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Special Issue

Riparian floristic diversity and carbon stock assessment of an urban landscape: The case of Marjoya River in Batangas City, Philippines

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ABSTRACT: Urban riparian forests remain understudied in the Philippines despite their importance in ecosystem services for anthropogenic landscapes, such as hosting the city's local biodiversity and contributing to carbon capture and storage. However, human activities constantly threaten these ecosystems and remain poorly studied. This study assessed the riparian floristic diversity and carbon stock of mangrove forests in the Marjoya River and the Batangas City Mangrove Conservation Ecopark to establish baseline information and inform conservation recommendations. Using multiscale random plot sampling across four stations (upstream, midstream, downstream, and a mangrove eco-park), researchers documented 59 plant species from 52 genera and 27 families, including 33 native species (8 endemic) and 26 exotic species, with 4 locally threatened species identified. Biodiversity metrics indicate moderate species diversity, likely influenced by proximity to human disturbance and fragmented forest patches. Carbon stock was estimated at 33.657 Mg C ha^{-1} (~123.521 Mg CO_2) in total, averaging 7.791 Mg C ha^{-1} (~28.594 Mg CO_2 ha^{-1}), which is substantially lower than national averages (~170 Mg C ha^{-1} or 623.9 Mg CO_2 ha^{-1}) and other local studies, although soil carbon data were not included. These results highlight the vulnerability of urban riparian forests to anthropogenic pressures and underscore the need for enhanced protection, conservation, and land use planning to sustain their ecological functions and carbon storage capacity amid ongoing urban development. The study contributes critical knowledge on urban mangrove ecosystems in the Philippines, emphasizing their role in biodiversity support and climate mitigation within anthropogenic landscapes.

KEY WORDS: biodiversity indices, carbon, mangroves, riparian, urban forest.

INTRODUCTION

Rivers have long been an integral component of human civilization. Since ancient times, exemplified by the Mesopotamians, Egyptians, Indians, and Chinese, rivers have been important drivers of civilizations and have served as an important natural asset in the sectors of agriculture, transportation, and trade (Macklin and Lewin, 2015, 2020; Pietz and Zeisler-Vralsted, 2021). In the modern era, rivers continue to be used for agricultural irrigation, energy generation, transport routes, and water sources for residential, commercial, and industrial applications (Best and Darby, 2020). River systems are also ecologically important as they contribute to various ecosystem services, not only to the benefit of humans but to other organisms as well, such as provisioning habitat for flora and fauna, transporting nutrients and sediments, and taking part in local biogeochemical cycles (e.g., hydrological cycle and nutrient cycling) (Postel and Richter, 2003). Essentially, river ecosystems act as a system for the flow of matter and energy (Harvey, 2016).

In modern times, river systems aided urbanization (Zhao *et al.*, 2013; Phong, 2015). Prior civilizations laid the foundations for urban development, and with it, humans' increasing control and influence on the natural environment, such as river systems (Royer, 2016). Since the dawn of civilization, rivers have acted as a source and sink, and with the recent and accelerated advancements in human society, the rise of anthropogenic landscapes has begun to significantly impact river ecosystems (Van Meter *et al.*, 2016). This leads to the emergence of environmental issues such as water quality degradation, disease transmission, droughts, modification of biodiversity, and the general deterioration of ecosystem services (Postel and Richter, 2003; Royer, 2016; Van Meter *et al.*, 2016).

Concerning river systems and urbanization, the main issue of biodiversity and climate change is apparent, as human influence significantly affects ecosystem health (Wohl, 2019; Cañedo-Argüelles *et al.*, 2023). Urban landscapes influence the ability of a metropolitan area to host local biodiversity and its role in carbon dynamics. These two major ecosystem services have a particular effect on other ecosystem services, and their instability construes serious and complicating impacts on the environment and the local population's health, well-being, and the entire social, political, and economic dynamics (World Health Organization, n.d., 2015; Churkina, 2016; Wu *et al.*, 2023). An ideal example of the importance of the aforementioned ecosystem services can be realized in how local biodiversity provides natural resources to humans (e.g., food, fiber, water, and other amenities) and maintains local ecological stability, while carbon dynamics are dependent on the existing land use and cover in determining the role of land as carbon source and sink (Seto *et al.*, 2012; Wang *et al.*, 2025). With the loss of biodiversity and the presence of anthropogenic climate change, the environment is on the brink of irreversible damage, thereby compromising human life.

In the Philippine setting, the role of urban areas in biodiversity and climate change is important to understand, but is obscured by the few available studies (Lumbres *et al.*, 2012; Tutor *et al.*, 2018; Pansit, 2019; Coracero *et al.*, 2022; Jumawan *et al.*, 2024). The country is megadiverse yet also a biodiversity hotspot, and although not a major contributor to climate change, the Philippines remains a significant greenhouse gas emitter among the low- and middle-income countries and will continue to increase its emissions in the upcoming years (Convention on Biological Diversity, n.d.; Crepin, 2013). Urban areas play a significant role in this regard, as more than half of the nation's population (54.0%) resided in urban areas according to a 2020 Philippine Statistics Authority (2022) report, and the number is expected to continue increasing, indicating a rapid urbanization process.

Riparian urban biodiversity has a significant role in affecting ecosystem services given its unique place as a transitional zone for terrestrial and aquatic ecosystems, such as water quality regulation, flood and erosion control and mitigation, and habitat and migration corridors for various flora and fauna (Guerry *et al.*, 2021; Davis *et al.*, 2025). Urban biodiversity in general is critical as it is sensitive to human disturbance and can lead to events like local species extinction and proliferation of exotic and invasive species (Murphy, 1988; Gaertner *et al.*, 2017; McKinney, 2002). Moreover, biodiversity affects climate change and vice versa, which can be illustrated by scenarios where climate change exacerbates precipitation that worsens floods and erosion, affects species survivability due to temperature changes, and accelerates the modification of the biophysical constitution of a river system, leading to regime shifts (Postel and Richter, 2003; Royer, 2016; Naka *et al.*, 2022).

On the other hand, urban climate dynamics show that urbanized areas are important carbon sinks. Studies show that the carbon sequestration potential of urban forests can be comparable to that of tropical rainforests and even forests in rural areas (Wilkes *et al.*, 2018; Jevon *et al.*, 2025). Moreover, riparian vegetation is an important area for carbon capture as it has the potential to significantly increase carbon sequestration while also contributing to long-term ecosystem services such as erosion reduction, minimization of nutrient runoff, and local hotspots of biodiversity due to their role as transitional ecosystems (Dybala *et al.*, 2019; Matzek *et al.*, 2020). Riparian restoration efforts show that successful revegetation can accelerate and increase initial carbon capture and higher soil carbon permanence (Matzek *et al.*, 2020). This benefit increases further in warm and wet climates, suggesting the important roles of tropical regions (Dybala *et al.*, 2019). Furthermore, riparian vegetation is often observed to sequester more carbon than its non-riparian counterparts (Pasion *et al.*, 2021). This can be due to factors like how groundwater enhances growth and productivity, and the unique soil characteristics present in riparian zones (e.g., higher accumulated organic matter and nutrients from erosion and deposition) (Pasion *et al.*, 2021; Rheinhardt *et al.*, 2012). In the context of urban areas, the presence of riparian vegetation can aid in sequestering emissions due to the fact that urbanized areas are a significant carbon source (Churkina, 2016). The establishment of riparian forests can further increase baseline carbon stocks, suggesting the importance of management consideration to integrate conservation strategies in urban planning and design and policy formulation (Garrastazú *et al.*, 2015).

Given the criticality of the topic on biodiversity and climate change, this study is made to generate baseline information on the local flora and carbon stock of the local riparian ecosystem in Batangas City, an urbanized landscape in Southern Luzon, Philippines. Specifically, this study focuses on the riparian vegetation of Marjoya River, including a mangrove conservation ecopark located in the southernmost portion of the Calumpang River. Moreover, this study is significant as it focuses on the area's general mangrove forest, a critically important ecosystem in the country. Mangrove forests protect coastal areas, shelter local organisms, filter streaming waters, and sequester carbon (Carugati *et al.*, 2018; UN Environment Programme, 2023). Understanding the urban vegetation of the area is crucial for the effective management of the area and the city in general, as well as identifying what possible future actions should be taken to ensure sustainability and ecological integrity. This study highlights the importance of baseline information and mainstreaming biodiversity and climate studies to inform decision-makers and stakeholders about effective and sustainable urban planning and management.

MATERIALS AND METHODS

Study Site

The study locale is located in the Marjoya River in the western part of Batangas City, draining out to the Bay of Batangas. It is a distributary of the Calumpang River and serves as a significant waterway of the city, as well as an important component of the sociocultural and ecological landscape of the area. The river system offers various environmental services, such as its utilization for fishing and irrigation, its support for local flora and fauna, its integral part in nutrient cycling, and its role as a natural buffer against flooding.

Like other river systems in urban areas of the Philippines, the Marjoya River faces challenges related to

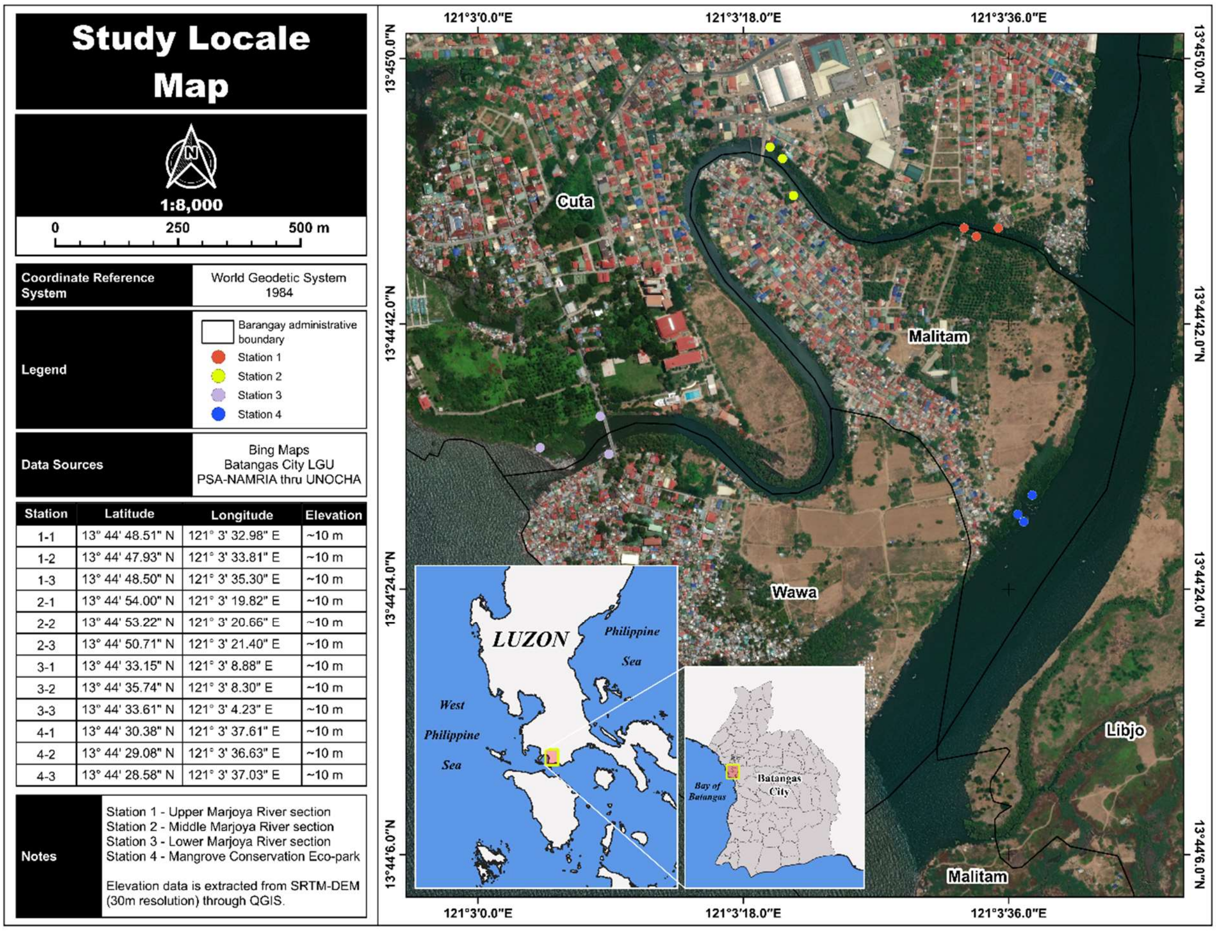

Fig. 1. A map of Batangas City and the study site. Sampling areas and their geographic coordinates are also included.

pollution and habitat degradation. On-site observations show that the river suffers from extreme pollution due to the effluents and solid wastes deposited there. Although not classified yet by the Department of Environment and Natural Resources (DENR), its parent waterbody, the Calumpang River, is a Class D freshwater body, indicating its suitability for navigation only (Class D: Navigable Waters). Class D is also the lowest category, which means that very high levels of contaminants and pollutants are present in the river.

Moreover, inquiries from local individuals identified that the existing vegetation of the river is fragmented from an original contiguous mangrove forest, which was cleared or transformed into other land use types as Batangas City became urbanized. Most of the vegetation observed on-site is situated in the riparian region, albeit some houses are too proximate to the river, leaving no easement and no area for riparian vegetation growth. The existing forest patches are usually composed of mangroves, and with government intervention, assisted mangrove forest regeneration is happening. Another conservation effort done by the local government is establishing a city mangrove conservation ecological park (hereinafter referred to as "ecopark") situated in the lowermost part of the Calumpang River. A map of the study locale is shown in Figure 1.

Floristic Diversity Assessment

Sampling Method – A multiscale plot sampling method was used to assess the locale's plant diversity. This method utilizes a nested plot configuration, i.e., three 1m x 1m plots for sampling forest floor species and two 5m x 5m plots for sampling understory species were nested in a 20m x 20m plot for sampling canopy species. This procedure is adapted from previous studies (Napaldet, 2023; Bullong *et al.*, 2024; Pocyoy and Napaldet, 2024), which also used three randomly distributed multiscale plots proximate to each other to constitute a sampling station. In this study, three sampling stations were placed in the upper, middle, and lower portions of the Marjoya River (hereinafter referred to as "UPMAR", "MIDMAR", and "LOWMAR" stations, respectively) while one station was placed within the ecopark (hereinafter referred to as "ECOPARK" station). The main map of Figure 1 highlights the locations of the sampling stations.

Physical Description of the Sampling Stations – To provide a more in-depth description of each sampling station, the following points were provided:

a. UPMAR Station – The upstream portion of the Marjoya River where it splits up with the larger Calumpang River. The area is characterized as agricultural land, as most vegetation was planted with coconuts and bananas. However, mangroves are still present in the riparian zone and are slowly encroaching on the stream region, thereby steadily closing the river bifurcation. A minimal residential built-up area land cover can be aerially viewed.

b. MIDMAR Station – The midstream portion of the Marjoya River. This area is where the majority of the built-up area is located. It also has a connecting bridge that links the fluvial island with the mainland. Most effluents are observed to flow out of the river in this area, given that residential, commercial, and industrial zones are located in this sector. The mangroves form a long and narrow strip along the riparian zone, as easement zones for built-up areas are no longer available.

c. LOWMAR Station – The downstream portion of the Marjoya River. One side (northern part as viewed in Figure 1) consists of a large blend of coastal, riparian, and coconut plantation vegetation, while the other part (southern part as seen in Figure 1) comprises residential built-up land use.

d. ECOPARK Station – The mangrove conservation ecological park under the management of the City Government of Batangas. A product of City Environment and Natural Resources Office (City ENRO) efforts to protect and conserve their environmental resources, the 6,500 m^2 ecopark aims to be a blue carbon sink and natural flood control for the area. The area is situated in the downstream portion of the Calumpang River and adjacent to grasslands and residential built-up zones.

Sampling Implementation and Assessment – Species within the sampling plots were taxonomically identified, and their respective population counts were recorded, including the circumference at chest height (CCH) data for canopy species. Additional data were derived from secondary sources, i.e., species endemicity, floristic elements, and local and international conservation status. Gathering this information follows the methodology of Bullong *et al.* (2024). To provide a brief overview, species endemicity provides the distribution data of the species following the classification provided in Pelser *et al.*'s (2011) Co's Digital Flora of the Philippines website: endemic for flora restricted within the country, indigenous for species naturally occurring within the country and is present in other countries, naturalized species for plants that are not originally native but become established and self-sustaining in the country, and cultivated but not naturalized for species that are maintained directly by humans often for human use. Floristic elements, on the other hand, represent phytogeographic distributions that indicate the extent of a species' native distribution. Species information on local and international conservation status was referred to DENR Administrative Order 2017-11 (Updated National List of Threatened Plants and their Categories) and the IUCN Red List of Threatened Species (2025), respectively.

Further, different biodiversity metrics were used to assess the plant biodiversity of the mangrove forests quantitatively, viz., Species Importance Value Index (SIVI), Shannon-Wiener Diversity Index (H'), Gini-Simpson Index of Diversity (D), Pielou Equitability Index (E), Margalef Index of Richness (R), Bray-Curtis Dissimilarity Index (BCDI), and Endemicity and Conservation Importance Indices (EI and CII, respectively) (Bullong *et al.*, 2024; Pocyoy and Napaldet, 2024). These indices were selected to quantitatively describe an array of floristic diversity information, i.e., species diversity (H' and D), species evenness (E), species richness (R), species dominance (SIVI), areal dissimilarity of species assemblage (BCDI), and the degree of the species community's endemism (EI) and proliferation of exotic and invasive species (CII). Moreover, Table S1 presents the biodiversity metrics equations and how the results were interpreted.

To explain the utilization of H' and D to assess the same aspect of species diversity, early studies show that the former is more sensitive to species richness, while the latter is more sensitive to species evenness (presence of dominant species in the area) (Johnson and Burnet, 2016; Nagendra, 2002). In addition, their respective approach (as defined in the formulae) distinguished their intent to interpret species diversity, i.e., H' measures the uncertainty in predicting the species identity from a random sampling, while D measures the probability that two randomly sampled individuals belong to different species (Roswell et al., 2021). While some studies opt to select one of the two indices (e.g., Alimbon and Manseguiao, 2021; Jumawan, 2022; and Goloran *et al.*, 2020), the majority of biodiversity studies utilize the two indices and are often complementary in interpreting species diversity (e.g., Bullong *et al.*, 2024; Calzeta *et al.*, 2024; Pocyoy and Napaldet, 2024; Pototan *et al.*, 2021).

The computations of the aforementioned biodiversity metrics were done using various software, with PAST 4.17 (Hammer *et al.*, 2001) used to determine H', D, E, and R; Microsoft Excel for SIVI, EI, and CII; and R 4.3.3 (R Core Team, 2024) via RStudio for BCDI. The computations for BCDI were further transformed into a dendrogram using the *vegdist* function of the *vegan* package (computation part) and R 4.3.3's *hclust* and *plot* functions (hierarchical clustering and visualization part, respectively). To elucidate, *vegdist* computes the pairwise BCDI of the sampling stations, *hclust* clusters the stations based on their pairwise values using an averaging algorithm, and *plot* visualizes the data as a dendrogram. This study uses the unweighted pair group method with arithmetic mean (UPGMA) algorithm to produce a dendrogram (Sokal and Michener, 1958). K-means clustering method is done with a *k* value of 3 (3 clusters) to visually show the groupings of the sampling stations into 3 groups. Advanced graphics manipulation of the dendrogram is achieved using the *factoextra* package (Kassambara and Mundt, 2020).

Carbon Stock Assessment

Biomass Determination – The total tree carbon stock of the mangrove forests was estimated by initially determining their biomass before converting it into their equivalent carbon content. The allometric equations of Komiyama *et al.* (2005) (Equation 15) and Chave *et al.* (2014) (Equation 16) were used to estimate the aboveground biomass (AGB) of mangrove and non-mangrove species, respectively. The equations require the diameter at breast height (DBH) and wood specific gravity (ρ), including the environmental stress factor (E) variable for Chave *et al.*'s (2014) equation. DBH is determined from the result of a circumference-to-diameter equation using the measured CCH of the trees. The ρ value is acquired from the database of Zanne *et al.* (2009) for tropical Southeast Asia, and in the instances of multiple values in a single species, the averaged ρ is determined. Moreover, species absent from the database are assumed to have a ρ of 0.574 based on the mean ρ for tropical Southeast Asia (Chave *et al.*, 2009). Finally, to determine the E value for the locale, the *computeE* function of the *BIOMASS* package (Réjou-Méchain *et al.*, 2017) is used using R 4.3.3. The AGB computed is expressed in kilograms.

$$\mathrm{AGB}_{est} = 0.251 \times \rho \times DBH^{2.46} \quad (15)$$

$$\mathrm{AGB}_{est} = \exp[(-1.803 - 0.976E + 0.976\ln(\rho) + 2.673\ln(DBH) - 0.0299[\ln(DBH)]^2] \quad (16)$$

To estimate the belowground biomass (BGB), the allometric equations of Komiyama *et al.* (2005) and Cairns *et al.* (1997) are used for mangrove and non-mangrove species, respectively (Equations 17 – 18). Likewise, the computed BGB is expressed in kilograms (kg). The sum of the AGB and BGB determines the total species biomass.

$$\mathrm{BGB}_{est} = 0.199 \times \rho^{0.899} \times DBH^{2.22} \quad (17)$$

$$\mathrm{BGB}_{est} = \exp(-1.0587 + 0.8836(\ln(AGB)) \quad (18)$$

Carbon Stock Determination – To convert the computed biomass into carbon stock, the biomass values were multiplied by the conversion factor of 0.44 for mangrove forests (Lasco and Pulhin, 2003). Moreover, to determine the estimated carbon stock per hectare, a summation of the sum (double summation) of all tree carbon content per plot *x* ($\Sigma\Sigma TCC_x$) is first averaged per station, then converted into a per-hectare value. Since it is best and standard to indicate the values in metric ton or megagram (Mg), a multiplicative factor of 0.001 converts the value from kg to Mg C. This process explains Equation 19.

$$\text{Carbon Stock per ha (Mg C ha}^{-1}) = \frac{\frac{\Sigma\Sigma TCC_x}{number\ of\ plots\ in\ station\ y}}{sampling\ area\ in\ m^2} \times \frac{1000\ m^2}{1\ ha} \times 0.001 \quad (19)$$

To determine the overall carbon stored in the area, estimated per-hectare carbon stocks per station were averaged before multiplying by the total site area. Excluding the nearby plantations of coconuts and bananas, the total mangrove forest area is estimated to be 4.37 ha, including the 0.65-ha ecopark. Equation 20 presents the formula for determining the total carbon stock of the study site.

$$\text{C Stock of Study Area (Mg C)} = \frac{\Sigma C\ Stock\ per\ ha\ of\ sampling\ station\ y}{number\ of\ sampling\ stations} \times study\ site\ area\ (ha) \quad (20)$$

Determining the equivalent carbon dioxide sequestered by the forests was computed using Equation 21 by multiplying the carbon content by a factor of 3.67. This value is derived from $C \rightarrow CO_2$ conversion, noting that C and O atoms have atomic masses of 12 and 16 amu, respectively, making CO_2 have a molecular mass of 44 g/mol. Thus, a CO_2–C ratio is equal to 44/12 or 3.67.

$$CO_2\ \text{sequestered} = C\ stock \times 3.67 \quad (21)$$

To determine whether a significant difference exists between sampling stations regarding carbon stock, with emphasis on the comparison between the remnant mangrove forests and the mangrove forest situated in the ecopark, a one-way analysis of variance (ANOVA) is used in conjunction with the Tukey post hoc test. Computations were done in the PAST 4.17 program.

Data limitations – In this study, given the limited time and monetary resources, the soil carbon stock is not included in the assessment, rendering the result underestimated. Estimations using existing studies in the Philippines do not satisfactorily provide an accurate soil carbon share, as results show a significant variation of soil carbon contribution to the total carbon stock of a mangrove forest, such as 23.76% in Padre Burgos, Quezon Province (Breva, 2022), 66.81% in Pagbilao, Quezon Province (Malabrigo *et al.*, 2017), 53.0% in Carigara Bay, Leyte Province (Decena *et al.*, 2024), and 40 – 90% in Macajalar Bay, Misamis Oriental Province (Lomoljo-Bantayan *et al.*, 2023).

RESULTS

Plant diversity of Batangas City Mangrove Forests

Species Composition – A total of 59 vascular plant species under 52 genera and 27 families were inventoried with the sampling station UPMAR (Station 1) being the most speciose among all sampling stations (n_s=27) followed by LOWMAR (Station 3) (n_s = 26) and the MIDMAR (Station 2) (n_s = 22) (Figure 2A). The ECOPARK is the least speciose, having only 9 species. Taxonomic richness-wise, the legumes family or Fabaceae has the greatest number of genera and species recorded (n_g = 8, n_s = 8), followed by the family of grasses or Poaceae (n_g = 5, n_s = 5), figs or Moraceae (n_g = 3, n_s = 5), and morning glories or Convulvulaceae ($n_g = 1$, $n_s = 4$) (Figure 2B). The rest of the identified families consist of fewer genera and species representatives, mostly two or one.

All recorded species are identified to be angiosperms, with 13 monocots and 46 dicots (Figure 2C). Moreover, the species comprise 19 canopy species, 12 understory species, and 28 forest floor species. Most forest floor species are in the UPMAR and LOWMAR stations (Stations 1 and 3, respectively). In contrast, canopy species are more abundant in the MIDMAR and ECOPARK stations (Stations 2 and 4, respectively) (Figure 2A). Understory species are moderate across the stations except in the ECOPARK station.

Regarding species endemicity, 8 (13.56%) are endemic, 25 (42.37%) are indigenous, 21 (35.59%) are naturalized, and 5 (8.47%) are cultivated but not naturalized (Figure 2D). Endemics are concentrated in the LOWMAR station (Station 3), with indigenous species more present in the UPMAR and LOWMAR stations (Station 1 and 3, respectively). On the other hand, exotics are more abundant in the MIDMAR station (Station 2).

The local species conservation status shows that 30 (50.85%) species are classified as other wildlife species (OWS), 2 (3.39%) are other threatened species (OTS), and 2 (3.39%) are vulnerable (VU) (Figure 2E). 25 (42.37%) species are uncategorized. On the other hand, referring to the international species conservation status through the IUCN Red List, 22 (37.29%) species are of least concern (LC), 1 (1.69%) species is endangered (EN), 1 (1.69%) is Data Deficient (DD), and 36 (59.32%) are not evaluated (NE). Locally threatened species (OTS and VU) are present along the entire Marjoya River (Stations 1 to 3), while the ECOPARK station (Station 4) houses none. The internationally recognized endangered species is found in the UPMAR station (Station 1). The least threatened and unassessed species are distributed across the sampling stations.

The specific species considered to be locally threatened are the following: OTS are *Acacia confusa* (local name: *akasya*) and *Artocarpus heterophyllus* (local name: *langka*), while the VU species are *Alternanthera sessilis* (local name: *bunga-bunga*) and *Ficus ulmifolia* (local name: *is-is*, *apling*) (Figure 2F). The internationally threatened EN species is *Swietenia macrophylla* (local name: *mahogany*). A full list of species with their endemicity and conservation categories is available in Table S2 of the Supplementary Materials.

Floristic Elements – At the generic level, a large percentage of the representative genera are pantropical ($n_g = 15$, 28.85%), followed by Indomalesian-Australian diffusion ($n_g = 6$, 11.54%) and neotropical ($n_g = 4$, 7.69%) genera. Fewer genera are cosmopolitan, Indomalesian, and paleotropical, with three (5.77%) representatives. The rest of the genera have only one or two representatives (see Table S3). Overall, 19 genera are tropical-affiliated (86.36%), 2 genera are *paleopolitan* (occurring both in the tropical and temperate Old World) (9.09%), and one genus is cosmopolitan (4.55%). There are no genera affiliated with the temperate elements.

On the other hand, at the species level, most of the species' floristic elements are either Philippinean ($n_s = 8$, 13.56%), Neotropical ($n_s = 6$, 10.17%), Caribbean ($n_s = 5$, 8.47%), Indochinese ($n_s = 3$, 5.08%), or Indomalesian-Northeast Australian diffusion ($n_s = 3$, 5.08%). The rest of the species' phytogeographic affiliations are enumerated in Table S4, where most floristic elements are tropical-affiliated.

Biodiversity Indices – The most dominant canopy species were the three mangrove species inventoried, i.e., *Avicennia marina*, *Rhizophora mucronata*, and *Sonneratia alba*, with SIVI of 25.264, 21.237, and 18.412, respectively. For the understory species, the dominant ones are *R. mucronata*, *Vachellia farnesiana*, and *A. marina,* with respective SIVIs of 23.267, 13.210, and 11.978 (Table 1). Further, the three most dominant forest floor species are *Coccinia grandis*, *R. mucronata*, and *Sida acuta* with SIVIs of 10.979, 10.961, and 9.080, respectively. Station-wise, the three mangrove species were usually the dominant species across the different sampling stations for the canopy and understory forest structures. The aforementioned understory species are also usually the dominant species per sampling station, although with the addition of some more species (e.g., *Cocos nucifera*, *Leucaena leucocephala*, *Nypa fruticans*, *Terminalia catappa*, etc.). For the case of forest floor species, the seedlings of *R. mucronata* and the herbaceous species *C. grandis* and *S. acuta* are the usual dominant species across the sampling stations. Table 1 presents the top three dominant species per sampling station and the overall site. Tables S5–S7 completely enumerate all inventoried species and their respective SIVIs.

Table 2 summarizes the different biodiversity indices regarding location (sampling station in this context), forest structure, and combined. The H' values of the sampling stations vary in location and forest structure. However, most values show an extremely low diversity, with only a few low or moderately diverse instances, except for the forest floor species. Overall, due to the contributive value of the high H' for forest floor species, the site is considered highly diverse (H' = 3.025), contradicting the results observed per component (per station or per forest structure in this context). As for the D values, most components are extremely diverse, with minimal moderately or highly diverse instances. The overall diversity in terms of D value is 0.897, which shows an extremely diverse community. However, considering that both H' and D indices measure diversity, the reason why D values appear higher than H' values is that the former is more sensitive to dominant species (influenced by species evenness) while the latter is sensitive to species richness.

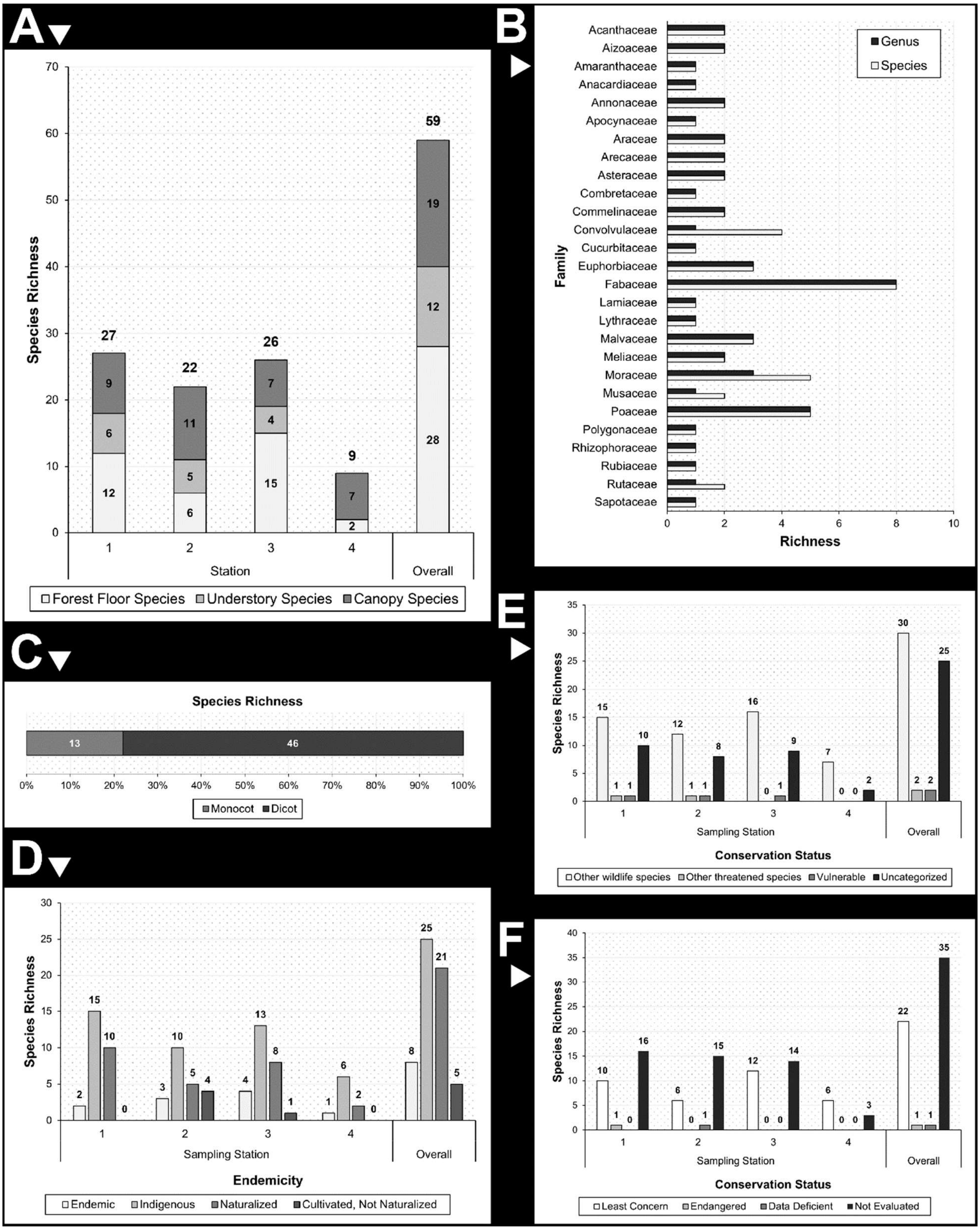

Fig. 2. Plant species composition of the study site. **A.** species richness per forest structure, station, and overall site, **B.** generic and specific richness per plant family, **C.** species richness in terms of plant division, **D.** species endemicity statistics, **E.** statistics on local species conservation status, **F.** status on international species conservation status.

Table 1. Dominant species per station and the overall site according to their species importance value index.

Category	Species Name	Species Importance Value Index				
		S1	**S2**	**S3**	**S4**	**Site**
Canopy	*Avicennia marina*	-	24.605 (2)	33.09 (1)	40.629 (2)	25.264 (1)
Canopy	*Azadirachta indica*	-	-	15.963 (3)	-	-
Canopy	*Cocos nucifera*	13.031 (3)	-	29.095 (2)	-	-
Canopy	*Rhizophora m*ucronata	24.158 (1)	7.584 (3)	-	46.909 (1)	21.237 (2)
Canopy	*Sonneratia alba*	14.182 (2)	33.193 (1)	-	12.462 (3)	18.412 (3)
Understory	*Allaeanthus luzonicus*	-	-	-	-	-
Understory	*Avicennia marina*	-	16.964 (2)	17.914 (2)	18.824 (2)	11.978 (3)
Understory	*Cocos nucifera*	-	-	-	7.941 (3)	-
Understory	*Kanapia monstrosa*	-	-	8.957 (3)	-	-
Understory	*Leucaena leucocephala*	11.522 (3)	-	-	-	-
Understory	*Macaranga tanarius*	-	-	-	7.941 (3)	-
Understory	*Melanolepis multiglandulosa*	17.283 (2)	-	-	-	-
Understory	*Nypa fruticans*	-	30.357 (1)	-	-	-
Understory	*Rhizophora mucronata*	30.978 (1)	13.393 (3)	-	49.412 (1)	23.267 (1)
Understory	*Terminalia catappa*	-	-	8.957 (3)	7.941 (3)	-
Understory	*Vachellia farnesiana*	-	-	43.182 (1)	7.941 (3)	13.210 (2)
Forest Floor	*Alternanthera sessilis*	-	-	10.185 (2)	-	-
Forest Floor	*Antigonon leptopus*	-	-	7.407 (3)	-	-
Forest Floor	*Asystasia gangetica*	12.404 (2)	-	-	-	-
Forest Floor	*Coccinia grandis*	12.084 (3)	33.333 (1)	-	-	10.979 (1)
Forest Floor	*Colocasia esculenta*	-	18.519 (2)	-	-	-
Forest Floor	*Ficus septica*	-	11.111 (3)	-	-	-
Forest Floor	*Ipomoea aquatica*	-	-	-	8.586 (3)	-
Forest Floor	*Murdannia nudiflora*	-	11.111 (3)	-	-	-
Forest Floor	*Rhizophora mucronata*	-	-	-	57.071 (1)	10.961 (2)
Forest Floor	*Sesuvium portulacastrum*	-	-	12.037 (1)	-	-
Forest Floor	*Sida acuta*	16.752 (1)	-	12.037 (1)	-	9.080 (3)
Forest Floor	*Sonneratia alba*	-	-	-	27.273 (2)	-
	Trianthema portulacastrum	-	-	7.407 (3)	-	-
Forest Floor	*Zamioculcas zamiifolia*	-	11.111 (3)	-	-	-

Note: **S1** – UPMAR Station (Agricultural-dominated area), **S2** – MIDMAR Station (Built-up-dominated area), **S3** – LOWMAR Station (Coastal-Riparian-Anthropic area), **S4** – ECOPARK Station (Human-managed area), **Site** – Overall study site. Results computed for the locale as of July 2024. Ordinal rankings are enclosed in parentheses.

Species evenness often ranges from moderately to highly even species composition across different locations and forest structures, with the overall community being highly even (E = 0.742). For the species richness, R values are often moderately rich, with some instances of having low richness and the unique example of high richness for forest floor species. The overall plant community is considered speciose (R = 9.518).

Most locations and forest structures have a moderate endemicity index. However, a few instances of canopy species have a lesser EI, while a single instance of understory species has a higher EI. This is also reflected in the moderate EI of the site (EI = 46.102). On the other hand, the conservation importance index of each component usually ranges from low to extremely low CII, with only a single instance of a moderate CII value for Station 2. Overall, the community has a low CII value (CII = 31.780).

Based on the information, details can be further gleaned by showing that H' and D values are positively related to species evenness (E), by showing that a diverse assemblage of species in the locale indicates a highly even species distribution, wherein a decrease in diversity also leads to a decline in species evenness. There is no clear relationship between species evenness (E) and richness (R), as some results show a positive relationship(e.g., Station 1 in the "Site" column) but other results indicate a negative effect (e.g., Station 2 in the "Forest Floor" column).

Areal Dissimilarity of Species Composition – A visualization of species dissimilarity per forest structure and the overall site is presented as dendrograms (Figure 3). Three distinct clusters were identified for canopy species: Station 1 and 4 cluster (UPMAR-ECOPARK), Station 2 (MIDMAR), and Station 3 (LOWMAR). This means that the species present in UPMAR and ECOPARK are similar, while the species MIDMAR and LOWMAR are highly distinct from the former and from each other due to the longer branch in the dendrogram (Figure 3A). For the understory species, there are also

Table 2. Biodiversity indices of the study site.

Index	Area	Canopy		Understory		Forest Floor		Site	
H'	S1	1.67	H'--	1.94	H'--	2.27	H'-	2.76	H'
H'	S2	1.28	H'--	1.73	H'--	1.69	H'--	2.52	H'
H'	S3	1.46	H'--	1.52	H'--	2.47	H'-	2.82	H'
H'	S4	0.69	H'--	1.28	H'--	0.86	H'--	1.07	H'--
H'	Site	1.74	H'--	2.44	H'-	3.04	H'+	**3.025**	**H'+**
D	S1	0.76	D+	0.81	D++	0.90	D++	0.90	D++
D	S2	0.86	D++	0.85	D++	0.81	D++	0.89	D++
D	S3	0.70	D+	0.72	D+	0.91	D++	0.92	D++
D	S4	0.45	D	0.65	D+	0.48	D	0.51	D
D	Site	0.75	D+	0.88	D++	0.94	D++	**0.897**	**D++**
E	S1	0.76	E+	0.78	E+	0.91	E++	0.84	E++
E	S2	0.56	E	0.89	E++	0.87	E++	0.82	E++
E	S3	0.75	E+	0.78	E+	0.89	E++	0.87	E++
E	S4	0.63	E+	0.72	E+	0.62	E+	0.49	E
E	Site	0.59	E	0.80	E+	0.88	E++	**0.742**	**E+**
R	S1	2.02	R-	2.87	R	2.87	R	5.23	R+
R	S2	2.34	R	2.27	R	1.82	R-	4.69	R
R	S3	1.97	R-	1.70	R-	3.76	R	5.33	R+
R	S4	0.51	R-	1.76	R-	0.86	R-	1.73	R-
R	Site	3.50	R	4.25	R	6.11	R+	**9.518**	**R+**
EI	S1	42.22	EI	50.00	EI	50.00	EI	48.15	EI
EI	S2	36.00	EI-	65.71	EI+	42.86	EI	45.45	EI
EI	S3	48.57	EI	48.57	EI	51.25	EI	51.54	EI
EI	S4	60.00	EI	53.33	EI	60.00	EI	55.56	EI
EI	Site	34.74	EI-	54.29	EI	51.11	EI	**46.102**	**EI**
CII	S1	30.56	CII-	31.25	CII-	37.50	CII-	32.41	CII-
CII	S2	33.33	CII-	28.57	CII-	42.86	CII	36.36	CII-
CII	S3	14.29	CII--	14.29	CII--	34.38	CII-	26.92	CII-
CII	S4	16.67	CII--	16.67	CII--	12.50	CII--	16.67	CII--
CII	Site	26.39	CII-	27.38	CII-	31.48	CII-	**31.780**	**CII-**

Note: H' – Shannon-Wiener Diversity Index, D – Gini-Simpson Index of Diversity, E – Pielou Equitability Index, R – Margalef Index of Richness, EI – Endemicity Index, CII – Conservation Importance Index. S1 – UPMAR Station (Agricultural-dominated area), S2 – MIDMAR Station (Built-up-dominated area), S3 – LOWMAR Station (Coastal-Riparian-Anthropic area), S4 – ECOPARK Station (Human-managed area), Site – Overall study site. Results computed for the locale as of July 2024. The verbal or descriptive interpretation of the shorthand symbols succeeding the index values can be referred to in Table S1.

three distinct clusters with the same grouping, that is, Stations 2 and 4 (MIDMAR-ECOPARK), Station 1 (UPMAR), and Station 3 (LOWMAR), although the MIDMAR-ECOPARK group has a longer branch compared to the dendrogram in Figure 3A, showing that despite being grouped as a single cluster, the species composition in MIDMAR and ECOPARK is still somewhat dissimilar, and extremely distinct from the species of UPMAR and LOWMAR (Figure 3B). The case is entirely different for the forest floor species with four clusters, i.e., Station 1, Station 2, Station 3, and Station 4 (not shown in the figure, check the caption of Figure 3 for details). Figure 3C shows that forest floor species in the four sampling stations are distinct from each other. Station 4 (ECOPARK) has a distinct forest floor composition from the rest of the sampling stations, rendering it not included in the dendrogram due to some null values in the output of the computational algorithm in RStudio.

Overall, when all species across the forest structure are combined, there are three identified clusters, viz., Stations 1 and 4 (UPMAR-ECOPARK), Station 2 (MIDMAR), and Station 3 (LOWMAR). The values, represented by the vertical lines that branched out, are above the BCDI of 0.5; therefore, there is a significant dissimilarity between the clusters.

Biomass and carbon stock of Batangas City Mangrove Forests

A total of 52, 47, 21, and 102 individual trees were inventoried for the carbon stock assessment of Stations 1 to 4, respectively, totaling 222 trees. The violin plots in Figure 4 show that the mean DBH for each station starting from Station 1 is 17.26 ± 14.86 cm (median = 11.62 cm), 22.42 ± 11.7 cm (median = 20.05 cm), 19.55 ± 9.34 cm (median = 17.51 cm), and 17.17 ± 10.4 cm (median = 14.64 cm), respectively. The highest mean DBH is in MIDMAR, followed by LOWMAR. Further inspection using species inventory shows that the reason why the mean DBH is higher in MIDMAR and LOWMAR (Stations 2 and 3) is due to the presence of larger species

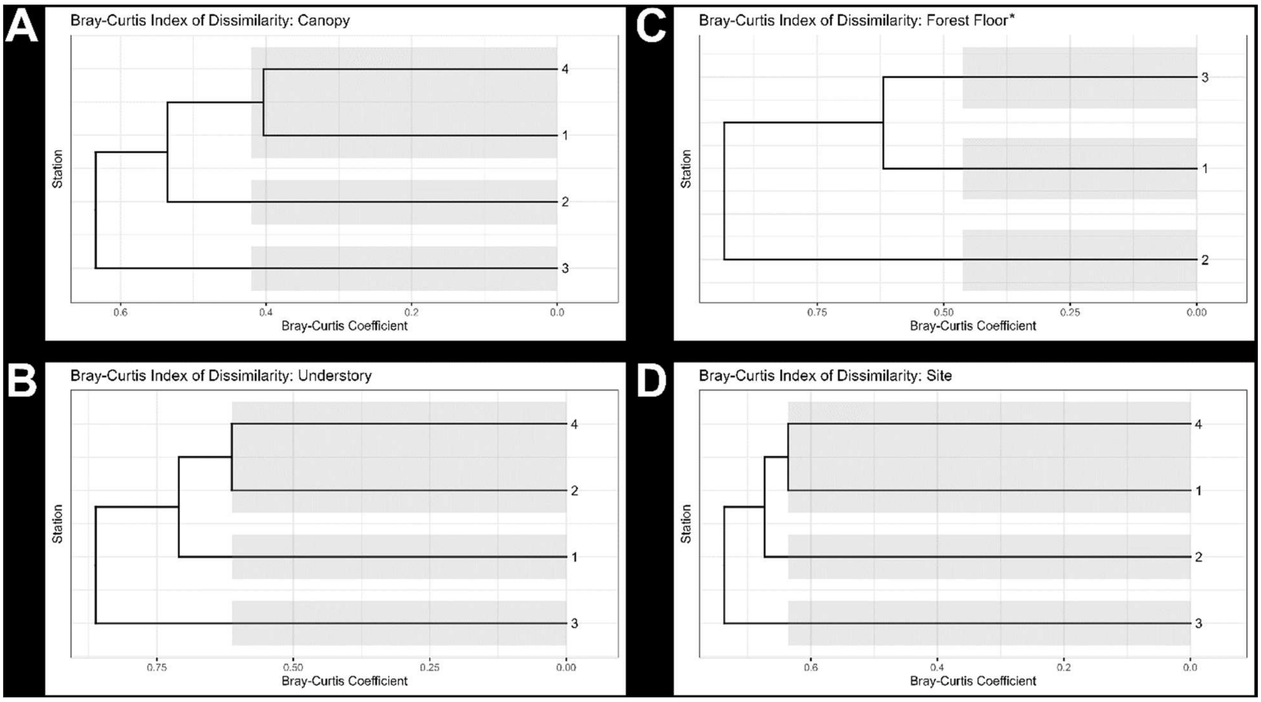

Fig. 3. Bray-Curtis Dissimilarity Index (BCDI) dendrograms. **A.** BCDI dendrogram for canopy species, **B.** BCDI dendrogram for understory species, **C.** BCDI dendrogram for forest floor species, **D.** BCDI dendrogram for the overall forest structure. *BCDI dendrogram for forest floor species only includes Stations 1 to 3. Station 4 is not included since the hierarchical clustering algorithm cannot proceed due to null-value errors. Manual data checking shows that many species in Station 4 are absent from the rest of the sampling stations. This affects the clustering algorithm, thus making it unable to create a dendrogram unless Station 4 data is removed.

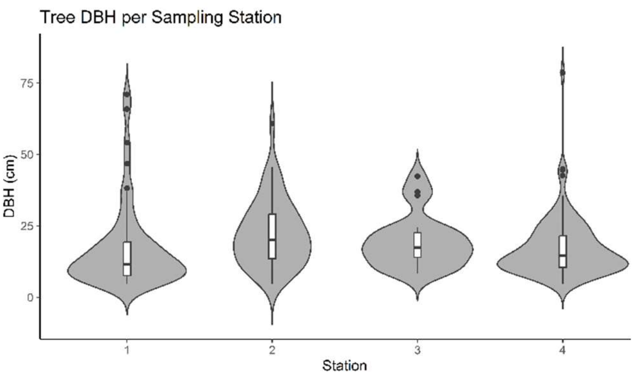

Fig. 4. Violin plots of the tree DBH distribution per sampling station.

of trees, such as S. macrophylla, S. alba, and C. nucifera, which also usually have the highest IVIs. Most species in the other stations are generally composed of thinner mangrove species (i.e., *A. marina* and *R. mucronata*), especially in the ECOPARK (Station 4).

The riparian vegetation along Marjoya River and the ecopark has a total tree biomass of 76.493 Mg (17.708 Mg ha^{-1}) (Table 3). This is equivalent to an estimated 33.657 Mg C (7.791 Mg C ha^{-1}) stored in its tree biomass, most of which is contributed by UPMAR and MIDMAR. When converted into its equivalent carbon dioxide, the riparian vegetation sequesters an overall total of 123.521 Mg CO_2 (28.594 Mg CO_2 ha^{-1}).

Using the biomass data of every species in each sampling station, the ANOVA yields a *p-value* of 0.00893 and an *F* value of 3.958. Since the *p-value* is below 0.05 ($p_{0.05}$) and the *F* statistic is larger than the *F* critical value (F_{crit} = 2.6460), there is a significant difference between the mean biomass of each station. The biomass data is used since the carbon and sequestered CO_2 data are derived from it. To determine specific significant differences among the sampling stations, a pairwise comparison is presented in Table 4. Tukey's post hoc test showed a substantial difference between the carbon stock of UPMAR and ECOPARK and between the MIDMAR and ECOPARK. Other pairwise comparisons between two sampling stations yield no significant comparisons at $p < 0.05$. The statistical analysis supports the visual inspection of the data, wherein UPMAR and MIDMAR stations have larger biomass, equivalent carbon, and sequestered CO_2 than the rest.

DISCUSSION

The riparian plant diversity of Marjoya river and Batangas City Mangrove Conservation Ecopark

Floristic Composition – The riparian plant diversity of the Marjoya River and Batangas City Mangrove Ecopark consists entirely of angiosperms, given that angiosperms constitute the largest taxon of the plant kingdom. Most species are dicotyledons, with only more than a fifth of monocotyledons, mostly in the form of grasses. The large

Table 3. Tree carbon stock and sequestered carbon dioxide (CO_2) of the study site.

Station	Area (ha)	Mg Biomass (m_B)†	Mg M_B ha^{-1}	Total Mg m_B	Mg C ha^{-1}	Total Mg C	Mg CO2 ha^{-1} sequestered	Total Mg CO2 sequestered
1	1.20*	28.72	23.93	28.72	10.53	12.64	38.64	46.37
2	1.12*	26.24	21.87	24.49	9.62	10.78	35.31	39.54
3	1.40*	11.22	9.35	13.09	4.12	5.76	15.10	21.14
4	0.65	18.82	15.68	10.19	6.90	4.49	25.32	16.46
Site	4.37	N/A	**17.708‡**	**76.493**	**7.791‡**	**33.657**	**28.594**	**123.521**

Note: S1 – UPMAR Station (Agricultural-dominated area), S2 – MIDMAR Station (Built-up-dominated area), S3 – LOWMAR Station (Coastal-Riparian-Anthropic area), S4 – ECOPARK Station (Human-managed area), Site – Overall study site. Results computed for the locale as of July 2024. *The station area is estimated and generally covers the greenbelt zone. †The estimated biomass of the sampling station.‡The estimated biomass and carbon stock per hectare for the site is the mean per hectare value of the four sampling stations.

Table 4. Tukey's pairwise test to determine the exact pairs of sampling stations with significant differences.

	Station 1	Station 2	Station 3	Station 4
Station 1		1	0.9998	**0.0346**[a]
Station 2	0.05349		0.9995	**0.0394**[a]
Station 3	0.1229	0.162		0.2548
Station 4	3.858	3.79	2.61	

Note: S1 – UPMAR Station (Agricultural-dominated area), S2 – MIDMAR Station (Built-up-dominated area), S3 – LOWMAR Station (Coastal-Riparian-Anthropic area), S4 – ECOPARK Station (Human-managed area). Results computed for the locale as of July 2024. Tukey's Q is located below the diagonal, while the *p*(same) is placed above the diagonal.
[a]Significant pairs are in bold typeface.

representation of leguminous species in the area can be attributed to Fabaceae being one of the largest families of flowering plants (Lewis, 2005). Further, research observations in Brazil and India, predominantly tropical countries, show that the family is among the dominant families identified in their study areas (Musisi *et al.*, 2025; Silva and Souza-Lima, 2013). Musisi *et al.* (2025) also pointed out that the resilience of Fabaceae species contributed to their dominance in riparian ecosystems despite the impacts of anthropogenic pollution. In addition, given that Fabaceae possess root nodules necessary for nitrogen fixing, the high amounts of riparian nitrogenous compounds in anthropogenically polluted rivers (Zhang *et al.*, 2015), such as the Marjoya River, and their relationship with the distribution of Fabaceae species, can be a good avenue for future investigations. This is because some identified Fabaceae species are also dominant with high SIVI values, viz., *Leucaena leucocephala* (local name: *ipil-ipil*) and *Vachellia farnesiana*.

The species endemicity of the area is somehow composed of equal representatives of native (endemic and indigenous) and non-native (naturalized and cultivated) species. Most of the endemics are concentrated in LOWMAR since it is originally part of the natural mangrove forests in the area and has the largest forest area among the sampling stations within the Marjoya River. The area is also a blend of three different ecosystem types, namely coastal, riparian, and agricultural, which have unique species composition and, due to edge effect and minimal disturbance, promote unique environmental conditions and habitat heterogeneity that can support high levels of floristic endemism and native species richness (Ferdiansyah and Ali, 2024; Sabo *et al.*, 2005). The increasing number of indigenous and especially exotic species in the MIDMAR and UPMAR is due to the anthropogenic disturbance that interferes with the original natural local ecosystems and provides means for the proliferation of non-native species and eventual spread into the local ecosystem, thereby reducing the existing ecological integrity and modifying the ecosystem services of the area (Gaertner *et al.*, 2017; McKinney, 2002). Satellite imagery (refer to Figure 1) reveals that the existing mangrove forests in the upper and middle portions of the Marjoya River are already fragmented and thinned due to the presence of houses and infrastructure that even extends to the riverbanks. On the other hand, the ECOPARK has the lowest number of non-native species due to the nature of being directly managed by the government and the presence of a monoculture stand of mangrove species.

To determine the source of the existing non-native species, phytogeographic distribution through floristic elements reveals that most of the exotic species that naturalized or cultivated in the area are originally from the nearby Indo-Pacific and the farther Neotropical regions. These non-native species were introduced by human vectors either accidentally or purposively (given their use in e.g., agriculture and horticulture), which results in competition with native plant populations, thus requiring conservation efforts to delimit their effects on local plant communities, especially in urbanized areas where intensive anthropogenic activities encourage the spread of nonnative species (McKinney, 2002; Rojas-Sandoval *et al.*, 2023). The presence of species with non-Philippinean floristic affiliations also increases the possibility of plant invasion due to their aggressive and rapid propagation that outcompetes local native plants.

Table 5. Biodiversity indices of some local urban and non-urban mangrove sites from reviewed literature in comparison with the findings of this study.

Site	Typology	H'	D	E	R	Source
Batangas City, Batangas	Urban	3.025	0.897	0.742	9.518	*This study*
Panabo City, Davao del Norte	Urban	1.027	-	0.638	0.515	Alimbon & Manseguiao (2021)
Cotabato City, Maguindanao del Norte	Urban	1.xx – 2.02	0.65 – 0.93	0.8x – 0.91	-	Dimalen & Rojo (2018)
Alabel, Sarangani	Urban	0.000 – 1.562	-	-	-	Jumawan (2022)
Lobo, Batangas	Rural	0.87 – 2.99	0.00 – 0.57	0.29 – 1.00	0.00 – 2.01	Calzeta *et al.* (2024)
Del Carmen, Surigao del Norte	Rural	0.958 – 3.211	0.46 – 0.95	0.39 – 0.88	-	Cortez *et al.* (2023)
Banaybanay, Davao Oriental	Rural	3.145	0.943	0.900	-	Pototan *et al.* (2021)

Note: Values denoted with "x" are uncertain since the base literature only provided the graph and no actual numerical values in text form are discussed.

Apart from the threat of exotic and invasive species, species extinction is also faced in the study site. Despite the notion that urban areas are already degraded natural ecosystems and regarded as having limited conservation value, urban areas are necessary for human-assisted conservation strategies, especially for the identified threatened species in the area (Gaertner *et al.*, 2017; Zhao *et al.*, 2023). One way to incorporate species conservation is to include threatened species in administratively protected areas such as ecoparks and green spaces. Further, the findings show that some species remained unassessed (e.g., the presence of data deficient and not evaluated species) and are possibly more threatened than their assessed counterparts (Roberts *et al.*, 2016; Borgelt *et al.*, 2022). This prompts collective efforts to assess the geographic distribution and population dynamics of these species, which involve both human and financial capital allocation.

Biodiversity Indices – Biodiversity indices at the community level show moderately high species diversity, richness, and evenness despite reaching low to moderate values when observed per forest structure or sampling station. This discrepancy in the result can be attributed to the scale of observation and the species' spatiotemporal arrangement in the community (Herrmann *et al.*, 2022; McCabe, 2011). It is pointed out by Sabo *et al.* (2005) that riparian ecosystems are not necessarily speciose; instead, the ecosystems' unique role as buffer landscapes and the edge effect phenomenon support significantly different species than their adjacent core ecosystems (Šálek *et al.*, 2013). Nonetheless, the results are comparable with other local urban (Alimbon and Manseguiao, 2021; Dimalen and Rojo, 2018; Jumawan, 2022) and non-urban (Calzeta *et al.*, 2024; Cortez *et al.*, 2023; Pototan *et al.*, 2021) mangrove sites with moderate and sometimes lower diversity, richness, and evenness (refer to Table 5 for the actual biodiversity index values). One reason the species diversity of the study area is higher than that of other non-urban mangrove sites can be attributed to the high number of exotic species, which are usually present in anthropic landscapes. The uneven population of native and non-native species in the site is also evident in the moderately high evenness (E) values reflected by the repeatedly dominant species (see species SIVI values).

The lack of general biodiversity indices to determine what affects the increase and decrease in species diversity and how it affects the local ecosystem can be further elaborated by the endemicity and conservation importance indices (EI and CII). These complementary indices highlight the need for conservation based on the weighted values of taxa, taking into account their endemicity and conservation status (Bullong *et al.*, 2024). The results show that the area has a moderate EI value; thus, it is still an ecologically resilient ecosystem, although it can be further weakened due to the alarming presence of exotic and invasive species and their impact on modifying the ecosystem (Gaertner *et al.*, 2017; McKinney, 2002). On the other hand, the area has a low CII value. This means that the area is approaching a threatened state due to the presence of some conservation-important species in the area. This is elaborated by the aforementioned narratives, showing how vulnerable unassessed species are and why conservation efforts must be redirected towards these species.

The EI and CII further assess the vulnerability of the ecosystem through simple information on endemicity and conservation status, which are not clearly defined by general biodiversity metrics. This illustrates that despite the high species diversity of the riparian vegetation of Batangas City as compared to other cited mangrove ecosystems in the country, some of the species inventoried pose risks to the natural forest landscape, such as the multiple presence of exotic and invasive species and the additional presence of conservation-important or threatened species.

A further observation of the species composition of each sampling site can also shed light on how species diversity is driven by existing land use proximate to the area. The Bray-Curtis dendrograms show that a sufficient fraction of taxa in the lower section of the Marjoya River (LOWMAR) differs from the other sections of the river and the ecopark. This is seconded by the midstream of the Marjoya River (MIDMAR), which also has a significant number of taxa different from the other sampling stations. Despite being clustered into one, the upper section of Marjoya River (UPMAR) and the ecopark (ECOPARK)

Table 6. Biomass and carbon stocks of some local urban and non-urban mangrove sites from reviewed literature in comparison with the findings of this study.

Site	Land Typology	**Biomass Density** (Mg ha^{-1})	**Carbon Stock Density** (Mg ha^{-1})	**CO_2 sequestered** (Mg ha^{-1})	Source
Batangas City, Batangas	Urban	17.708	7.791	28.594	*This study*
Panabo City, Davao del Norte	Urban	77.45	37.18	136.44	Alimbon & Manseguiao (2021)
Cotabato City, Maguindanao del Norte	Urban	604.94	490.69	1,799.83	Dimalen & Rojo (2018)
Butuan City, Agusan del Norte	Urban	9.308	4.375	16.065	Jumawan *et al.* (2024)
Pinabacdao, Samar	Rural	401.07	188.50	691.81	Abino *et al.* (2014a)
Puerto Princesa, Palawan	Rural	757.7	529.9	1944.5	Abino *et al.* (2014b)
Padre Burgos, Quezon	Rural	152.99, 133.68, 134.51	92.36, 139.07, 70.18	339.97, 510.41, 257.56	Breva (2022)
San Juan, Batangas	Rural	954.33	115.45	424.22	Gevaña & Pampolina (2009)
Macajalar Bay, Misamis Oriental	Rural	419.2	581.15	2,132.83	Lomoljo-Bantayan *et al.* (2023)
Pagbilao, Quezon	Rural	132.51	184.84	678.36	Malabrigo *et al.* (2017)

still significantly harbor different species since the forks of the dendrograms are above 0.5 (moderate species similarity/dissimilarity). A species similarity between UPMAR and ECOPARK can be due to the specific mangroves present at both sampling stations, as the latter only generally constitutes mangrove species.

Carbon stock and sequestration potential assessment of the riparian vegetation of Marjoya River and Batangas City Mangrove Conservation Ecopark

The upper and middle portions of the Marjoya River contributed the bulk of the entire site's biomass and carbon stock. This can be attributed to the species composition variance observed in the site using the BCDI, and that the majority of larger species inventoried are situated in the northern portion of the study area (refer to the violin plots in Figure 4). This is also supported by the results of the ANOVA and the post hoc assessment, which show that the upper and middle portions of the Marjoya River are significantly different in terms of biomass and carbon stock.

A review of the publication by Lasco and Pulhin (2003) unfortunately shows that the average biomass and carbon density of the study site fall short of the national average (~400 Mg ha^{-1} and ~170 Mg ha^{-1}, respectively). This can be attributed to the patch configuration of the sampling stations, where all riparian vegetation is constrained into long strips and is fragmented. Further, the violin plots in Figure 4 show that most species are still young due to their smaller DBH. To illustrate, the DBH of mature individuals of *A. marina*, *R. mucronata*, and *S. alba* can reach up to 70 cm, 20 cm, and 120 cm, respectively (Primavera *et al.*, 2004). Given that species growth follows a sigmoidal curve, it can be projected that the annual biomass gains and carbon sequestered will further increase. However, it is still recommended that the area coverage of the mangrove forest be further expanded to keep up with the increasing carbon emissions associated with the ongoing urbanization process.

In addition, comparison with other site-specific studies shows that the biomass and carbon stock densities of the locale are mostly low compared to those of other studied urban (Dimalen and Rojo, 2018; Alimbon and Manseguiao, 2021; Jumawan *et al.*, 2024) and non-urban (Gevaña and Pampolina, 2009; Abino *et al.*, 2014a,b; Malabrigo *et al.*, 2017; Breva, 2022; Lomoljo-Bantayan *et al.*, 2023) mangrove forests in the Philippines, except for the findings of Jumawan *et al.* (2024), which have lower values since they only considered aboveground partitions (refer to Table 6 for actual values). Representative sites from other nearby countries also show that the findings of this study on carbon stock density are lower compared to those in Aceh, Indonesia (81.37 Mg C ha^{-1}) (Dewiyanti *et al.*, 2024), Selangor, Malaysia (151.40 – 246.21 Mg C ha^{-1}) (Hong *et al.*, 2017), Yangon, Myanmar (150.25 Mg C ha^{-1}) (Aye *et al.*, 2022); Kerala, India (139.82 Mg C ha^{-1}) (Harishma *et al.*, 2020), and Taiwan (134.50 – 292.23 Mg C ha^{-1}) (Lin *et al.*, 2023); though, higher than that in Flores Island and West Kalimantan, Indonesia (0.56 – 0.78 Mg C ha^{-1} and 0.36 – 7.24 Mg C ha^{-1}, respectively) due to their relatively younger age (Wiarta *et al.*, 2019; Wirabuana *et al.*, 2025).

Emphasizing the comparison with other local sites in the Philippines, the available locale maps show that the typology (urban or rural) can affect the biomass and carbon densities, including the CO_2 sequestration capability of thearea. This can be observed where rural areas have significantly higher values than urban areas, albeit it still depends on the extent of the mangrove forest. The other sites studied based on the reviewed literature have extensive coverage compared to the minimal and often fragmented coverage of this study's site. It has been documented from previous investigations that fragmented forests usually decrease carbon capture and instead increase carbon emissions as forest fragmentation decreases patch size and increases edge areas, which in turn alter microclimate and increase the vulnerability and mortality of tree species (Islam *et al.*, 2017; Ma *et al.*, 2017; Fischer *et al.*, 2021).

In addition, this study only limits the data to complete vegetation partition and neglects the contribution of soil carbon. There are existing studies that highlighted the significance of soil or sediment to sequester carbon, as the

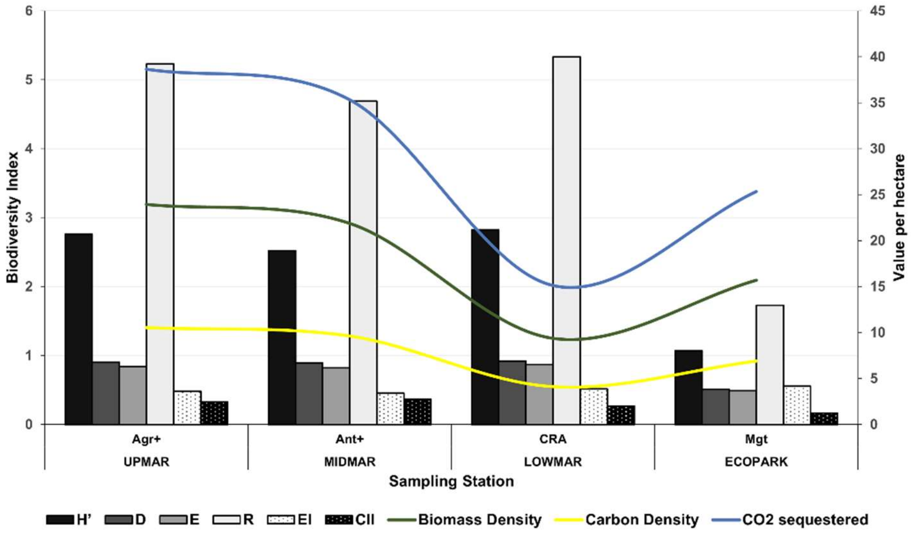

Fig. 5. Combination diagram of biodiversity indices and computed biomass, carbon, and CO2 densities. *Legend: H' – Shannon-Wiener Diversity Index, D – Gini-Simpson Index of Diversity, E – Pielou Equitability Index, R – Margalef Index of Richness, EI – Endemicity Index, CII – Conservation Importance Index; UPMAR – Upstream of Marjoya River, MIDMAR – Midstream of Marjoya River, LOWMAR – Downstream of Marjoya River, ECOPARK – The City Mangrove Conservation Ecoporak; Agr+ - Agricultural-dominated land use, Ant+ - Anthropic-dominated land use, CRA – Coastal-Riparian-Agricultural Blend Ecosystem, Mgt – Human-managed land use. Note: The left axis values are intended for biodiversity indices (columns) while the right axis values are intended for biomass, carbon, and CO_2 densities (lines).

bulk of blue carbon sinks can be traced to the soils (Malabrigo *et al.*, 2017; Lomoljo-Bantayan *et al.*, 2023; Castillo and Castillo, 2024). If further investigations were possible, the results of this study may not be underestimated and can be comparable to other urban mangrove sites from the reviewed literature. As mentioned in the previous section, the researchers did not utilize conversion factors to determine the estimated soil carbon due to high variability in results across local and regional areas. Still, it is recommended that the existing edge areas be decreased by linking fragmented forests, thereby increasing the patch size along the riparian area.

Nonetheless, the existing forest cover is still important in the city's carbon capture. Blue carbon storage remains an important contributor to global carbon capture due to its effective carbon storage, typically through its belowground or soil compartment, which can even surpass terrestrial ecosystems (Mcleod *et al.*, 2011; Rovai *et al.*, 2022; Song *et al.*, 2024). Mangrove forests are vital blue carbon sinks, capturing significant amounts of carbon and making them essential for national and global efforts to reduce carbon emissions. Incorporating mangrove conservation and management into climate policies can enhance the protection and restoration of mangroves. This integration ultimately supports the achievement of international climate goals, as outlined in the Paris Agreement (Choudhary *et al.*, 2024).

The Relationship of Land Features, Floristic Biodiversity, and Carbon Stock

To further determine the relationship between land use, floristic diversity, and carbon stock, a combination diagram is created to see how different land use types affect biodiversity and carbon storage (Figure 5). The behavior of species diversity, particularly the H' and D indices, are related to species richness and evenness: H' and D are higher when the area is species rich, even, or both, though H' is more sensitive to species richness (R) while D is more sensitive to species evenness (E) (since D is easily affected by dominant species) (Johnson and Burnet, 2016; Nagendra, 2002; Strong, 2016). EI and CII values are independent of sample size and sampling extent, as they utilize different species information, i.e., phytogeographic distribution and conservation status, to assess the condition of the ecosystem (Bullong *et al.*, 2024).

Based on the results, agricultural-dominated (UPMAR), anthropic-dominated (MIDMAR), and hybrid ecosystems comprising Coastal-Riparian-Anthropic blend (CRA) are all species diverse, rich, and even in their respective land use. This can be supported by the species dissimilarity dendrograms, where each sampling station significantly differs from the others. The agricultural ecosystem adjacent to the riparian vegetation of UPMAR harbors species different to MIDMAR station where majority of the land use is built-up and the presence of exotic species are prevalent, which in turn, is also different to the blend of coastal, riparian, and human land use (agricultural and residential) ecosystem in LOWMAR. This is true of Sabo *et al.* (2005) mentioned that riparian zones "[harbor] different, not more, species," since these ecotonal regions are usually a merger of two or more biological communities and are sensitive to the ecosystem type with which they are adjacent to (Šálek *et al.*, 2013). On the other hand, the human-managed mangrove ecopark (ECOPARK) yields lower biodiversity index values and can be traced to habitat simplification (e.g., less environmental heterogeneity, lower genetic diversity, and vegetation homogenization) done by humans as compared to complex ecological structures and established biogeochemical cycles present in natural environments (Carugati *et al.*, 2018; Zimmer *et al.*, 2022; Lin *et al.*, 2024).

Concerning the relationship between plant diversity and carbon stocks, it has already been mentioned in previous studies that the relationship is usually scale-dependent, species composition-dependent, and contradictory (Di Marco *et al.*, 2018; Van de Perre *et al.*, 2018), with some studies showing a positive relationship (e.g., Chen *et al.*, 2018; Haq *et al.*, 2024), while some firmly assert a weak to negative or no relationship at all (Mandal *et al.*, 2014; Banoho *et al.*, 2020; Gebrewahid and Meressa, 2020; Sunardi *et al.*, 2020). In the case of Marjoya River, higher biomass and carbon stocks were observed for agricultural-dominated and anthropic-dominated landscapes of UPMAR and MIDMAR, respectively, while lower in the natural-anthropic hybrid ecosystem of LOWMAR. On the other hand, moderate results were identified for the human-managed ecopark. Based on this, it can be initially thought that anthropic landscapes (agricultural, built-up, and managed lands) can sequester more carbon than disturbed natural landscapes. However, caution should be applied as this was not necessarily the case. Referring back to the violin plots, the DBH size distribution significantly affected the carbon stock of the sampling stations. Moreover, taxonomic classification of the species also contributed to the differences in the results as genetics govern their growth rate and morphometry (i.e., DBH and volume sizes), and how the presence of non-native (exotics and naturalized) species affected the results as non-native species usually grow faster and larger and can accumulate biomass quicker (Montesinos, 2022). Therefore, it is better to interpret the findings of this study by concluding that the relationship between plant diversity and carbon stock is not significant and is open to variation. However, it is still important to note that land use still plays an important role in the efficacy of a certain ecosystem in sequestering carbon. Natural ecosystems have more complex structures than modified or simplified structures in anthropic-dominated landscapes.

To synthesize, the variances in species composition between these sampling stations, despite their proximate distances to each other, can be due to the vegetation fragmentations, vegetation area, and the land use types proximate to it. There is no observed significant relationship between plant biodiversity and carbon stock. However, human-managed ecosystems like the conservation ecopark are an important avenue for blue carbon capture efforts, as they can capture and store carbon comparably with other natural ecosystems.

Recommendations for Management and Conservation

The following narratives are some of the recommendations derived from the findings of this study:

Management of exotic species – The database of CABI (2024) and the Global Compendium of Weeds by Randall (2017) provide a comprehensive list of invasive species, as well as the latter's inclusion of a global risk score, a quantifiable method of prioritizing invasive species for management and control (Randall, 2016). Controlling the propagation of these exotic species while maintaining their socioeconomic importance is necessary since some of the recorded species are agriculturally important (e.g., *A. squamosa* and *A. heterophyllus* are fruit-bearing trees), potential phytoremediators (e.g., *Cenchrus purpureus* or Napier grass), and horticulturally used (e.g., *Monoon longifolium* as a landscape ornamental) (Belnap *et al.*, 2012).

Despite the notion that exotic species are fast-growing and can sequester more carbon, the long-term benefits of native species in carbon sequestration outweigh the ecological harm that exotics can do to their non-native environment, given the state of global climate volatility (Lázaro-Lobo *et al.*, 2023). With the presence of exotics in the area, it is recommended that selective thinning be implemented for exotic species. Moreover, selected exotic species can also act as nurse species to facilitate native species regeneration, where short-term carbon storage is achieved while the forest transitions from exotic to native species (Pritchard *et al.*, 2024).

Conservation of threatened species – Given the urban landscape, the survival of these species requires human-assisted conservation efforts. This involves prioritizing their growth and reproduction, and the possible inclusion of these species as riparian vegetation to increase the species richness of the existing conservation ecological park of the city. Suggested interventions are the following: retaining local native vegetation during project developments, promoting ecological succession of native species in ruderal areas, and prioritizing native and threatened species in urban green spaces (McKinney, 2002).

Utilization of existing flora in urban planning and management – As evident by the biodiversity status and low carbon capture of the riparian vegetation, it is recommended that the available green spaces of the area be expanded. This also aligns with the existing documents on the target land use plan of the affected barangays, specifically focusing on the greenbelt zone along Marjoya and Calumpang Rivers. The actual status of the forests shows that they are fragmented and are vulnerable to the existing exotics thriving in the area. Moreover, it is proposed that the identified native threatened species be included as cohabitants of the mangrove conservation ecopark, as it is under the direct management of the local government. On the other hand, to manage the existing exotic species, it is recommended that their population be reduced, specifically for aggressive invasive species. In addition, some identified exotic species in the area, i.e., *C. purpureus* and *Ipomoea aquatica*, are supported by studies to be great phytoremediators and candidate species for establishing constructed wetlands to minimize the existing water pollution in the area (Li and Li, 2009; Anit *et al.*, 2015; Napaldet and Buot, 2019; Galve *et al.*, 2021; Guila *et al.*, 2024).

Policy Formulation and Community Participation – Further local policies should be implemented to support existing national mangrove conservation and management policies. As supported by on-site observations during the fieldwork of this study, focus should be given to proper solid waste management along the riparian and coastal areas to address excessive pollution that affects the local biodiversity and land and water quality. Further, the local government should implement the appropriate buffer zone or easement along riverbanks as this can reduce environmental hazards for affected residents (e.g., during floods) and ample space for greenery by extending the existing mangrove forests and addressing the fragmented vegetation land use along the greenbelt zone of the city as indicated in their existing land use plan. The mangrove rehabilitation and expansion recommendations can also serve as biodiversity corridors and enhance ecosystem health by treating patch fragments and reducing vulnerable forest edges. Nonetheless, community environmental awareness is also important, highlighting the need for their involvement in government programs and activities, such as but not limited to information, education, and communication (IEC) campaigns, coastal and river clean-up drives, project development consultations, and greening programs. There is a necessity for multipartite cooperation involving the government, private sectors, and the community to address the existing issues of the site.

CONCLUSION

The assessments of the riparian floristic diversity and carbon stock of the Marjoya River highlight the critical role these urban ecosystems play in maintaining biodiversity and contributing to carbon capture. The study reveals that despite the challenges posed by pollution and habitat degradation, the Marjoya River still supports a variety of plant species, including native and threatened ones, which are essential for the local ecosystem's resilience and functionality. Moreover, the area remains an important blue carbon sink for the city.

Key findings show that a total of 59 plant species were identified, with a mixture of native and exotic species. However, through various biodiversity metrics, the moderate species diversity and the alarming presence of exotic species populations across sampling stations suggest that urban disturbance significantly impacts the ecosystem's health. On the other hand, carbon stock assessment shows that the riparian vegetation has sequestered approximately 33.657 Mg C, equal to around 123.521 Mg CO_2, thereby contributing to the local carbon capture and storage.

Based on the research findings, conservation recommendations were also included, as the study underscores the need for effective conservation strategies, including protecting threatened species and establishing and expanding green spaces. Some of the proposed actions include the reduction of the population of exotic species, cohabitating threatened species in the established conservation eco-park, and utilizing identified species as phytoremediators. These measures are vital for enhancing the ecological integrity of the urban landscape and ensuring the sustainability of the local biodiversity.

Overall, the findings of this study serve as a call to action for local authorities and stakeholders to prioritize the conservation of urban riparian ecosystems. By implementing proper land use planning and management practices, we can safeguard these vital areas against further degradation and promote a healthier environment for wildlife and the community. The Marjoya River stands as a testament to the potential of urban ecosystems to thrive amidst challenges, provided that concerted efforts are made to protect and restore them.

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