to Samal City's unique environmental situation. Specifically, it seeks to achieve the following objectives: assess the mangrove biodiversity indices in terms of abundance, richness, and evenness, and determine the relationship between environmental gradients and mangrove species distribution using canonical correspondence analysis (CCA). The results of the findings will be additional knowledge of what factors can drive the distribution of specific mangrove species and profound the idea of relevant stressors that may affect the stability of mangrove ecosystems. Importantly, it provides comprehensive information that may be used to develop policies for the conservation and protection of mangrove ecosystems in Samal City and possibly the Philippines as a whole.

2. Materials and Methods

This study used quantitative research design to identify and establish the taxonomic profiles and distribution of mangrove species in Island Garden City of Samal, Davao del Norte. The intricacy of this method enables identification of prevalent and underlying environmental trends and patterns in the area and how they are relational to the dispersal of mangrove species. Additionally, a descriptive research design was employed to paint a comprehensive and accurate picture of the data collected. The classified mangrove species were analyzed according to their taxonomic profiles, indices, and physico-chemical parameters, warranting the use of the aforementioned research design. It served as an effective initial step before delving into more quantitative aspects of the subject.

2.1. Research Locale

Figure 1 illustrates the locale of the study, Garden City of Samal in the province of Davao del Norte. It is bounded on all sides by Davao Gulf, on the west by the municipal waters of Davao City, at north by the municipal waters of mainland Province of Davao del Norte, on the east by the municipal waters of the provinces of mainland Davao de Oro and Davao Oriental.

Figure 1. *Locale of the Study.*

2.2. Data Collection

This study used stratified sampling technique for identification and classification of mangrove species, this technique ensures variation leading to a more accurate assessment in biodiversity, considering mangrove ecosystem has natural heterogeneity and zonation patters. Sites were selected based on accessibility, diversity of mangrove species, and environmental variability. Group of mangroves in the area were investigated and the researchers identified 3 sites. Three 10 m by 10 m quadrats in 1 transect line per site were set in place as recommended by English et al. [4]. This presents an efficient and convenient evaluation of the species present.

The environmental variables collected span from conductivity, total dissolved solids, temperature, salinity and pH levels. A tiny water sample was placed within the glass prism to measure each variable. A refractometer was used to measure the salinity of the water in the study area. Assessing the level of salinity monitors the stress level of mangroves and helps to understand how mangrove ecosystems respond to changes in water flow, tides, and freshwater influx. A pH meter was used to determine the water's pH level; this measures the changes that can affect the microbial community, impacting the food web in mangrove ecosystems. The temperature of the water was also measured using a digital thermometer; assessing temperature influences the metabolic rates of mangrove growth and development. Total dissolved solids (TDS) and conductivity were also measured using a water quality multimeter. In measuring TDS, it helps to understand the balance of absorption of water and nutrients in mangrove; more so, conductivity directly helps to assess the changes in water salt concentration that would affect the species composition and biodiversity. The mangrove species were documented using a camera, and their identification was done using the field guide booklet authored by Primavera et al. [12] of the Southeast Asian Fisheries Development Center. The study also utilized the "Principles of Taxonomy and Classification Current Procedures for Naming and Classifying Organisms" by Ohl [9] as a guide to correctly identify present species.

Upon completion of the mangrove identification in the area, a few analytical tools were utilized to aid in uncovering meaningful patterns in the data. Each type of species was tallied individually, counting them one by one, as such the Shannon diversity index is a suitable metric to describe species diversity within a community. This index takes into account the abundance, richness, and evenness of species present.

2.3. Data Analysis

Mangrove species diversity was assessed using the Shannon Index of Diversity (H) and the Simpson Index of Diversity. Species were counted for each kind separately. The Shannon Index (H) is a regularly used statistic for describing species diversity within a community, taking into account species abundance, richness, and evenness. In contrast, the Simpson Index is characterized as a dominance index since it favors the common or dominating species.

Moreover, the study used multivariate environmental variables, Canonical Correspondence Analysis. This analytic tool generates an ordination diagram wherein species and sites are depicted as points, while environmental variables are represented by vectors. This diagram illustrates the variations in community composition that are primarily influenced by environmental factors and also provides a representation of species distributions along each environmental variable.

3. Results and Discussion

Table 1 shows the seven (7) mangrove species found in the study area and three families were classified, namely, Avicennia alba, Avicennia marina, and Avicennia rumphiana belong to the Family of Avicenniaceae. Rhizophora apiculata, Rhizophora mucronata, and Rhizophora stylosa belong to the Plantae kingdom under the Rhizophoraceae family and Sonneratia alba belong to Family Lythraceae. All mentioned and classified mangrove species were confirmed valid and accurate by a local scientist and evaluated through the Field Guide to Philippines Mangroves by Dr. J. H Primavera and other related literatures.

Table 1. *Taxonomical classification of mangrove species.*

Common Name	**Taxonomical Classification**						
	Kingdom	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**Species**
	Plantae	*Tracheophyta*	*Magnoliopsida*	*Lamiales*	*Avicenniaceae*	*Avicennia*	*alba*
Miapi	*Plantae*	*Tracheophyta*	*Magnoliopsida*	*Lamiales*	*Avicenniaceae*	*Avicennia*	*marina*
Piapi	*Plantae*	*Tracheophyta*	*Magnoliopsida*	*Lamiales*	*Avicenniaceae*	*Avicennia*	*rumphiana*
Bakuan-Babae	*Plantae*	*Tracheophyta*	*Magnoliopsida*	*Rhizophorales*	*Rhizophoraceae*	*Rhizophora*	*apiculata*
Bakuan-Babae	*Plantae*	*Tracheophyta*	*Magnoliopsida*	*Rhizophorales*	*Rhizophoraceae*	*Rhizophora*	*mucronata*
	Plantae	*Tracheophyta*	*Magnoliopsida*	*Rhizophorales*	*Rhizophoraceae*	*Rhizophora*	*stylosa*
Pagatpat	*Plantae*	*Tracheophyta*	*Magnoliopsida*	*Myrtales*	*Lythraceae*	*Sonneratia*	*alba*

3.1. Species Composition and Abundance

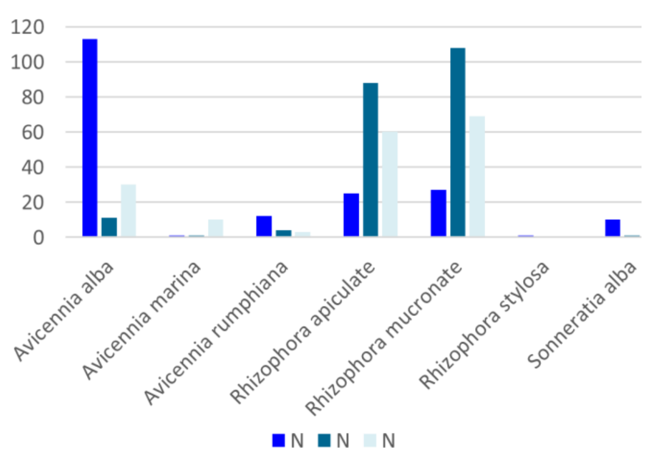

Figure 2. *Mangrove species total number per study sites.*

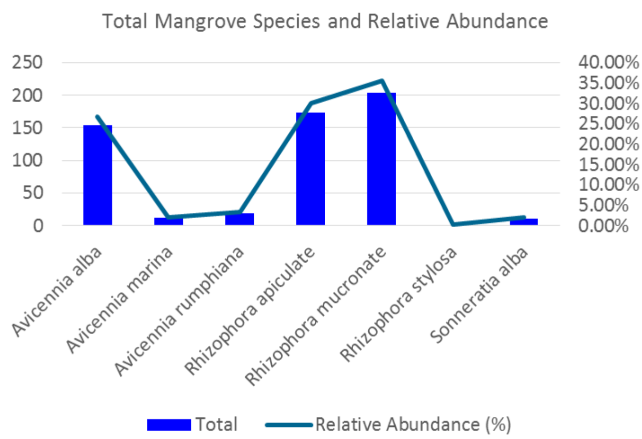

Figure 3. *Mangrove species and their relative abundance.*

Figure 2 shows the mangrove species and relative abundance on the study area. Out of the seven species classified, *Avicennia alba* got the highest number of individuals in sampling plot 1 with the total number of 113 but *Rhizophora mucronate* got the highest total number of individuals collected in the study area with the total number of 204, followed by *Rhizophora apiculata* with 173, *Avicennia alba*, *Avicennia rumphiana*, *Avicennia marina*, *Sonneratia alba*, and *Rhizophora stylosa* with the total number of 154, 19, 12, 11, and 1, respectively.

Figure 3 illustrates the mangrove species and their relative abundance of the study. From the mentioned total individuals in the study area collected in figure 2, *Rhizophora mucronata* got the highest relative abundance with the percentage of 35.5%, followed by *Rhizophora apiculata* with relative abundance of 30.1%, the *Avicennia alba* with relative abundance of 26.8%, *Avicennia rumphiana*, *Avicennia marina*, *Sonneratia alba*, *Rhizophora stylosa* with the relative abundance of 3.3%, 2.1%, 2.0%, 0.2%, respectively.

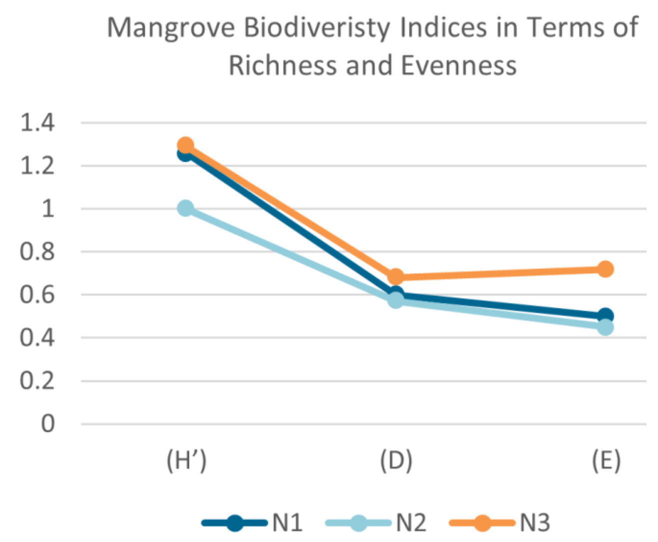

Figure 4. *Mangrove species biodiversity indices in terms of richness and evenness.*

Legends*
N1- sampling plot 1: H'- Shannon-Weiner's Diversity Index
N2- sampling plot 2: D – Simpson's Diversity Index
N3- sampling plot 3: E – Evenness Index

Figure 4 represents the mangrove species' biodiversity indices in terms of richness and evenness in the study area. In sampling plot 1 were seven (7) species identified with 189 having 1.26 shannon-weiner's diversity index which implies a very low diversity according to the classification scheme by Fernando et al. [5]. And 0.60 in simpson's diversity index that implies a moderate degree of diversity or heterogeneity, then has 0.50 evenness index that describes unbalance distribution based on the ranging ranges and values for evenness by Hussain et al. [7]. This is also visible in sampling plot 2 where 213 identified mangrove species still have the 1.0 shannon-weiner diversity index with 0.57 simpson's diversity index which means a moderate degree of diversity or heterogeneity with 0.45 evenness index that describes less even distribution of species. Overall, the diversity score is very low due to the unequal distribution of mangrove species. This shows that certain species dominate the region which is *Avicennia alba* in sampling plot 1 and *Rhizophora mucronate* in sampling plot 2, resulting in higher richness than others and unbalanced ecosystem.

Moreover, in sampling plot 3 with 172 total mangrove species identified has Shannon-weiner's diversity index of 1.29 which means a very low relative value, as to the simpson's diversity index with 0.68, a moderately high degree of diversity or heterogeneity and has 0.72 evenness index which implies a moderate distribution among species. In totality, compared to the other sampling plots mentioned, sampling plot 3 describes to have moderate distribution of species which it has a semi-balanced ecosystem and have high degree of diversity based on the guidelines for interpreting simpson's diversity index scores by Guajardo [6].

3.2. Environmental Variables to Relative Abundance of Mangrove Species Using Canonical Correspondence Analysis

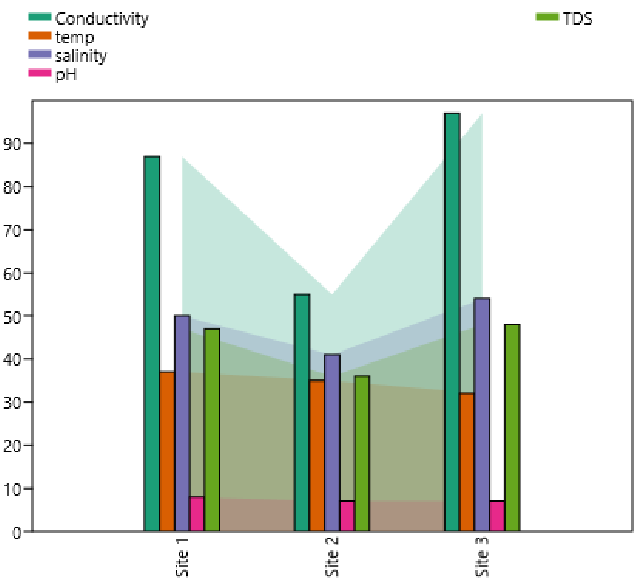

Figure 5. *Environmental variables in each study sites.*

Figure 5 represents the environmental variables from each study site. Site 1 had a cumulated value of conductivity with 87.32 µs/cm, temperature measured to have 37.03˚C, salinity value is 49.89 ppm, pH value is 7.64, and a total dissolved solids (TDS) value is 47.24 mg/l. With regards to the site 2 conductivity, temperature, salinity, pH, and TDS cumulated values of 54.83 µs/cm, 34.86 ˚C, 41.01 ppm, and 36.06 mg/l, respectively. And site 3 of the study gathered 96.52 µs/cm conductivity, 32.13 ˚C in temperature, 53.94 ppm in salinity with 7.33 pH level and with 48.17 mg/l total dissolve solids value. Overall, site 3 had the highest levels of conductivity and salinity, which explains why it is described as having a moderate mangrove species distribution, as indicated in figure 3. According to Ahmed et al. [1], some specific mangrove species with high salt tolerance can provide a significant increase of richness relativity to other mangrove species in the same area, but Chowdhury et al. [3] mentioned, that having too much salinity in the water column can develop a fundamental mechanism for mangrove deterioration. This means that, fluctuation of salinity level in mangrove forest determines the potential abundance of species in the ecosystem, more so, monitoring in mangrove ecosystems must be applied as an essential practice to sustain the variation of species and increase the reproduction rate of specific species of mangrove with sufficient environmental conditions.

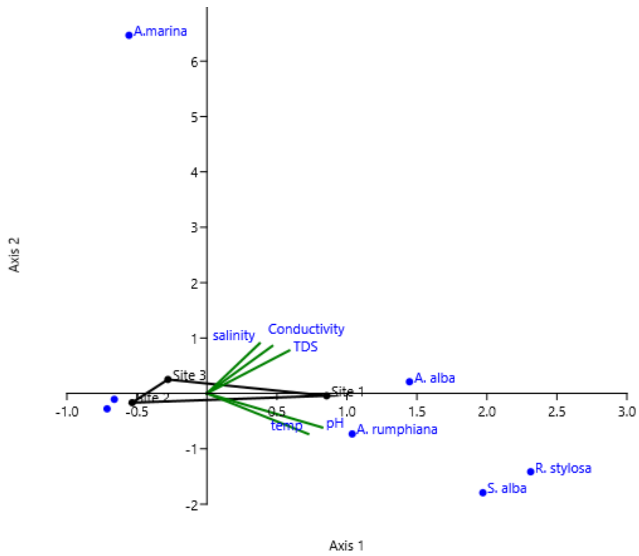

Figure 6. *Environmental variables to mangrove species using CCA.*

Figure 6 shows the relationship between environmental variables to mangrove species using canonical correspondence analysis. The first quadrant of the CCA biplot includes *A. alba* under the influence of higher levels of total dissolved solids (TDS), conductivity, and salinity as environmental factors. Then, as observed, TDS has more impact on the *A. alba* as revealed by the longer arrow compared to the other environmental assemblages such as conductivity and salinity. In the fourth quadrant, *A. rumphiana*, *S. alba*, and *R. stylosa* under the influence of pH and temperature, which then revealed pH has more factor on the *A. rumphiana* and *R. stylosa*. Moreover, in the second and third quadrants, it presents low influence of environmental factors; salinity, conductivity, and TDS to some mangrove species such as *A. marina, R. apiculate, and R. mucronate.*

CCA yields ordination plots as a product of environmental and species data variability. In the present study, environmental variables were correlated with the mangrove species using CCA, which showed a significant correlation ($p < 0.006$). Samples and quadrants were associated with ecological gradients, which indicated a significant effect on sample distribution in the respective quadrants.

Among the environmental variables with the strongest influence on the mangrove species were pH, temperature, and TDS in sampling plot 1, and conductivity also significantly affected the mangrove species.\

4. Conclusions

Based on the analysis of the data gathered, the following findings were summarized; there were seven species of mangroves found in the area namely; *Avicennia alba*, *Avicennia marina, Avicennia rumphiana, Rhizophora apiculate*, *Rhizophora mucronate*, *Rhizophora stylosa*, and *Sonneratia alba.*

The study examined the species composition and abundance of mangroves in the area, revealing significant findings. *Avicennia alba* was most prominent in sampling plot 1 with 113 individuals, but *Rhizophora mucronata* had the highest overall count in the study area, totaling 204 individuals. *Rhizophora apiculata* followed with 173 individuals, while *Avicennia alba*, when aggregated across all plots, totaled 154. Other species included *Avicennia rumphiana* (19 individuals), *Avicennia marina* (12), *Sonneratia alba* (11), and *Rhizophora stylosa* with just 1 individual. In terms of relative abundance, *Rhizophora mucronata* led with 35.5%, followed by *Rhizophora apiculata* at 30.1% and *Avicennia alba* at 26.8%. Lesser abundances were noted for *Avicennia rumphiana (3.3%), Avicennia marina (2.1%), Sonneratia alba (2.0%), and Rhizophora stylosa (0.2%)*. These findings underscore the dominance of *Rhizophora mucronata* and *Rhizophora apiculata* in the local mangrove ecosystem.

Moreover, the biodiversity of mangrove species across three sampling plots, showed notable differences in species distribution and diversity. Sampling Plot 1 identified 7 species with a total of 189 individuals, dominated by *Avicennia alba*. This plot had low diversity (Shannon-Weiner Index of 1.26) and moderate heterogeneity (Simpson's Index of 0.60), with an uneven distribution (Evenness Index of 0.50). Sampling Plot 2 recorded 213 individuals, predominantly *Rhizophora mucronata*, showing low diversity (Shannon-Weiner Index of 1.0) and moderate heterogeneity (Simpson's Index of 0.57), with a less even distribution (Evenness Index of 0.45). Sampling Plot 3, with 172 individuals, had relatively better diversity (Shannon-Weiner Index of 1.29) and higher heterogeneity (Simpson's Index of 0.68), and a more balanced distribution (Evenness Index of 0.72). Overall, the area had low biodiversity due to the dominance of specific species, leading to an unbalanced ecosystem, except in Plot 3, which showed a more balanced and diverse ecosystem.

Also, the study examined how environmental factors like conductivity, temperature, salinity, pH, and total dissolved solids (TDS) affect mangrove species distribution across three sites. Site 1 showed moderate values across all factors, while Site 2 had lower levels. Site 3 had the highest conductivity and salinity, which corresponded to a moderate mangrove distribution. High salinity and conductivity in Site 3 were linked to species richness but also indicated potential risks for mangrove health if levels become too excessive. CCA revealed that *Avicennia alba* was most affected by high TDS, conductivity, and salinity. Meanwhile, *Avicennia rumphiana*, *Sonneratia alba*, and *Rhizophora stylosa* were more influenced by pH and temperature. *Avicennia marina*, *Rhizophora apiculata*, and *Rhizophora mucronata* were less influenced by these factors. Overall, significant correlations were found between these environmental variables and mangrove species distribution, highlighting the importance of pH, temperature, TDS, and conductivity in determining species patterns.

5. Recommendation

Based on the study's findings on environmental influences on mangrove species distribution, the following recommendations are key: prioritize monitoring of salinity levels to balance species richness and ecosystem health, integrate pH and temperature into management strategies for comprehensive environmental stewardship, focus conservation efforts on areas with optimal conditions for mangrove diversity, and invest in further research to enhance understanding and resilience planning in mangrove ecosystems, especially amidst climate change challenges.

Abbreviations

CCA	Canonical Correspondence Analysis
TDS	Total Dissolved Solids

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Author Contributions

Anthony Amores: Conceptualization, Resource, Formal Analysis, Investigation, Writing – original draft, Writing – review and editing

Errole Maxey: Data curation, Validation

Sophia Nadenn Aguilar: Methodology, Visualization

Joseph Pentason: Project administration, Resources, Supervision, Software

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Anthony Estandarte Amores is a Filipino educator and researcher currently residing in Mati City, Davao Oriental. He is pursuing a Ph. D. in Environmental Science with a minor in Zoology at the University of the Philippines Los Baños, Laguna, and holds a Master of Arts in Education. He holds the position of Research, Innovation, and Extension Coordinator at Davao Oriental State University. His research focuses on environmental issues, including species diversity in seagrass, mangrove, and bivalves, and toxicology aquaculture. He has presented his research at various international and national conferences and is deeply interested in ecosystem structure, environmental policy, and environmental impact assessment.

Sophia Nadenn Arma Aguilar is a Filipino educator and researcher currently residing in Mati City, Davao Oriental. She holds a Master of Science Education majoring in General Science from Mindanao State University – Iligan Institute of Technology, where she also earned her undergraduate degree in Secondary Education with honors (Cum Laude). Her academic and research pursuits focus on environmental and ecological studies, with her current projects including research on species diversity and spatial structure of intertidal seagrass, and the development of educational materials on fungi species in Davao Oriental. She has also served as a resource speaker on various educational topics and presented her research at national and international conferences.

Errole Augusto Maxey is a Filipino educator and researcher. He currently resides in Dahican, Mati City, Davao Oriental. He is pursuing a Master of Science in Environmental Science, majoring in Natural Resource Management at Davao Oriental State University, where he also completed his undergraduate degree in Physical Sciences. Since July 2023, he has been an instructor at Davao Oriental State University, with previous experience as a senior lecturer in the Faculty of Teacher Education. His academic roles include serving as a thesis panelist and adviser for students in environmental and physical sciences. He has been involved in research projects focused on fungi species identification, biodiversity assessment, and the evaluation of sediment and water quality in Davao Oriental.

Joseph Revamonte Pentason is a professional teacher and pursuing a Ph. D. in Environmental Science with a minor in Zoology at the University of the Philippines Los Baños, Laguna. Currently, he is a science faculty of Arcadia High School, USA in Virginia and a member of NASA Space Regional Project – Plant to the Moon. His research focused on toxicology and biodiversity, presently, he is conducting human urine-based fertilizer and polychromatic light source on growth and morphometric responses of peas (*Pisum sativum*) under lunar regolith condition. He was awarded as the champion coach in regional science fair awards for the Eastern Shore of Virginia.

Research Field

Anthony Estandarte Amores: Ecosystem Structure and Dynamics, Systems Analysis, Quantitative Methods in Natural Resources Management, Contemporary Issues in Environment and Development, Environmental and Natural Resource Policy Formulation, Economic Valuation of Environmental Resource System, Population Dynamics, Landscape Ecology, Animal Toxicology, Advance Invertebrate Biology, Community Ecology of Animals

Errole Augusto Maxey: Natural Resource Management, Biodiversity Assessment, Marine Ecosystem Community Structure, Water and Sediment Analysis, Economic Valuation of Natural Resource System

Sophia Nadenn Arma Aguilar: Spatial Analysis, Biodiversity Assessment, Educational Material Development

Joseph Revamonte Pentason: Quantitative Methods in Natural Resources Management, Environmental and Natural Resource Policy Formulation, Economic Valuation of Environmental Resource System, Population Dynamics, Landscape Ecology, Animal Toxicology, Advance Invertebrate Biology, Community Ecology of Animals