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Diversity and morphometry of mangrove species and it's relation to environmental factors in Tagum City, Davao del Norte, Philippines

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Abstract. *Punong A, Pentason J, Amores A. 2025. Diversity and morphometry of mangrove species and it's relation to environmental factors in Tagum City, Davao del Norte, Philippines. Intl J Bonorowo Wetlands 15: 20-27.* Mangroves are a vital component of sustainable marine ecosystems, providing numerous ecosystem services that promote coastal protection, biodiversity conservation, carbon sequestration, and water quality improvement. This study focuses on the mangrove species found in Sitio Cabugan, Barangay Busaon, Tagum City, Davao del Norte, Philippines. Result shows that there were seven species in the studied area namely, *Avicennia marina, Nypa fruticans, Bruguiera gymnorhiza, Rhizophora mucronata, Rhizophora apiculata, Sonneratia alba,* and *Avicennia rumphiana*. *Avicennia marina* had the highest population, with a total of 567, a relative abundance of 70.79% and a cumulative distribution of 74.51, while *A. rumphiana* had the lowest number with only two individuals and a relative abundance of 0.25% with a cumulative distribution of 74.77. Moreover, it revealed poor species diversity and uneven distribution across the sampling stations. Environmental factors such as water temperature, salinity, and pH were within the normal range for growth and development, with station-specific variations influencing species distribution. Trunk size plays a significant role in structuring site-species interactions, indicating favorable environmental conditions to particular species. *Sonneratia alba*, *R. mucronata*, and *A. marina* showed a preference for stable environments, while *B. gymnorhiza* and *N. fruticans* demonstrate adaptability to contrasting conditions. This research underscores the need for conservation strategies and ongoing monitoring to ensure mangrove ecosystem stability and biodiversity preservation.

Keywords: Community structure, mangrove species vegetation, morphometry, sustainable marine ecosystem, Tagum City

Abbreviations: IUCN: International Union for Conservation of Nature, PCA: Principal Component Analysis

INTRODUCTION

Mangrove forests are located in coastal areas of tropical and subtropical regions, and considered as one of the most biologically important ecosystems with diverse flora. They contribute to energy flow between land and sea and provide vital ecosystem services like coastal protection, biodiversity habitat, food production and recreation (Nehru and Balasubramanian 2018). Globally, there is a total of 54 true mangrove species and 60 species of mangrove associates. At the species level, mangrove plays a unique function in the ecosystem. For example, the study conducted by Govindhan (2024) reveal the critical role of mangroves like *Avicennia marina* (Forssk.) Vierh. in environmental stability and pollution mitigations as it has specific responses to pollutants, including trace metal. Previous studies in Pichavaram coastal areas highlighted *A. marina's* antioxidant capacity amidst heavy metal contamination and identified bioactive compounds with promising therapeutic potential.

Despite their importance, global population of mangroves has been experiencing a worrisome decline primarily because of human activities. These actions present a significant peril to the mangrove ecosystem and the rich variety of life within these areas. As a response, considerable efforts have been undertaken to restore large areas of mangrove forests, primarily for the purposes of obtaining timber and safeguarding coastal regions (Rovai et al. 2018). Many studies have revealed that adverse environmental conditions led to a decline in the population of mangrove species. Noor et al. (2015) conducted research in Pakistan that investigated the impact of various environmental factors on two mangrove species. The study revealed that factors such as temperature fluctuations, salt stress, and water and oxygen stress caused by siltation negatively affected the survival of mangroves in the Pakistan mangrove forest. The same study conducted by Ghanbarzad Dashti et al. (2021) on the impact of salinity and temperature stress on survival and responses of mangrove and it results negatively and correlatedly affect the mangrove productivity and diversity. The study of Chen et al. (2017) in China investigated extreme water temperature in mangrove response. The findings revealed significant differences in how mangroves respond to extreme temperatures across different geographic locations and species. During this event, it was observed that certain species, including *Bruguiera sexangula* (Lour.) Poir., *Sonneratia alba* Sm., and *Rhizophora mucronata* Lam., displayed a high susceptibility to cold temperatures. Conversely, species such as *Kandelia obovata* Sheue, H.Y.Liu & J.W.H.Yong, *Aegiceras corniculatum* (L.) Blanco, *A. marina*, and *Bruguiera gymnorhiza* (L.) Lam. remained unaffected by the temperature changes (Sippo et al. 2017). This lack of impact can be attributed to the fact that the temperature did not reach a low enough level to significantly affect these particular species. Additionally, in Sri Lanka most mangrove species showed reduced performance, measured by stand basal area and biomass, as soil salinity increased (Cooray et al. 2021).

The Philippines has been perpetually recorded as one of the top biodiversity hot spots of the world (Marchese 2015). This is due to its archipelagic nature and tropical climate within the country. According to Primavera et al. (2004) and Ono et al. (2016), it is estimated that mangroves in the Philippines span approximately 36,000 km, encompassing over 7,000 islands in total. According to Hogarth (2015), the Philippines is home to approximately 44 true mangrove species. Despite the favorable temperature conditions for mangroves in the country, there remains a threat to these species due to recorded water pollution in coastal areas, especially in proximity to chemical factories, as stated by Mialhe et al. (2016). It is crucial to identify the species present and determine the abundance, richness, and evenness of the population. However, the understanding of the relationship between mangrove physicochemical parameters has been limited.

Despite numerous ecological studies of mangrove ecosystems in the Philippines, a comprehensive assessment of the mangroves in Tagum City, particularly in Sitio Cabugan, Barangay Busaon, remains unexplored. This research fills that gap by offering a detailed taxonomic profile, analyzing the diversity and morphometry of local mangroves, and investigating their relationship with physicochemical parameters. On that note, this would be the first study in the area that aims to provide essential insights into the ecological dynamics of mangrove populations and how environmental parameters influence the diversity of mangrove species and lay the groundwork for sustainable conservation practices in the region. The declining mangrove population highlighted the urgency of this study, and the potential understanding of the species response to stimuli or the outside environment is in need, and what certain tolerable conditions these mangroves need to sustain biodiversity.

MATERIALS AND METHODS

Study area

This study was conducted in Sitio Cabugan, Barangay Busaon, Tagum City, Davao del Norte, Philippines, which has a total land area of 19,580 hectares (Figure 1). Land uses are dominated by agriculture, which produces various crops. Tagum City becomes a wonderful destination for tourist because of their mesmerizing water banks with the presence of mangroves. The Barangay Libuganon is geographically located at 7°10’ N and 125°20’ E. The intertidal zone is located on the coast which borders the terrestrial ecosystems (Nordlund et al. 2018; Wang et al. 2019). The intertidal zone is the narrowest because that zone is strongly influenced by tides.

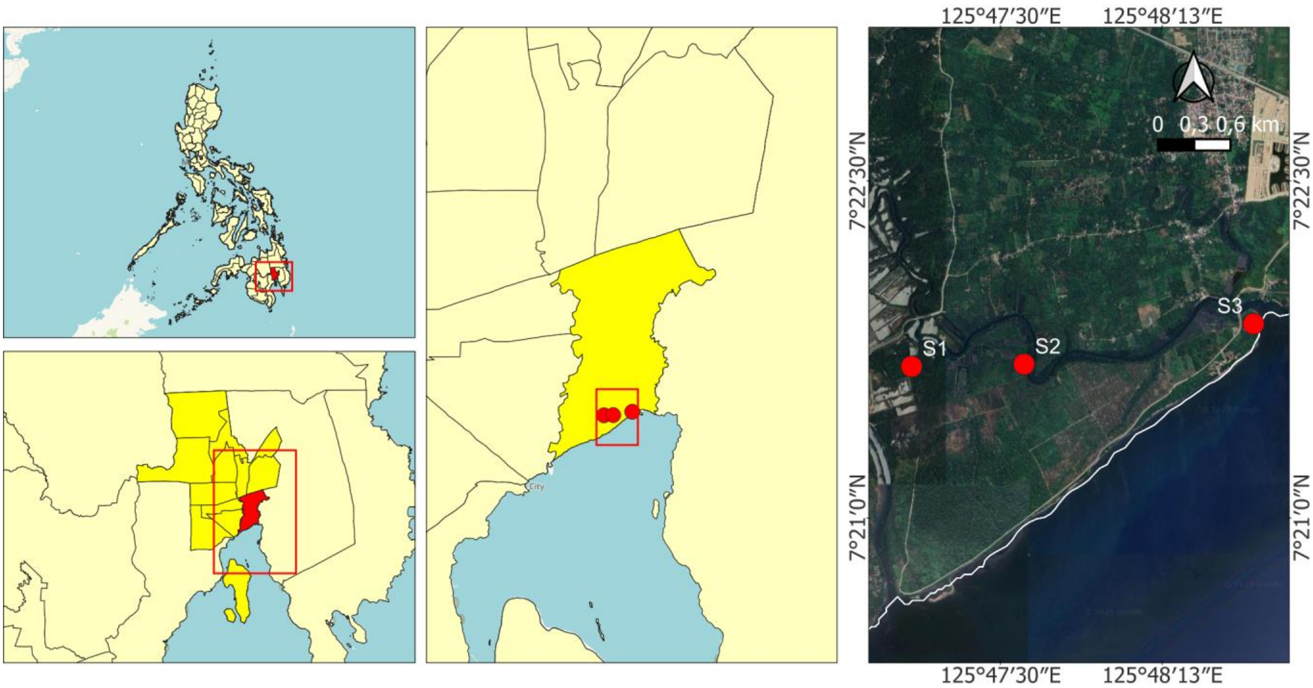

Figure 1. Map of study location in Sitio Cabugan, Barangay Busaon, Tagum City, Davao del Norte, Philippines

Procedures

This study used a quantitative approach using the descriptive design since the researchers intend to identify and establish the taxonomic profiles of the mangrove species present in Tagum City. Using this method, the data gathered was recorded and analyzed quantitatively to obtain an accurate result. Primavera et al. (2004) suggest that quantitative research design provides an effective approach for reaching conclusive results and either validating or refuting a hypothesis. This design is favored due to its longstanding use and consistency across various scientific fields and disciplines. Since the mangrove species present in Tagum City was observed and analyzed according to their taxonomic profiles, indices and physicochemical parameters, descriptive research design is a valid method for research and a precursor to more quantitative studies regarding this subject.

The materials and instruments used in this study were the transect lines approximately 100 m long, a 10 × 10 m quadrant, refractometer, pH meter, digital thermometer, camera for documentation, Field Guide Manual to Philippine Mangroves by Primavera et al. (2016) for the identification of mangroves species present in the area. Figure 2 represents the layout of transect established at each station. The transect line was a 100-meter rope laid perpendicular to the shore. A 10 × 10 m steel quadrant was laid along the transect line. There were four quadrants laid in one transect line in three different stations. A 10 m x 10 m quadrant was used to account the mangroves present in the area. In the study area, salinity of the water was measured using a refractometer. A small sample of water was placed in the refractometer's glass prism. The pH level or acidity of the water was measured using a pH meter. Additionally, a digital thermometer was utilized to determine the water temperature. The camera was used for the documentation of the mangrove species and the field guide manual for the identification of mangrove species.

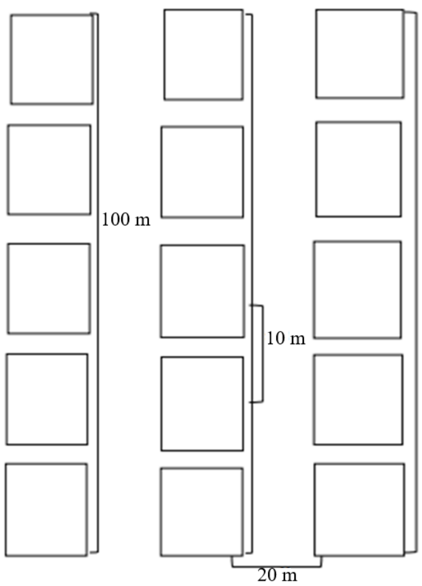

Figure 2. Layout of transect was established in each station for vegetation sampling

Determination of the quadrant

The researchers checked the parcel of mangroves in the area and established the quadrant with size of 10 × 10 m based on English et al. (1994) as cited in JC et al. (2016). The adaptation of the use of quadrants was instructed by the local scientist/personnel since this is commonly used for most of their flora assessments. The researchers are using a meter tape to measure the indicated quadrant in one station in the mangrove. The researchers divided the identified quadrant into four.

Collection of data for mangrove morphometry

In collecting data on mangrove species, the researchers employed a combination of opportunistic and direct observational methods to accurately document the diversity and characteristics of mangroves within the study site. Opportunistic observations allowed the researchers to adapt their data collection based on the availability and accessibility of specific mangrove species in the area, ensuring comprehensive documentation. Upon locating mangrove stands, the researchers systematically recorded the observable morphological characteristics of the mangroves within designated quadrants. These characteristics included attributes such as trunk diameter, leaf size and shape, bark texture, and color variations of leaves and stems. This detailed documentation provided essential data for accurate species identification and ecological analysis. To ensure coherence in data collection and maintain consistency across the study site, a quadrant division system was applied. Each station was subdivided into 1 × 1 m quadrants, where the presence of mangrove species was recorded. For each quadrant, the researchers listed the species present and counted the number of individual mangrove trees or seedlings. This structured approach ensured that data were systematically gathered and comparable across different stations within the study area.

Photographic documentation was also an essential aspect of data collection. The researchers captured high-quality images of the identified mangrove species, focusing on key distinguishing features such as leaves, stems, roots, and reproductive structures. These photographs served as a visual reference for subsequent species identification and verification. To measure the physical attributes of the mangroves, the researchers employed standard field measurement techniques. The trunk diameter of each mangrove tree was measured by wrapping a measuring tape around the tree at breast height (approximately 1.3 meters above the ground) to obtain the Diameter at Breast Height (DBH). The height of each mangrove tree was measured using a steel tape, extending from the base of the trunk at ground level to the highest point of the tree canopy. These measurements provided valuable data for understanding the growth patterns and biomass distribution of the mangrove species in the area.

Species identification and taxonomic classification were conducted up to the species level. The researchers referred to the Field Guide Manual to Philippine Mangroves authored by Primavera et al. (2004) as the primary reference for identifying and classifying the mangrove species. The identification process was further verified by consultation with a local scientist familiar with the flora of the region to ensure the accuracy and reliability of the findings. In compiling the taxonomic profiles of the mangrove species, the researchers adhered to established principles of taxonomy. The study drew upon the foundational concepts outlined in Ohl's (2014) book, Principles of Taxonomy and Classification: Current Procedures for Naming and Classifying Organisms. This resource provided guidance on the systematic classification of mangroves, facilitating a comprehensive understanding of their taxonomy. Additionally, related scientific studies were reviewed and incorporated as supporting references to strengthen the taxonomic framework.

Data collection for biodiversity indices

Species richness and evenness were determined by listing and counting the number of species found at the specific site of area. Counting plants within clearly defined sample units is a longstanding technique employed to assess vegetation density. To determine the number of plant species, the researchers individually counted mangroves of the same species using the stick method and recorded the data in a notebook. Documentation was facilitated through the use of a camera, which captured photographs of suitable specimens to record their morphological and diagnostic characteristics.

Data collection of physicochemical parameters

The physicochemical parameters were measured to obtain the average of each quadrant and to get the value per station and the average per station as the final value. Water temperature (°C) was obtained per station during the field sampling using the thermometer. The average temperature of coastal surface waters is about 17°C (62.6° Fahrenheit). The water salinity (ppt) was obtained every station using the refractometer. To measure the salinity of the water in the study area, a small amount of water was placed in the glass prism of the refractometer. Then the refractometer gave the measurement by looking through the eyepiece. The pH meter was utilized at each station to determine the pH level of the water. Pure water has a pH of 7, and if the pH is below 7, the water is considered acidic, while a pH above 7 indicates basic properties. In the case of groundwater systems, the typical pH range falls between 6 and 8.5.

Data analysis

For taxonomic classification, the study documented all collected plant species and classified through taxonomic nomenclature following Brooks et al. (2019). The mangroves were identified and classified taxonomically up to the species level using the Field Guide Manual to Philippine Mangroves by Primavera et al. (2004). It was initially identified using the morphological structure and was validated and verified by a local scientist using photographs and the documented measurement.

This study used Shannon-Wiener's diversity index (H') and Simpson's index to assess and interpret mangrove species diversity and composition. Individuals were counted for each species. The Shannon diversity index (H) is a widely used metric to describe species diversity within a community. This index takes into account the abundance, richness, and evenness of species present. On the other hand, the Simpson index is considered a dominance index as it places greater emphasis on common or dominant species. In this context, the presence of a few rare species with limited representation does not significantly impact the overall diversity (Battaglia 2017). Moreover, result shown from the field experiment of five different sample in three stations using various instruments. Data was recorded from the result of pH meter for water pH, refractometer for water salinity and digital thermometer for water temperature. The analysis was anchored on the study of Imamsyah et al. (2020).

Descriptive statistics were used to summarize species composition, abundance, indices, and morphometric variables such as tree height and trunk diameter. To detect significant variations in morphometric traits among study sites, Pearson's linear correlation (r) with Bonferroni correction was performed for normally distributed data. More so, Principal Component Analysis (PCA) was employed to visualize patterns and relationships among environmental factors, species diversity, and morphometric variables. PCA, in particular, helped identify the most influential environmental variables affecting mangrove growth and structural characteristics, transforming complex data into interpretable principal components. Correlation and regression analyses further explored the relationships between morphometric traits and environmental factors, such as temperature, salinity, and water pH, providing predictive insights. These statistical approaches collectively enabled a comprehensive evaluation of the ecological dynamics within the mangrove ecosystem, supporting conservation and sustainable management efforts.

RESULTS AND DISCUSSION

There were seven species of four family of mangroves found in the study area. Family Avicenniaceae consisted of *A. marina* with local name of *Miapi*, and *Avicennia rumphiana* locally known as *Piapi*; family Arecaceae included *Nypa fruticans* Wurmb with local name of *Nipa*; family Rhizophoraceae included *B. gymnorhiza* locally called *Putotan-Pula, R. mucronata* locally known as of *Bakhaw-babae* and *Rhizophora apiculata* Blume with local name of *Bakhaw-lalaki*; and family Lithraceae consisted of *S. alba* locally called *Pagatpat*. Malik et al. (2015) conducted a study on mangrove biodiversity and identification in South Sulawesi, Indonesia. The study identified ten mangrove species belonging to six families (Avicenniaceae, Rhizophoraceae, Euphorbiaceae, Combretaceae, Arecaceae, and Sonneratiaceae).

Morphometric characteristics of mangrove species

The morphometric characteristics of mangrove species in the study area are presented in Table 1 with description detailed below.

Table 1. Morphometric characteristics of mangrove species in Tagum City, Davao del Norte, Philippines

Mangrove species	Max. height (m)	Max. trunk size (cm)	Trunk color	Roots system	Leaves shape and texture	Leaves color	Flowers or buds colors
Avicennia marina (Forssk.) Vierh.	28	50	Grey	Broad lateral system with pneumatophores	Oblong	Light green	Light green
Avicennia rumphiana Hallier fil.	30	40	Grey	Broad lateral system with pneumatophores	Elliptic	Dark green	Light brown
Nypa fruticans Wurmb	6	2	Light green	Adventitious roots	Long blade	Green	Red-like and yellow
Bruguiera gymnorhiza (L.) Lam.	5	2	Brown	Short prop roots	Ovate	Green	Reddish brown
Rhizophora apiculate Bl.	25	52	Green	Aerial and stilt	Oblong	Green	Light yellow
Rhizophora mucronata Lam.	28	45	Dark green	Aerial and stilt	Oblong	Dark green	Cream and yellow
Sonneratia alba Sm.	26	60	Cream and brown	Presence of pneumatophores	Elliptic	Light green	Light green

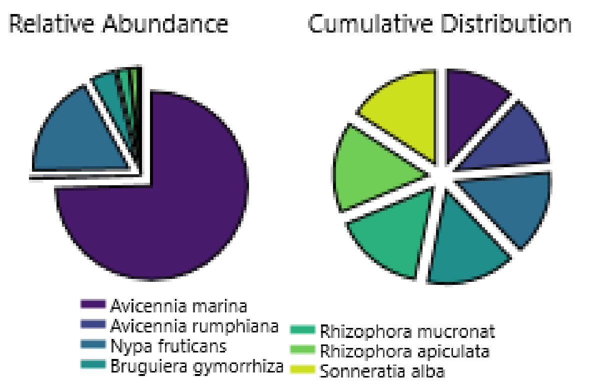

Figure 3. Species composition and relative abundance of mangrove species in Tagum City, Davao del Norte, Philippines

Avicennia marina, the species can reach a height of 28 meters. With a diameter of up to 50 cm, the trunk is a combination of grey in color. The roots have a wide lateral system that is surrounded by pneumatophores (breathing roots) and can grow up to 20 cm tall. Leaves are oblong with a round tip and can be up to 8 by 5 cm in size. The leaves are a light green color. The leaves are arranged in a diagonal pattern. Buds are light green in color and have an oval curve with a pointed apical beak.

Avicennia rumphiana, the species grows up to 30 m tall. It is grey in color and mostly grows straight. The trunk has a diameter of up to 40 cm. It also has a broad lateral root system with breathing roots or the pneumatophores. The leaves are elliptic in shape that measures 9 by 6 cm. The leaves are dark green in color with powdery hair underneath. The buds are color light brown, oval shape with a pointed apical beak.

Nypa fruticans, the species grows up to 6 m. It is a light green color. It has a cluster arrangement on a single stalk. The trunk has a diameter of up to 2 cm. The roots have additional adventitious roots arise from the lower part of the stem. The leaves are green in a long blade in shape and can grow up to 15 cm. It is arranged spirally. Flowers are in color red-like and yellow in a globular cluster.

Bruguiera gymnorhiza, the tree grows up to 3.5 to 5 m tall. The trunk is up to 2 cm in diameter. The trunk is glabrous with color brown and a reddish brown bark with stipules on young branches. The roots are a short prop root. The leaves are color green and ovate and lathery. Flowers's axillary, solitary, drooping and is reddish brown in colors.

Rhizophora mucronata, the tree grows up to 25 m tall. The trunk measures up to 52 cm. Evergreen tree with horizontally fissured dark brown bark. The roots are composed of aerial and stilt roots emerging from the lower branches of the roots. Leaves are green, leathery, slightly oblong and arranged oppositely. Flowers are light yellow; buds have 2 lobed leaflets near the base.

Rhizophora apiculata, the tree grown up to 28 m tall. Trunk diameter is up to 45 cm. Dark green smooth oblong leaves with reddish leaf stalks. Flowers are composed of cream-colored petals that are linear in a cross-shaped pattern. It has a read stipules and a yellow sepal. Buds are elliptical in shape and finely fissured.

Sonneratia alba, the tree grows up to 26 m. The trunk is diameter is up to 60 cm. It is having a smooth longitudinal fissure that is a combination of cream and brown in color. It has a pneumatophore or breathing roots that develop from the main roots. Leaves are light green, elliptic in shape with a broad leaf tip. Buds are oblong and green in color.

Species composition and abundance

Figure 3 shows the species composition and abundance on the study area. *Avicennia marina* had the highest number of individuals with a total of 567 with a relative abundance of 70.79% and a cumulative distribution of 74.51, followed by *N. fruticans* with a total number of 173 with a relative abundance of 21.60% and a cumulative distribution of 92.25; *B. gymnorhiza* with a total number of 31 and a relative abundance of 2.87% and a cumulative distribution of 96.32; *R. mucronata* with a total of 15 and a relative abundance of 1.87% and a cumulative distribution of 98.29; *R. apiculata* with a total number of 9 and a relative abundance of 1.12% and a cumulative distribution of 99.48; *S. alba* with a total number of 4 and a relative abundance of 0.50% and a cumulative distribution of 100; and *A. rumphiana* was the lowest with with a total number of 2 is and a relative abundance of 0.25% and a cumulative distribution of 74.77.

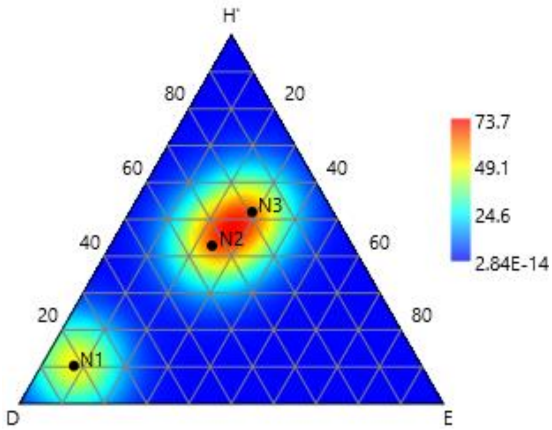

Figure 4. Ternary plot of biodiversity indices of mangrove species in Tagum City, Davao del Norte, Philippines. Note: H': Shannon-Wiener diversity index; D: Simpson index; E: Evenness index

The dominant species found in the study sites, *A. marina* and *N. fruticans*, is in line with the study by Baleta and Casalamitao Jr (2016) which revealed the most abundant species in Puerto Princesa, Palawan were *N. fruticans, B. sexangula, A. marina, A. lanata* and *Xylocarpus granatum* J.Koenig. The dominance of the two species is due to their suitability to live in muddy-sandy substrate (Malik et al. 2015). On the other hand, species with the lowest number of individuals was *A. rumphiana* and is listed as vulnerable, which aligns with the study of Pototan et al. (2021). The species *A. rumphiana* is facing a threat from the loss of its mangrove habitat across its distribution range. This loss is mainly attributed to activities such as extraction and coastal development. Additionally, the effects of global warming and climate change are expected to have further impacts on these areas (Rovai et al. 2018).

Figure 4 shows the ternary plot of biodiversity indices of mangrove species in terms of richness and evenness. At station 1, there were four species found with a total number of 146 individuals and a Shannon-Wiener diversity index of 0.12 (low), Simpson index of 0.96 (high) and Evenness index of 1.044 (less even). The low diversity index was because there were only four species found in the study area with only one individual for each of the three species while the majority belonged to one species, i.e., *A. marina*. At Station 2, there were six species with a total number of 345 individuals, the highest of the three stations. Station 2 had a Shannon-Wiener's diversity index of 0.75 (low), Simpson's index of 0.96 (moderate) and Evenness index of 0.43 (less even). At station 3, there were six species of mangroves with a total number of 270 individuals and a Shannon-Wiener diversity index of 1.17 (medium) and Simpson index of 0.43 (moderate) and Evenness index of 0.65 (more even).

The diversity of mangrove species is influenced by the substrate type and salt intrusion. The presence and distribution of mangrove species in the study area are influenced by the physical characteristics of the area and the type of substratum where these species thrive (Baleta and Casalamitao Jr 2016). Physiological adaptations, such as substrate type and salt extrusion, also play a role (Naskar and Palit 2015). Station 2, which exhibited the highest diversity index, was characterized by a sandy-muddy substrate that is rich in organic matter and supports the growth of various fauna and flora, contributing to the diversity and abundance of mangrove species in the area. Smoothly distributed substrate particles in certain areas contain higher levels of organic matter, creating a favorable environment for diverse and robust mangrove growth (Windusari et al. 2014). *Avicennia marina* is commonly found in areas with clay mud or muddy substrates (Ono et al. 2016). Research conducted by Islam et al. (2016) indicates that *A. marina* and *S. alba* thrive in regions with high salinity, particularly coastal areas.

Physicochemical parameters

The physicochemical parameters in the sampled area indicated a normal range for mangrove ecosystem. The pH at station 1 was 8.16, while that at stations 2 and 3 was 8.11 and 8.13, respectively. The salinity ranged from 17.9 to 18.6 ppt in the three stations, indicating normal condition in tropical area, while water temperature ranged from 32 to 32.3°C. In the investigation conducted by Sippo et al. (2017) on the impact of alkalinity output from mangrove tidal creek in Australia, it was observed that water in close proximity to the mangroves exhibited a higher pH level (8.1) compared to seawater farther away from the coastal mangroves (pH 7.3). This variation in pH was attributed to the presence of fallen leaves, stems, and roots on the ground, which undergo decomposition and contribute to the acidity of the water. A similar study conducted by Islam et al. (2016) demonstrated an average salinity of 18.2 ppt. The salinity levels are influenced by factors such as evaporation, runoff, and rainfall (Ono et al. 2016). Increased sunlight penetration into the water column intensifies evaporation, leading to higher salinity levels, whereas higher rainfall contributes to lower salinity levels.

Water temperature is one factor that can affect the condition of mangrove vegetation. The difference in temperature is also affected by the high and low density of mangroves. The temperature will increase if the mangrove density is low because of the high intensity of sunlight received by waters, otherwise, the temperature will decrease if the density of mangroves is high. Biswas and Biswas (2020) stated that lack of light penetration is the main limiting factor in growth for mangroves. Water temperature reading in the study area were in the range for the survival of aquatic organisms (Osland et al. 2020).

Relationship between mangrove species morphometry and environmental factors

Figure 5 shows the Principal Component Analysis (PCA) biplot that illustrates the relationships between environmental variables, mangrove species, and sampling sites, providing insights into the factors influencing community structure and morphometric traits. In this study, the PC1 eigenvalue has 15179 while PC2 has an eigenvalue of 817.91, meaning that PC1 represents 93.71% of the variance among variables while PC2 significantly represents 5.05% of the variance among variables with the cumulative correlation of more than 98.76%, implying that the cluster of samples is highly explained by the variables measured.

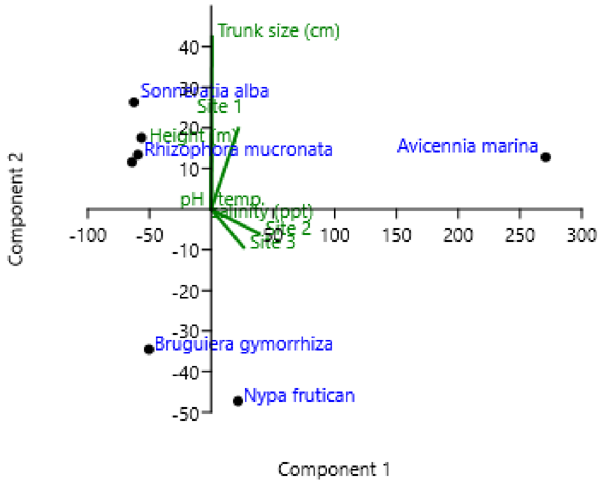

Figure 5. Principal component analysis showing the relationship between environmental variables and mangrove morphometry

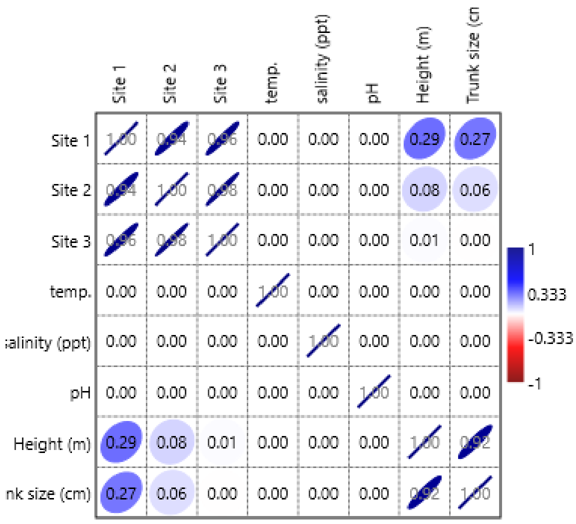

Figure 6. Linear Pearson r with Bonferroni correction showing the relationship between mangrove species morphometry and study sites

To specify, from the three stations of the study, station 1 had the close relative influence of the abundance of *S. alba*, considering the environmental parameters measured, where water temperature, salinity, and pH with 32.4°C, 18 ppt, and 8.11 ppt, respectively. The length and direction of these vectors indicate the strength and relationship of variable such as trunk size, temperature, pH, and salinity. Trunk size exhibits a strong association along component 2, suggesting its importance in structuring certain species and site interactions. This explains the study of Srivastava and Mehta (2023) that trunk size often has more extensive contribution to specific mangrove species growth and development.

The positions of mangrove species reveal their distinct ecological preferences. *Sonneratia alba*, *R. mucronata*, and *A. marina* are associated with environmental gradients positively, indicating their potential preference for larger trunk sizes and favorable environmental conditions. Conversely, *B. gymnorhiza* and *N. fruticans* are positioned negatively, suggesting their adaptability to contrasting environmental conditions. *R. apiculata* and *R. mucronata* thrive best in site 3 considering the bearable environmental conditions present. However, station 2 had the least accumulative pH compared to the other stations in this study. Alsumaiti and Shahid (2018) mentioned a possible contribution of pH to the abundance of mangrove and Kida and Fujitake (2020) emphasized that neutral pH 7 considered to be the suitable measurement for mangrove growth and development.

Figure 6 illustrates the relationship between mangrove species morphometry and environmental factors across three study sites, using Pearson's correlation coefficients with Bonferroni correction for statistical significance. Positive correlations are depicted in blue, with stronger relationships indicated by deeper shades and larger circles. Station 1 demonstrates positive correlations with mangrove height with the r value of 0.29 and trunk size with the r value of 0.27, suggesting that mangroves in this site tend to grow taller and develop thicker trunks compared to other locations. In contrast, stations 2 and 3 show negligible or no meaningful correlations with morphometric features, indicating less favorable conditions or less pronounced growth patterns.

Environmental parameters such as temperature, salinity, and pH exhibit no strong correlations with mangrove morphometry, implying that these factors may be stable or uniformly distributed across the study sites. Notably, there is a strong positive correlation between height and trunk size with the r value of 0.92, indicating that taller mangroves tend to have thicker trunks. Overall, station 1 appears to offer more favorable conditions for mangrove growth, while environmental factors remain consistent across the locations, showing limited influence on morphometric variations.

In conclusion, seven mangrove species were identified in the study: *A. marina*, *A. rumphiana*, *N. fruticans*, *B. gymnorhiza*, *R. mucronata*, *R. apiculata*, and *S. alba*, with *A. marina* being the most dominant and *A. rumphiana* the least abundant. Station 1 had four species with low diversity but high dominance by *A. marina*; Station 2 supported six species with similarly low diversity and moderate evenness; and Station 3 had the highest diversity and evenness among six species. Moreover, environmental conditions were stable across stations, with minor differences favorable to mangrove survival, though lower pH at station 2 may explain *A. marina*'s abundance. PCA analysis revealed that trunk size significantly influenced species distribution, with *S. alba*, *R. mucronata*, and *A. marina* preferring stable environments, while *B. gymnorhiza* and *N. fruticans* adapted to variable conditions. The findings highlight the need for targeted conservation and environmental monitoring to maintain mangrove ecosystem health. Future research should incorporate more ecological variables, and explore mangrove taxonomy at the cellular level to deepen understanding of species traits and vulnerabilities. Lastly, comprehensive educational materials and community engagement, combined with robust conservation efforts and ecological monitoring, are essential for ensuring the long-term resilience and sustainability of the mangrove ecosystem.

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