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Heavy Metal Levels and Length-Weight Dynamics of *Anodontia philippiana* (Reeve, 1850) from Barobo and Hinatuan, Surigao del Sur, Philippines

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A B S T R A C T

Anodontia philippiana is among the commercially valuable edible clams found in Brgy. Wakat, Municipality of Barobo, and Brgy. Loyola, Municipality of Hinatuan, Surigao del Sur, Philippines. However, anthropogenic activities may pose a threat to the abundance and quality of this species. This study aimed to determine the levels of lead (Pb), nickel (Ni), chromium (Cr), and mercury (tHg) in both the sediments and flesh of *A. philippiana* using Atomic Absorption Spectrophotometry (AAS). Additionally, the length-weight relationship (LWR) of *A. philippiana* was assessed to determine the size structure of the species' population. Among the heavy metals tested, only the concentration of Cr (59±0.38 ppm) in Hinatuan exceeded the prescribed tolerable limit of ≥50 ppm (FAO, 1993). Conversely, the heavy metal levels in the flesh of *A. philippiana* consistently remained below tolerable limits. Furthermore, *A. philippiana* from Barobo exhibited a positive allometry (B>3), while those from Hinatuan showed a negative allometry (B<3), suggesting the influence of environmental stressors on growth patterns. The LWR in *A. philippiana* exhibited significant differences (P<0.001) between the two stations. Despite heavy metal concentrations in *A. philippiana* flesh and sediments were mostly below standard limits, the observed negative allometric growth pattern in Hinatuan indicates the presence of ecological stressors in the sediments. This study underscores the potential impact of heavy metals on the growth patterns of *A. philippiana.* It is recommended that regular monitoring of heavy metal concentrations be conducted in these areas. Further studies can provide better insights into morphometric patterns in *A. philippiana* and other commercially significant bivalves.

Keywords: *allometry, bioaccumulation, environmental stressors, growth patterns, LWR*

1 Introduction

Heavy metals are metallic elements or metalloids that pose a significant risk to the environment and human health due to their toxic properties. These substances are present in varying concentrations in the Earth's crust and can enter soil and water systems through natural processes and human-related activities (Tchounwou et al. 2012). Heavy metal pollution occurs when the concentration of these elements exceeds the required or desired levels in living organisms, leading to various dysfunctions in cellular components. The pollution of heavy metals has become a pressing environmental issue due to anthropogenic activities and industrialization. Human-related activities such as mining, smelting, fossil fuel usage, waste disposal, and manufacturing processes are the primary sources of heavy metal pollution (Asati et al. 2016).

Once these elements enter the food chain through soil and water, they can accumulate in the tissues of living organisms, affecting their health and survival. While some heavy metals are essential for daily nutrition, excessive amounts of others, such as lead, nickel, chromium, and mercury, can harm organisms and cause issues with growth, reproduction, and survival. The environment plays a crucial role in transporting and distributing heavy metals, and various environmental factors, such as soil and water properties, can influence their dispersion. The bioavailability of heavy metals can be affected by the physical and chemical conditions of the environment, making some areas more prone to contamination than others. Heavy metal pollution in the environment can lead to biodiversity loss and ecosystem changes (Jaishankar et al. 2014).

There have been studies on heavy metal accumulation in bivalves in Cagayan Valley (Raju 2021), Davao Oriental (Bersaldo et al. 2022), and Manila Bay (Montojo et al. 2021). These studies indicate that bivalve mollusks, such as clams, are known to have the ability to accumulate heavy metals and are widely used as bioindicators for monitoring heavy metal pollution in aquatic environments. Due to their efficient filter-feeding mechanism, these animals directly ingest metal-enriched particles, demonstrating their bioaccumulation capability in their habitat. Heavy metal accumulation in bivalves and the environment has become more frequent with increased human activity. Prolonged exposure to these pollutants can adversely affect the growth and morphology of bivalves, particularly in terms of length and weight (Raju 2021). Moreover, high concentrations of these heavy metals can also pose risks to humans, depending on the mode of exposure and the nutritional state of the exposed marine organism (Tchounwou et al. 2012).

Anodontia philippiana (Reeve, 1850) is commonly found in mangrove mudflats and intertidal sandy beaches. These clams are significant in abundance, biomass, and density. They play a crucial role in the food chain and food webs of mangrove forests, serving as primary mollusks (Myers et al. 2011). *A. philippiana* is widely distributed in the Indo-West Pacific region. In the Philippines, it is considered a seafood delicacy known as "Imbao" in Surigao del Sur. Due to their large size, high protein content, and ample flesh, they are highly valued in the region (Bersaldo et al. 2022). These clams provide a vital source of accessible protein for higher trophic levels, contributing to the shift from primary forest production to higher trophic levels in animal production (Carter 2014).

Surigao del Sur is a province characterized by an extensive network of streams and oceans, where small-scale gold mining activities are prevalent (Quisil et al. 2014). The Sorex River, also known as the Tambis River System, flows through the municipality of Barobo and neighboring areas, which are well-known for small-scale mining activities (Fajardo et al. 2015). This river serves as the primary source of water that empties into the Hinatuan coast, where fishing and artisanal fishery are the primary livelihoods of local communities. Despite the popularity of commercially sold *A. philippiana* as a food source in the Municipalities of Barobo and Hinatuan, limited information is available regarding the levels of metal contamination, including lead (Pb), nickel (Ni), chromium (Cr), and mercury (tHg), as well as the allometry, length-weight relationships, and the physical and chemical variables of the *A. philippiana* habitat. This study aims to determine the physicochemical properties of water in the coastal areas of Barobo and Hinatuan, Surigao del Sur, establish the length-weight relationship (LWR) of *A. philippiana*, and quantify the concentration of Pb, Ni, Cr, and tHg in both *A. philippiana* flesh and sediments collected from the sampling stations.

2 Materials and Methods

Study Area

The study was conducted in two municipalities of Surigao del Sur— Brgy. Wakat, Municipality of Barobo and Brgy. Loyola, Municipality of Hinatuan, Surigao del Sur, Philippines (Figure 1). Both are mangrove areas and local collection sites for the commercially sold *A. philippiana*. The sampling site in the Municipality of Barobo (8°34'9.876" N, 126°6'50.652" E) is located relatively far from residential areas and mining sites. On the other hand, Brgy. Loyola in Hinatuan (8°21'12.1824" N, 126°19'7.1004" E) serves as the primary exit point of the Tambis River system. This river system is a slow-moving water channel, approximately 15-20 m in width, stretching up to 20 km, and known for the highest number of small-scale mining activities in the Province of Surigao

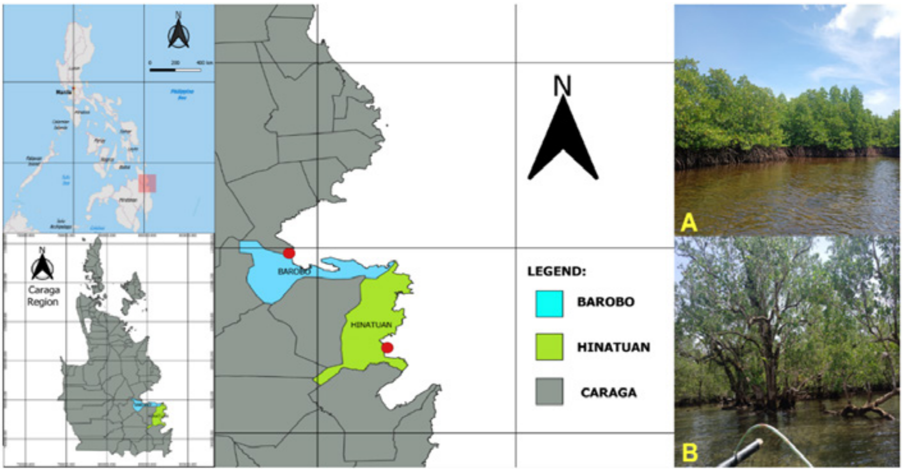

Figure 1. Map showing the study sites in Brgy. Wakat, Municipality of Barobo (blue; A) and Brgy. Loyola, Municipality of Hinatuan (green; B), Surigao del Sur, Philippines

del Sur (Fajardo et al. 2015). Sampling was done during the low tides of August 2022 to ensure efficient collection of *A. philippiana* and sediments.

Sample collection and preparation

Determination of physicochemical parameters (pH, dissolved oxygen, electroconductivity, temperature, total suspended solids, and salinity) was done using the Hanna Multiparameter Portable Meter (Hanna Instruments, Ltd.). The probe was submerged in the surface water until measurements were displayed and data were logged.

The sediment samples were collected using the protocol of the Association of Analytical Communities (AOAC) Official Method 999.11 for analyzing samples, with slight modifications based on the availability of *A. philippiana* in the sediment stations, which were subjectively selected. Pooled wet sediment samples were collected using an improvised non-metal grab sampler. Non-sediment components were removed by hand. The *A. philippiana* samples in these areas were hand-picked for Length-Weight Relationship analysis. The *A. philippiana* adults were measured for their shell length (cm) using a vernier caliper and an analytical scale for the weight (g). The mature individuals (at least 3.5 cm; n=15) were utilized for heavy metal analysis. The flesh was removed from their shells and pooled. The collected samples were subsequently placed in a resealable bag, properly labeled, stored in an ice-filled chiller, and transferred to the laboratory in less than 24 hours for digestion and analysis.

Heavy metal analysis of sediment

Careful homogenization of the material and equipment was carried out in the laboratory to prevent cross-contamination. Methods for the acid digestion of sediments of the United States Environmental Protection Agency (U.S. EPA) were used (U.S. EPA 1996). Personnel trained in acid-related stages performed the digestion operation by transferring a sample weighing 1-2 g (wet weight) or 1 g (dry weight) to a digestion vessel. An acid vapor scrubber system was recommended for the fume hood during the operation for safety purposes. The sample underwent heating and cooling and concentrated HNO_3 until the reaction was complete. After the evaporated solution, water and 30% H_2O_2 were added, and the sample was subjected to another round of heating and cooling. The resulting digest was filtered, centrifuged, or settled before analysis by Flame Atomic Absorption Spectrometry (AAS) for Pb, Ni, and Cr, while Cold Vapor AAS for tHg.

Heavy metal analysis of A. philippiana flesh

HM metal in flesh was done following the protocol of the Association of Official Analytical Chemists (AOAC) International (2019). The pre-treatment involved drying a 10-20 g test portion of the samples using a drying oven, water bath, or hot plate at 100°C. The ashing process involved gradually raising the temperature to 450°C at a maximum rate of 50°C/h, allowing it to sit for at least eight hours or overnight, and adding 1-3 mL of water to wet the ash. The ash dissolved in 0.1M HNO_3, and the analytes using flame and graphite techniques were identified. After digestion, the residue was dissolved in 10.0-30.0 mL of 0.1M HNO_3, and the calibration curves were constructed using at least three standards with background corrections. The analytes of interest, namely Pb, Ni, and Cr, were analyzed using Flame AAS, while Cold Vapor AAS was used to determine the concentration of tHG.

Data analyses

The length-weight relationship was determined by the equation $W = aL^b$, where 'W' is the total body weight, 'a' is the regression intercept, 'L' is the average length, and 'b' is the regression coefficient (Urban and Campos 1994; Urban 2000). The regression coefficients 'a', 'b,' and the coefficient of determination (R^2) were assessed by least squares regression inquiry of the logarithm transformed LWR illustration Log W = b log L + log a. The value of 'b' was used to determine the growth pattern: b=3, isometric growth; b>3, positively allometric growth; and b<3, negatively allometric growth. The strength of the relationship between the variables X and Y was indicated by the regression analysis's coefficient of determination 'R^2' values (Vasconcelos et al. 2018).

Significant differences between the groups of heavy metals were determined using the Mann-Whitney U test. Any correlations between variables of the length-weight were determined using Spearman rank order correlation and point biserial correlation. Differences with $P<0.05$ were considered statistically significant.

3 Results and Discussion

Physico-chemical analysis of surface water

The physical and chemical characteristics of seawater were analyzed at two coastal stations in Surigao del Sur (Table 1). The results indicated that, out of the six parameters tested in the Municipality of Barobo, the electroconductivity (EC) and temperature met the required minimum water quality standards according to DAO (2016) and USEPA (1976) guidelines. Similarly, in Hinatuan, the pH, temperature, and total suspended solids were within the required minimum levels. However, the dissolved oxygen (DO) and salinity levels at both stations, along with the pH and total suspended solids (TSS) in Barobo and the electrical conductivity (EC) in Hinatuan, did not meet the required standards. Further analysis revealed no significant difference in the physicochemical parameters between the two stations ($P>0.05$).

The physicochemical parameters are indicators of water quality in the area (Awoyemi et al. 2014). The impacts of human activities on water quality are extensive and diverse, to the extreme point that they destroy the natural flow and limit water use that may affect the marine organism and their habitat (Bhadja and Kundu 2012). Notably, the dissolved oxygen (DO) for both areas did not reach the minimum levels, with 2.74±0.31 ppm and 2.08±0.38 ppm in Barobo and Hinatuan, respectively. DO is the concentration of oxygen gas dissolved in water. Sufficient DO is critical for bivalves' respiration, which can significantly affect their growth and reproduction. Low DO levels can cause hypoxia, which may adversely affect marine organisms (Ning et al. 2011).

Heavy metal analysis of sediments

Concentrations of heavy metals in the sediments from the Municipalities of Barobo and Hinatuan are summarized in Table 2. The order of the average concentrations of heavy metals in the sediment in Barobo is Pb>Cr>Ni>tHg, while samples in Hinatuan are Cr>Pb>Ni>tHg. Only Cr

Table 1. Physicochemical characteristics of seawater in the Municipalities of Barobo and Hinatuan stations in comparison to the recommended levels of local and international standards

Parameters	Mean±SD		P-value	DAO (2016)	USEPA (1976)
	Barobo	Hinatuan		Range/ Min. levels	
pH	6.65±0.51*	7.12±0.10	0.10	7.0–8.5	6.5–8.5
Dissolved Oxygen (ppm)	2.74±0.31*	2.08±0.38*	0.20	5	5
Electroconductivity (µs/cm)	48.36±0.96	58.21±19.16*	1.00	30–55	–
Temperature (ºC)	30.22±0.18	30.98±0.06	0.10	26–30	29–32
Total Suspended Solids (mg/L)	24.51±0.09*	35.33±12.21	0.70	25	25
Salinity (ppm)	31.78±0.50*	59.33±4.00*	0.10	100	75

**Mean values with an asterisk indicate levels not within the standard limits*

(59±0.38 ppm) exceeded the tolerable limit set by FAO (1993). The concentration of tHg, on the other hand, is less than the reported limit of GFAA and ICP-MS with a value of 0.002 ppm. There are no significant differences in heavy metal concentration from both sites (P>0.05).

Sediments play a vital role in the marine ecosystem, providing a habitat for marine organisms such as the mangrove clams *A. philippiana*. Sediments are also the primary contact point for the toxicity of heavy metals that accumulate in the ecosystem (Zahra et al. 2014). Heavy metals are known to have detrimental effects on the environment even in minute amounts. Heavy metals at low concentrations in seawater can negatively affect marine bivalves, reducing growth rates, decreasing reproduction, and increasing mortality (Chen et al. 2010). However, it is noteworthy that among the sediments and heavy metals tested, only Cr from the Municipality of Hinatuan exceeded the prescribed limit set by international standards. Brgy. Loyola, the collection site for sediments in Hinatuan, is situated at the drainage basin of the Tambis River system, where small-scale gold mining activities are particularly active, especially upstream of this water body (Fajardo et al. 2015). Although mercury and cyanide are commonly used in small-scale gold mining, the presence of Cr is usually associated with gold deposits (Haldar 2016). Hence, the elevated levels of Cr contamination could be due to the extraction of Cr-containing ore upon gold mining. Cr can be harmful when taken in high concentrations over an extended period (Sireli et al. 2006). Another study by Azmat et al. (2018) and Fawad et al. (2017) suggested that heavy metals like Cr can build up in marine organism muscles, particularly in bivalves, and can affect their metabolic and enzymatic processes.

Heavy metal analysis of A. philippiana flesh

Table 3 summarizes the concentration of heavy metals in the flesh of *A. philippiana* collected from the Municipalities of Barobo and Hinatuan. In the Municipality of Barobo, the highest concentration was observed for Pb (0.5±0.02 ppm), followed by Cr (0.25 ppm), Ni (0.25 ppm), and tHg (0.01 ppm). Cr (0.37±0.02 ppm) was the highest in the Municipality of Hinatuan, followed by Pb (0.35±0.01 ppm), Ni (0.25 ppm), and tHg (0.01 ppm). All heavy metals tested are below the tolerable limits set by FAO/WHO (1984) and the European Commission (2006). Similarly, there is no significant difference between the levels of heavy metals among the two sites (P>0.05).

Mangrove clams, being benthic eaters, can acquire food and toxic chemicals from the environment, making them efficient bioindicators of heavy metal contamination (Tamele and Loureiro 2020). The effects of heavy metals on marine organisms are widely studied. The accumulation of heavy metals in the muscles of bivalves can have detrimental effects on their morphology and growth. Studies have demonstrated that even small amounts of heavy metals can induce oxidative stress, DNA damage, and gene expression changes,

Table 2. Mean concentration of heavy metals in sediments collected from Barobo and Hinatuan, Surigao del Sur, Philippines

Heavy Metal	Barobo (in ppm)	Hinatuan (in ppm)	Tolerable limits (in ppm)	References
Lead	5.12±0.22	17.80±0.06	≤100	FAO (1999)
Nickel	1.63±0.06	11.80±0.50	≤25	WHO (2001)
Chromium	5.03±0.22	59.00±0.38**	≤50	FAO (1993)
Mercury	<0.002*	<0.01*	≤0.1	FAO (1999)

**Reporting limit by AAS; **Concentration beyond the tolerable limits*

Table 3. The mean concentration of heavy metals in the flesh of *A. philippiana* collected from the Municipalities of Barobo and Hinatuan, Surigao del Sur, Philippines

Heavy Metal	Barobo (in ppm)	Hinatuan (in ppm)	Tolerable limits (in ppm)	
			FAO/WHO (1984)	EC (2006)
Lead	0.5±0.02	0.35±0.01	≥ 1.50	≥ 0.50
Nickel	<0.25*	<0.25*	≥ 80.0	≥ 1.50
Chromium	<0.25*	0.37±0.02	≥ 13.0	≥ 20.0
Mercury	<0.01*	<0.01*	≥ 13.0	≥ 1.00

**Reporting limit by AAS*

potentially leading to developmental abnormalities (Nordberg et al. 2007; Angeles-Agdeppa et al. 2011). Moreover, chronic exposure to low levels of heavy metals can result in long-term effects on the health and morphology of marine bivalves (Hossen et al. 2015). Other studies have observed changes in bivalve morphology, including reduced shell length and thickness, and alterations in muscle growth and development (Yap et al. 2003; Siringan and Tongson 2011; Navarro et al. 2014; Stewart et al. 2021). The concentrations of heavy metals in bivalves can also have broader ecological consequences. Richir and Gobert (2016) discovered that heavy metal exposure can lead to decreased survival rates of bivalve species, potentially disrupting the food chain and other ecological processes.

Nevertheless, the quantified concentration of metals in the flesh of *A. philippiana* is way below the tolerable limits, some of which are at the lowest possible reporting limit of the AAS (Ni, Cr, and tHg). It is noteworthy also that despite the high concentration of Cr in the sediments of the Municipality of Hinatuan, the accumulated Cr in the flesh of *A. philippiana* was only 0.37±0.02 ppm, which is 35- or 54-fold lower than FAO/WHO (1984) and EU (2006) standards, respectively.

LWR in A. philippiana shells

Collection *A. philippiana* for LWR analysis was done in the Municipalities of Barobo (n=576) and Hinatuan (n=196), Surigao del Sur. The mean length and weight of *A. philippiana* are significantly larger in Hinatuan (5.26±0.57 cm; 35.39±13.62 g) compared to samples from Barobo (3.93±0.84 cm; 20.08±15.40 g) ($P<0.05$) (Table 4). A significant and strong relationship exists between the LWR of *A. philippiana* in Barobo and Hinatuan ($P<0.001$). The *A. philippiana* clams tend to be bigger in size and heavier in Hinatuan than in Barobo. Morphometric analysis showed positive allometric growth in Barobo and negative allometric growth in Hinatuan (Figure 2).

The use of the LWR is significant for the assessment of the growth and production of species. LWR is used for evaluating the weight corresponding to a given length, and condition factors are used for comparing the condition, fatness, or well-being of species based on the assumption that heavier organisms of a given length are in better condition (Froese 2006). Bivalve growth is influenced by biotic and abiotic factors. Among these factors that affect the growth of bivalves are the quality of food sources, water quality, type of sediments, type of bottom, and wave exposure (Babaei et al. 2010).

The negative allometric pattern in the Municipality of Hinatuan indicates that the rate of increase in shell length and weight is not proportional. Although food availability is the main influence on the growth and reproduction of bivalves (Haberle et al. 2020), environmental factors such as the quality of water are also pivotal for the growth of bivalves and lead to negative allometry (Zuo and Cai 2017). Although the concentration of Pb, Ni, Cr, and tHg in the flesh of *A. philippiana* is below the tolerable limits set by international organizations, it was observed that Cr in sediments exceeded the tolerable limit of FAO (1993) and the DO of surface water did not meet the minimum level of DAO 2016-08. The positive allometric growth pattern shown by *A. philippiana* in the Municipality of Barobo indicates that the species is not affected by its biological condition, which can be seen in the lower heavy metal concentrations in both sediments and bivalve muscles. The collection sites are far from the residential area and no known disturbing anthropogenic activities were observed.

Interestingly, the *A. philippiana* from the

Table 4. Mean length and weight of *A. philippiana* collected in Barobo and Hinatuan

Parameters	Mean±SD		P-value	DAO (2016)
	Barobo	Hinatuan		Range/ Min. levels
pH	6.65±0.51*	7.12±0.10	0.10	7.0–8.5
Dissolved Oxygen (ppm)	2.74±0.31*	2.08±0.38*	0.20	5
Electroconductivity (µs/cm)	48.36±0.96	58.21±19.16*	1.00	30–55
Temperature (ºC)	30.22±0.18	30.98±0.06	0.10	26–30
Total Suspended Solids (mg/L)	24.51±0.09*	35.33±12.21	0.70	25
Salinity (ppm)	31.78±0.50*	59.33±4.00*	0.10	100

**Mean values with an asterisk indicate levels not within the standard limits*

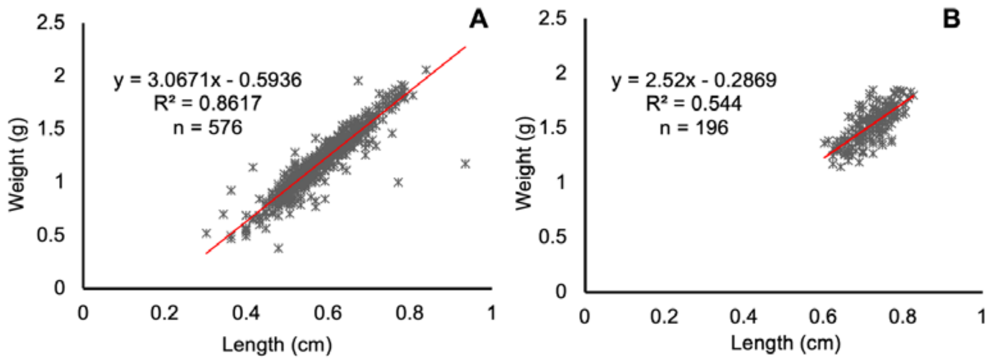

Figure 2. Relationship between the total weight and shell length of *A. philippiana* in the Municipalities of Barobo (A) and Hinatuan (B) with its equations and coefficient of determination R^2 values

Municipality of Hinatuan is larger and heavier than the Barobo samples. Collection sites differ in their soil types—Barobo tends to be sandy, while Hinatuan is characterized as mudflat. In general, coarse-textured soil is the poorest habitat for any marine organism, as it supports less biota than mudflat types. Muddy types of sediments provide more biota than sand because organic matter is more likely to lodge on them, providing food to organisms like the *A. philippiana* (McLean et al. 2021). Moreover, another factor that may contribute to the growth of bivalves is the ease of access to *A. philippiana* in sandy sediments, and the exposure of clam beds during low tide makes them highly visible to harvesters, leading to a decline in the overall size of the population.

4 Conclusion and Recommendations

This study aimed to determine the levels of heavy metals in the sediments and the flesh of *A. philippiana* collected from the Municipalities of Barobo and Hinatuan, Surigao del Sur, alongside the LWR of *A. philippiana* samples. The relative order of the average concentrations of HM in the sediment across two stations is Cr>Pb>Ni>tHg, with Cr from the Municipality of Hinatuan exceeding the tolerable limits. On the other hand, the accumulated heavy metals in the flesh of *A. philippiana* have remained below the tolerable limits. It was also determined that heavy metal concentration in sediments is relatively higher than in the flesh of *A. philippiana.* The LWR of *A. philippiana* showed positive allometry in the Municipality of Barobo and negative allometry in the Municipality of Hinatuan, suggesting environmental stressors affecting growth. It is recommended that heavy metal levels be monitored to capture seasonal variations. Additional research is needed to gain better insights into morphometric patterns concerning HM accumulation in *A. philippiana* and other commercially relevant bivalves. This will help identify direct and indirect anthropogenic stressors, enabling more effective management of these economic resources.

5 Acknowledgement

The authors would like to thank the Local Government Units of the Municipality of Barobo and Municipality of Hinatuan for allowing the researchers to conduct the study in their respective municipalities.

Statement of Conflict of Interest

To maintain impartiality in the article's evaluation, Joycelyn Jumawan, who serves as the EIC of JESEG refrained from involvement in the review process of this article.

Author Contribution

RR Ecleo conducted the study, collected data, performed the analysis, wrote the original draft, and JJ Rosal conceptualized the study design, editing, and supervision of the project. RR Ecleo and JJ Rosal wrote the manuscript with input from all authors. JC Jumawan and EM Buenaflor provided technical inputs in the design, implementation, and analyses of the research. All authors approved the final version of the article.

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Assessing the Water Quality of Creek Systems at Caraga State University-Main Campus, Philippines, using Macroinvertebrate-based Biotic Indices

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ABSTRACT

Macroinvertebrates are widely utilized for monitoring water bodies and assessing water quality. In this study, macroinvertebrates were sampled from different gradients (upstream, midstream, and downstream) of four creeks within the main campus of Caraga State University. The study utilized a modified kick-net method to evaluate their species diversity, composition, and richness. A total of 20 taxa of macroinvertebrates from seven orders and 16 families were collected and identified across the subsampling stations. Gastropoda was the most abundant order, making up 65.51% of the total, with representatives from five families. Despite this abundance, the Shannon Diversity Index indicated very low diversity across all creek systems. However, the Pollution Tolerance Index (PTI) and the Biological Monitoring Working Party (BMWP) scores consistently showed good water quality across all subsampling stations. These results align with the Family Biotic Index (FBI) score, which suggests excellent water quality with no apparent organic pollution throughout the creeks. This study highlights the value of family-level identification in biomonitoring programs at CSU and similar environments. This method is cost-effective and practical, particularly in contexts with limited systematic knowledge of macroinvertebrates.

Keywords: *Biological indicator, biomonitoring, BWMP, diversity index, tropical stream*

1 Introduction

Water pollution is a global issue that deteriorates water quality and restricts its usability for various purposes (Etemi et al. 2020). For water to be safe for drinking, agriculture, or recreational use, it must adhere to specific physicochemical and microbiological standards. Consequently, water quality assessments often involve examining various physicochemical, microbiological, and biological parameters essential for evaluating ecological and environmental health (Popovic et al. 2016; Atique & An 2018; Kebede et al. 2020). There is also a growing focus on monitoring freshwater ecosystems worldwide to enhance their ecological, recreational, and economic value (Zamora-Munoz & Alba-Tercedor, 1996; Tanaka et al. 2016; DEPC 2000; Kebede et al. 2020).

Unlike traditional physicochemical assessment methods, biological indicators offer a cumulative view of ecosystem health by reflecting the responses of aquatic communities to various stressors in their habitat (Kebede et al. 2020). Characteristics such as diversity, richness, and abundance of these communities are used to gauge pollution levels, complementing and enhancing physicochemical data (Arimoro et al. 2007; Edward & Ugwumba 2011; Flores & Zafaralla 2012).

The use of macroinvertebrates in the biological evaluation of water bodies includes several advantages: (1) benthic macroinvertebrates are common and present in the majority of aquatic habitats; (2) different groups have different environmental needs and tolerances to pollution; (3) they are the food source for many species of fish; (4) small order streams often do not support fish but do support macroinvertebrate communities; (5) due to their immobility, benthic invertebrates serve as indicators of the local environment; (6) their body size is ideal to be easily collected and identified (Etemi et al. 2020); and (7) sampling is easy and cost-effective.

Biomonitoring employs indicators or sentinel species to evaluate environmental health or pollution by combining diversity metrics with pollution tolerance information into a single index or score. Benthic macroinvertebrates are among the most reliable indicators for biotic indices (Etriieki & Kucukbasmaci 2024). Numerous studies on Philippine freshwater systems have utilized these organisms to assess stream and river conditions, often correlating macroinvertebrate data with water classifications based on physicochemical parameters (Magbanua et al. 2023). Commonly used biotic indicators in the Philippines include the Pollution Tolerance Index (PTI), Biological Monitoring Working Party (BMWP), and Family Biotic Index (FBI). However, studies may vary in their evaluations of stream conditions.

In the Caraga Region, no specific study has employed a biotic index to assess water quality through macroinvertebrate evaluation. The research by Paylangco et al. (2021) focused solely on the relationships between macroinvertebrates and water physicochemical parameters in ten littoral zone stations across four municipalities of Lake Mainit, Philippines. In this study, we aimed to fill this gap by using the biotic index to assess the health of the creek systems at Caraga State University (CSU) by examining macroinvertebrate communities. The study focused on determining macroinvertebrates' abundance, composition, and diversity and utilized macroinvertebrate-based indices to evaluate water quality. Although the composition of macroinvertebrate assemblages is affected by various factors, such as water quality, physical habitat structure, and flow regime, these elements were not included in the analysis due to time constraints during data collection.

2 Materials and Methods

Study area and establishment of sampling stations

This field study was undertaken between April 25–26, 2022, during the dry season when sites were accessible and hydrologically stable. The field sampling was carried out in four selected creek systems inside Caraga State University, province of Agusan del Norte, specifically in the areas of Harrison Bridge (S1), Eco-Park (S2), Carabao Center (S3) and Basag (S4), respectively (Figure 1). Caraga State University is surrounded by domestic activities, agricultural fields, and residential areas where the creeks become contaminated with wastewater, agricultural runoff, industrial discharges, solid waste, and other pollutants, the principal anthropogenic stressors on the streams.

The creek flow's upper section (Harrison Bridge) was connected to the Ampayon Public Market and probably disturbed by domestic activities. The Eco-Park was located in a forest area in CSU, where the stream appears stagnant due to the very shallow streambed. Carabao Center is near the agricultural pastures and rice fields, with abundant moist plant debris and fallen logs. Lastly, the Basag area is surrounded by rice fields and residential areas.

Four sampling stations (creeks) with three represented subsamples were determined: the upper stream, middle stream, and downstream. At each sampling station, a 100-m transect line parallel to the stream flow to the water body was established in an accessible area. Three sampling points that serve as subsamples were established by marking twenty meters with a twenty meter-interval in a 100-meter transect line.

Macroinvertebrate collection and identification

The collection of macroinvertebrates was done using the kick-net method. A modified kick-net measuring 0.5 m width with 500µm opening mesh size was used to collect the organisms. The collection used a standard three-minute kick/sweep method (Armitage et al. 1990) by disturbing the streambed in a kicking motion in the direction of the modified dip-net. Sampling was carried out from the downstream to the upstream direction. The collected samples were placed in labeled containers with water. A 0.5mm mesh sieve separated the organisms from stream sediments and other debris. The collected

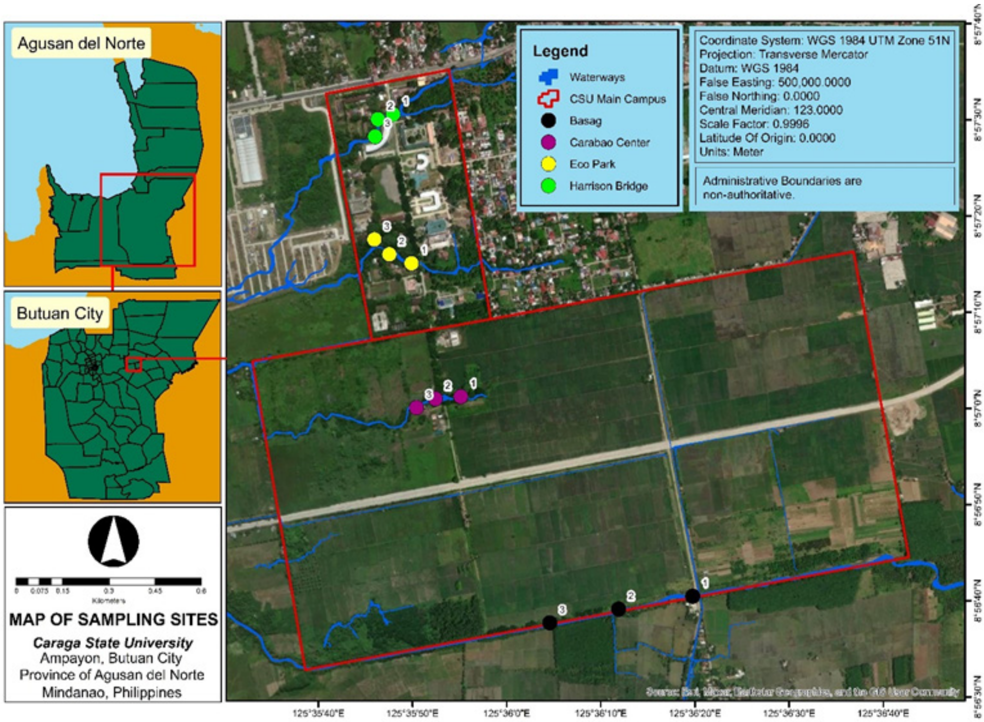

Figure 1. Map showing the sampling points for aquatic macroinvertebrate assessment across the four stream systems within Caraga State University-Main Campus

samples were sorted and stored in 95% ethanol in the laboratory. Using the principal manuals of Bouchard (2004) and Nesemann et al. (2011), identification was only at the family level. This study was limited to identifying and determining the composition, abundance, and richness of macroinvertebrates collected at the sampling sites during the sampling period. Several factors affect these variables, but the temporal distribution was not studied due to limited data-gathering time. Physicochemical parameters of water were also not included in this study.

Pollution Tolerance Index (PTI)

In this study, the Pollution Tolerance Index (PTI) was utilized to evaluate the condition of the creek systems at Caraga State University. This index involved analyzing the presence and abundance of macroinvertebrate species. Each identified taxa was categorized according to its pollution tolerance level (sensitive, somewhat tolerant, or tolerant), referencing regional or local ecological guides. Tolerance scores were assigned numerical values ranging from 1 to 3 for sensitive species, 4 to 7 for somewhat tolerant species, and 8 to 10 for tolerant species (Barbour et al. 1999).

Biological Monitoring Working Party Index (BMWP)

The Biological Monitoring Working Party Scoring System developed by Forio et al. (2017) was used to classify and score the identified macroinvertebrates. Each macroinvertebrate taxon is assigned a sensitivity score, with higher scores indicating greater sensitivity to environmental disturbances. The sensitivity scores of all observed taxa were accounted for at each site. A higher cumulative score signifies better ecological quality. The total was calculated and then divided by the number of taxa scored. The resulting value is the BMWP, which is shown in Table 1.

Family Biotic Index (FBI)

Hilsenhoff's (1977, 1988a, 1988b) Family Biotic Index was also used to assess water quality in the sampling stations. This index was calculated by multiplying the number in each family by the family-level pollution tolerance value/score, adding the results, and dividing by the total number of individuals in the sample. Table 2 describes the value obtained by the FBI.

Taxon richness, evenness, and diversity indices

The collected data were used to compute taxon richness(d'), evenness, Shannon- Wiener diversity index (H'), and Simpson's dominance index (S') (D). Shannon-Weiner was classified based on a modified scale (Table 3).

3 Results and Discussion

Abundance, composition, and diversity of macroinvertebrates

A total of 20 taxa, encompassing 1801 macroinvertebrates across seven orders and 16 families, were collected during the sampling period (Table 4). Among the sites, Carabao Center had the highest number of individuals, followed by Harrison Bridge, Eco-Park, and Basag area. Carabao Center had a greater number of individuals. Figure 2 illustrates the relative percentage composition of the major macroinvertebrate taxa in the four streams. Among the collected taxa, segmented worms (Oligochaeta), pebble snails (Hydrobiidae), and rock snails (Pleuroceridae) were frequently found in the Harrison Bridge, Eco-Park, and Carabao Center sites. Still, they were notably absent in the Basag area (Table 4).

The density and diversity of benthic groups identified in this study may be influenced by physicochemical properties altered by human activities (Dumbrava-Dumbrava and Petrovici, 2010). During the field assessment, sampling points in Eco-Park and Carabao Center, located upstream, exhibited cloudy water, domestic animals, and leaf litter. However, these factors might not significantly impact the overall health of the creek ecosystem. Conversely, a higher abundance of Hydrobiidae was observed at Harrison Bridge, Eco-Park, and

Table 1. Biological monitoring working party index scores and indication

Score	Indication
> 100	Very Good
71-100	Good
41-70	Poor
11-40	Poor
< 11	Bad

Source: Forio et al. (2017)

Table 2. Water quality based on the Family Biotic Index values from Hilsenhoff (1988b)

Family Biotic Index	Water quality	Degree of organic pollution
0.00–3.50	Excellent	No apparent organic pollution
3.51–4.50	Very good	Possible slight organic pollution
4.51–5.50	Good	Some organic pollution
5.51–6.50	Fair	Fairly significant organic pollution
6.51–7.50	Fairly poor	Significant organic pollution
7.51–8.50	Poor	Very significant organic pollution
8.51–10.0	Very poor	Severe organic pollution

Table 3. H' diversity value and its qualitative equivalence

H' value	Relative values
>3.5	Very high
3.0-3.49	High
2.5-2.99	Moderate
2.0-2.49	Low
<1.99	Very low

Source: Fernando (1998)

Table 4. List of macroinvertebrates collected in four creek systems and their corresponding taxa groupings based on their sensitivity to pollution and their respective family tolerance values

Order	Family	Common name	Number of individuals					Taxa groupings	FBI tolerance values for the Family biotic index	BMWP tolerance values
			S1	S2	S3	S4	Total			
Annelida	Hirudinea	Leech	9	82	*	*	91	3	1,2,38	63
	Oligochaeta	Segmented worms/ aquatic earthworm	14	5	145	*	164	3	1,2,310	61
Araneae	Dictynidae	Diving bell spider	*	*	*	2	2	1	14	-
Collembola	Poduroidea	Water springtails	2	*	1	*	3	3	49	-
Diptera	Ceratopogonidae	Non-biting midge	204	4	*	*	208	2	47	54
	Ceratopogonidae	Biting midge	*	*	2	*	2	2	47	54
	Tipulidae	Crane flies	*	*	2	*	2	2	44	62
Gastropoda	Hydrobiidae	Pebble snail	225	133	414	*	772	3	47	75
	Pleuroceridae	Rock snail	121	67	119	*	307	3	42	63
	Valvatidae	Round-lipped snail	*	1	1	*	2	3	42	63
	Sphaeriidae	Pea clam	*	*	98	*	98	3	17	74
	Ancylidae	Limpet	*	*	1	*	1	3	12	74
Hemiptera	Veliidae	Water strider	*	3	*	131	134	2	14	65
	Veliidae	Broad-shouldered water strider	*	*	5	*	5	2	14	65
	Veliidae	True bugs	*	*	1	*	1	2	15	65
Odonata	Gomphidae	Clubtail dragonfly	*	2	*	*	2	2	10	74
	Coenagrionidae	*Narrow-wing damselfly*	1	1	*	*	2	2	13	64
	Calopterygidae	Broad-wing damselfly	1	2	*	*	3	2	13	64
	Macromiidae	Dragonfly nymph	*	*	1	*	1	2	14	66
	Macromiidae	Dragonfly	*	*	*	1	1	2	14	66
		TOTAL	577	300	790	134	1801			

Note: (*) not found; (-) no available data; [1]Barbour at al. (1999); [2]Lenat (1993); [3]Resh et al (1995); [4]USEPA (2019); [5]Chessman (2003a); [6]Le et al. (2002); [7]Ruiz-Picos et al. (2017)

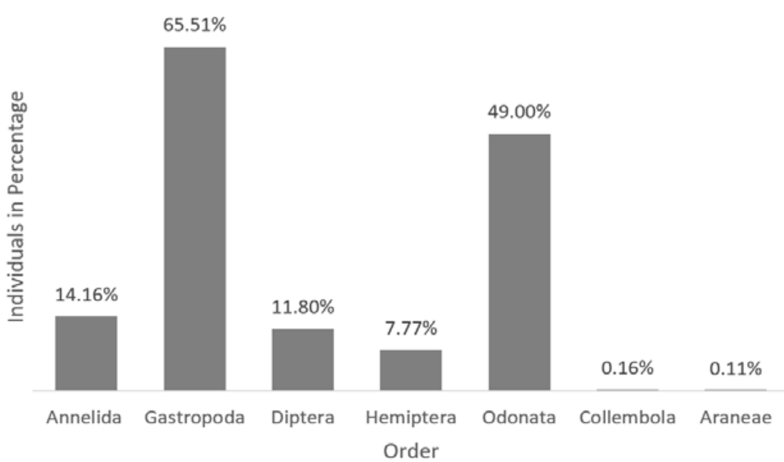

Figure 2. Taxonomic order of aquatic macroinvertebrates showing its percent composition collected in the four stream systems with Caraga State University-Main Campus

Carabao Center, areas characterized by notable upstream domestic and agricultural activities. According to Hepp et al. (2010), pollution-tolerant macroinvertebrates are likely due to runoff from domestic sewage, livestock, and agricultural operations. However, Xu et al. (2014) found that Hydrobiidae species typically thrive in environments with excellent water quality, particularly those with high levels of dissolved oxygen.

The order Gastropoda (65.51%), followed by Annelida (14.16%), Diptera (11.80%), and Hemiptera (7.77%), showed the highest abundance among macroinvertebrates (Figure 2). These organisms, which reside within the sediment, are known to tolerate organic pollution, low oxygen levels, and sediment disturbances (Amiard-Triquet & Berthet 2015). Hydrobiidae, the most abundant taxa, are typically found in moist plant debris, under rocks, among low vegetation, mulch, and fallen logs-ideal hiding spots observed at the Carabao Center. The presence of Gastropoda, Annelida, Diptera, and Hemiptera across the four creeks suggests that these species are generalists. Bhandari et al. (2018) noted that species in these orders, except Hemiptera, prefer habitats with stones, pebbles, boulders, cobbles, and gravel. Hemiptera, on the other hand, are site-specific. Additionally, most Gastropoda and Annelida species are highly tolerant of pollution. The least collected taxa belonged to the order Odonata, which, despite being generalists (Bhandari et al. 2018), are known to be facultative organisms, typically associated with moderately polluted waters (Olomukoro and Dirisu 2014).

Taxa diversity within an ecological community is assessed by considering both taxa richness (the number of different taxa present) and the evenness of their abundance. The evenness index, which ranges from 0 to 1, indicates how evenly individuals are distributed among the taxa, with a value of 1 signifying that all taxa are equally represented (Smith and Wilson 1996). An ecosystem exhibits low taxa evenness when a few species are highly dominant, while others are sparsely represented. In this study, the highest evenness index was recorded at Harrison Bridge (0.44), whereas the lowest was at Carabao Center (0.31) (Table 5). Evenness indices reflect standardized abundance, which is higher when most individuals are concentrated within a few taxa (Smith and Wilson, 1996). Moore (2013) notes a correlation between species richness and evenness: as both increase, so does the overall species diversity.

In terms of diversity, the creek in Eco-Park exhibited the highest Shannon-Weiner index value among the surveyed creeks. Nevertheless, according to Fernando's index (1998), all the creeks received very low ratings for their macro-benthic assemblages (Table 6). The low taxa richness underscores the severe impacts of impoundment on macroinvertebrates and the stress from pollution resulting from increased human activities (Arimoro et al. 2007; Latha and Thanga 2010; Edward and Ugwumba 2011; Andem et al. 2012). These factors contribute to the overall low diversity

Table 5. Biodiversity indices of four sampling areas

Biodiversity Indices	Harrison Bridge (S1)	Eco-Park (S2)	Carabao Center (S3)	Basag area (S4)
Richness	8	10	12	3
Abundance	577	300	790	134
Dominance	0.32	0.32	0.35	0.96
Shannon	1.26	1.33	1.29	0.12
Evenness	0.44	0.38	0.31	0.38

Table 6. Shannon diversity index (H') values of aquatic macroinvertebrates across the creek systems of Caraga State University-Main Campus

Sampling Area	H' value	Relative values
Harrison Bridge (S1)	1.26	Very low
Eco-Park (S2)	1.33	Very low
Carabao Center (S3)	1.29	Very low
Basag area (S4)	0.12	Very low

observed in the four areas. Specifically, these streams are used as bathing spots for domesticated animals and humans, laundry sites, and the surrounding riparian zones, where livestock like goats and carabao are grazed.

Pollution Tolerance Index, Biological Monitoring Working Party, and Family Biotic Index

The PTI and BMWP scores indicated that the water quality at all four subsampling stations is very good. However, in station S4, the macroinvertebrates collected were limited to only water striders (Hemiptera) and dragonflies (Odonata). The presence of dragonflies suggests slow-moving water, while the high abundance of water striders could imply moderate or slightly polluted water quality. In contrast, the macroinvertebrates found in stations S1, S2, and S3 were predominantly from the orders Annelida, Diptera, Odonata, and Gastropoda. These groups thrive in a wide range of water quality conditions, including moderate quality, and are particularly tolerant of poor water quality. The abundance of these organisms was attributed to the high organic matter content in the surrounding substrate and is consistent with their feeding habits as deposit feeders, making them more adaptable to environments with silting, decomposition, and varying flow rates compared to other macrobenthic groups (Olomukoro and Dirisu 2014) (Table 7).

Rivers and creeks are critical ecosystems with immense ecological significance (Nguyen et al. 2018). The health of these waterways is essential for the human communities that depend on them (Dickens et al. 2018). In this study, creek systems at Caraga State University (CSU)-including Harrison Bridge, Eco-Park, Carabao Center, and Basag area-achieved scores of 2.65, 2.76, 2.65, and 2.06, respectively. These scores indicate "Excellent Water Quality" with "No apparent organic pollution" (Table 8). These results are consistent with the PTI and BMWP assessments, confirming a very good water quality. The organisms identified at these subsampling stations are generally considered generalist and highly tolerant species. This complex composition likely stems from the stations' proximity to agricultural, residential, and commercial areas.

Interestingly, there is a conflicting result between the biodiversity and biotic indices used in this study. While the biodiversity index indicates very low diversity, suggesting poor stream health, the biotic indices imply excellent water quality, with no significant organic pollution. This low diversity across all sampling stations predominantly features moderately to highly tolerant invertebrates, reflecting threatened stream health. In contrast, healthy aquatic ecosystems typically support a wide variety of macroinvertebrate species, including those sensitive to pollution (USEPA 2023).

Assessing water quality is vital for monitoring environmental conditions and evaluating the health of CSU's ecosystems and their neighboring habitats. Degraded water quality can negatively impact aquatic life and the overall vitality of these ecosystems (Tampo et al. 2021).

Table 7. Pollution Tolerance Index and Biological Monitoring Working Party (BMWP) scores and the degree of pollution across the creek systems of Caraga State University-Main Campus

Sampling Area	PTI Score	Degree of pollution	BMWP Score	Degree of pollution
Harrison Bridge (S1)	491.43	Very Good	2,509	Very Good
Eco-Park (S2)	187.67	Very Good	1,171	Very Good
Carabao Center (S3)	360.25	Very Good	1,823	Very Good
Basag area (S4)	178.67	Very Good	661	Very Good

Table 8. Family Biotic Index (FBI) scores across the creek systems of Caraga State University-Main Campus

Sampling Area	FBI score	Water quality	Degree of organic pollution
Harrison Bridge (S1)	2.65	Excellent	No apparent organic pollution
Eco-Park (S2)	2.76	Excellent	No apparent organic pollution
Carabao Center (S3)	2.65	Excellent	No apparent organic pollution
Basag area (S4)	2.06	Excellent	No apparent organic pollution

4 Conclusion and Recommendations

This study is the first to explore and report the diversity, composition, and richness of macroinvertebrates in the tributaries of Caraga State University (CSU) in Ampayon, Butuan City, Philippines. The findings reveal that the Carabao Center tributary had the highest taxa and individuals. However, all subsampling stations exhibited very low diversity overall. Despite this low diversity, the PTI and BMWP scores indicated that the water quality across the four creek systems was very good. These results align with the FBI score, confirming that the water quality is excellent and shows no signs of organic pollution. Evaluating the overall health of CSU's creek systems with the available data is crucial, as the current analysis does not include the water's physicochemical properties and lacks associative insights. Additionally, the indices and their tolerance values used in this study were adapted from international sources, which feature different macroinvertebrate communities. Despite these constraints, the results suggest that CSU's creek ecosystems remain robust and conducive to macroinvertebrate life, indicating that the university's environmental management practices are effective.

To gain a deeper understanding of the microhabitat dynamics within the campus, it is crucial to incorporate additional parameters, such as the physicochemical properties of both water and soil. Philippine researchers also need to develop a localized biotic index tailored to assess the country's diverse freshwater ecosystems. Moreover, examining seasonal changes in macroinvertebrate diversity will enhance water quality evaluation in these streams. The study also highlights the value of using family-level identification for biomonitoring programs at CSU and similar environments. This method is cost-effective and practical, especially given these areas' limited systematic knowledge of macroinvertebrates.

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Statement of Conflict of Interest

To maintain impartiality in the article evaluation, MV Elvira and RA Seronay, members of the JESEG Editorial Board, did not participate in the review process of this article. The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Author Contribution

MV Elvira: Conception and design of study, analysis and interpretation of data, drafting and revision of the manuscript for significant intellectual content. LKL Abujan, CJD Singson: Conception and design of study, acquisition of data, drafting of the manuscript, analysis and nterpretation of data. RA Seronay: Analysis and interpretation of data, approval of the version of the manuscript to be published.

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Floristic Inventory, Diversity, and Community Structure of the Riparian and Coastal Sand Dune Landscapes in the Lower Padsan River Basin, Laoag City, Ilocos Norte, Philippines

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ABSTRACT

Padsan River basin, the largest river system in Laoag City, Ilocos Norte, encompasses two vital ecological landscapes: coastal sand dunes and riparian areas. Despite its ecological importance, the floristic diversity of these landscapes still needs to be better understood and documented. A vegetation assessment was conducted to characterize the composition, diversity, and community structure of plants in the lower Padsan River landscapes. Eighteen 10 m x 10 m nested quadrats were established across six sampling stations. The study recorded 82 species of vascular plants from 80 genera and 41 families. Fifty-two percent are introduced species, 48% are native species, and 27% are invasive species. The plant life forms are composed of trees (34 spp.), herbs (17 spp.), vines (13 spp.) and grasses (9 spp.). Fabaceae and poaceae were the most species-rich plant families. *Prosopis juliflora* (Candaroma) was the most dominant tree species, comprising 29% of the entire population. The lower Padsan River basin landscapes exhibits moderate tree diversity (H' = 2.7), with Shannon diversity indices ranging from 0.89 to 2.43 across sampling locations. The riparian areas showed higher tree Shannon diversity, richness, and evenness, while the coastal sand dune areas had higher tree dominance but lower Shannon diversity. The plant community structure varies between the two types of ecological landscapes (ANOSIM Global R=0.7, p<0.05). *P. juliflora* dominates the coastal sand dune, while a mix of the *Leucaena-Pithecellobium-Terminalia* community characterizes the riparian area. This study provides essential baseline information on the floristic diversity and community structure, serving as a foundation for developing an integrated river management plan and strategies for conserving important ecological landscapes in the downstream section of the Padsan River Basin.

Keywords: *Downstream, Ecological landscapes, Laoag River, Northwestern Luzon, Plants, Vegetation*

1 Introduction

The Padsan River Basin, also known as the Laoag River or Sarrat River, is the largest river system in the province of Ilocos Norte, with a total length of 73.1 kilometers and a drainage basin of 1,320 km² (DENR EMB 2021). Its main channel and bodies of water bisect and run through the eastern towns in Ilocos Norte down to Laoag City, the province's capital city. The watershed and significant tributaries of the Padsan River originate from the central portion of the Cordillera Mountains, the most extensive mountain range running north and south in the Northern Part of Luzon Island (JICA 1997). This mountain range is also an important site for floristic studies. It is considered the last frontier of contiguous old-growth forests in the Ilocos Region and the northwestern portion of the country (Batuyong et al. 2021). The river basin provides various ecosystem services in Ilocos Norte, such as food sources, protection from storms, habitat for flora and fauna, and maintenance of water quality, among others (DENR EMB 2021).

The riparian and coastal sand dunes are the two significant ecological landscapes that dominate the lower Padsan River basin. The riparian zones occur along riverbanks and floodplain areas. Meanwhile, the river mouth comprises coastal sand dunes, which are composed of loose, well-sorted, fine-grained sub-angular to subrounded sand, with a thickness varying from 0 to 50 meters (JICA 1997). This is part of the more enormous La Paz sand dune, the only significant dune field development located on the northwest coast of the Philippines (Hesp 2004). These coastal flats and beachfront areas are known for recreational activities such as sandboarding in Laoag City. Despite its ecological significance, more studies are needed to understand these important landscapes' floristic diversity, composition, and status in the lower Padsan River Basin.

Coastal sand dunes are fragile and globally threatened ecosystems that serve as a natural barrier against waves and windy storms and are generally generated by the interaction of tides, waves, and sand particle size (Kutiel et al. 2000; Šilc et al. 2017; Anbarashan et al. 2022). Plant and animal communities in the sand dunes ecosystem have particular ecological requirements, which determine their position along the environmental gradients from the seashore (Carboni et al. 2010; Anbarashan et al. 2022). The coastal sand dune vegetation has been extensively studied in other areas of the tropics (Tordoni et al. 2021; Anbarashan et al. 2022,); however, biodiversity studies and information, particularly flora, of such important and only sand dune ecosystem in the Philippines is lacking and remains poorly understood.

The riparian areas constitute a small part of a watershed that contributes to rivers' overall diversity and functioning (Goebel et al. 2003; Pasion et al. 2021). Riparian zones, riverbanks, riversides, and floodplains are distinct terrestrial landscapes, serving as ecotones that bridge the river's aquatic ecosystem with the adjacent land ecosystem. (Nilsson and Svedmark 2002; Pasion et al. 2021). These ecosystems provide important services such as protecting water quality and reducing stream bank erosion, which act as natural protection areas from frequent flood and flow pulse events and provide a habitat for a diverse group of organisms (Pasion et al. 2021). The vegetation of the riparian ecosystem is characterized by a continuum of species dispersed from the higher slope to the active river channel. This ecosystem supports multiple life forms, including trees, shrubs, herbs, and grasses.

Rapid urbanization, human encroachment, and industrial development activities are among the major environmental disturbances in the lower Padsan River. For instance, dredging activities are conducted in the lower Padsan River to reduce siltation and flooding, gain economic benefits, and create local livelihoods (DENR EMB 2021). Human economic activities can interfere with river structure and function in varying forms and intensity, affecting plant communities' character, diversity, and species richness (Myśliwy 2010; Stępień et al. 2019).

This study provides an inventory of plants in the less explored coastal sand dune and riparian landscapes, including their diversity and community structure, in the Lower Padsan River Basin, Ilocos Norte. The information is a foundation for policymakers and local government units to develop integrated river management strategies and conservation efforts for these ecologically important landscapes, which are subject to multiple uses and environmental disturbances.

2 Materials and Methods

Study Area and Entry Protocol

The study was conducted in the Lower Padsan River Basin, Laoag City, Ilocos Norte, Northwestern Luzon, Philippines, in November 2019 (Fig. 1). North-western Luzon experiences a monsoon climate characterized by a dry season in the lowlands spanning from November to April and a wet season from May to October (Stevenson et al. 2010). Laoag City has an annual rainfall of 2187 millimeters, a mean annual temperature of 27.6°, and a mean relative humidity of 79% (PAGASA-CADS 2024). Notably, during the wet season, rainfall shortages linked to the ENSO phenomenon can occur (Stevenson et al. 2010).

All research activities were conducted following an approved entry protocol established in collaboration with the Provincial Government

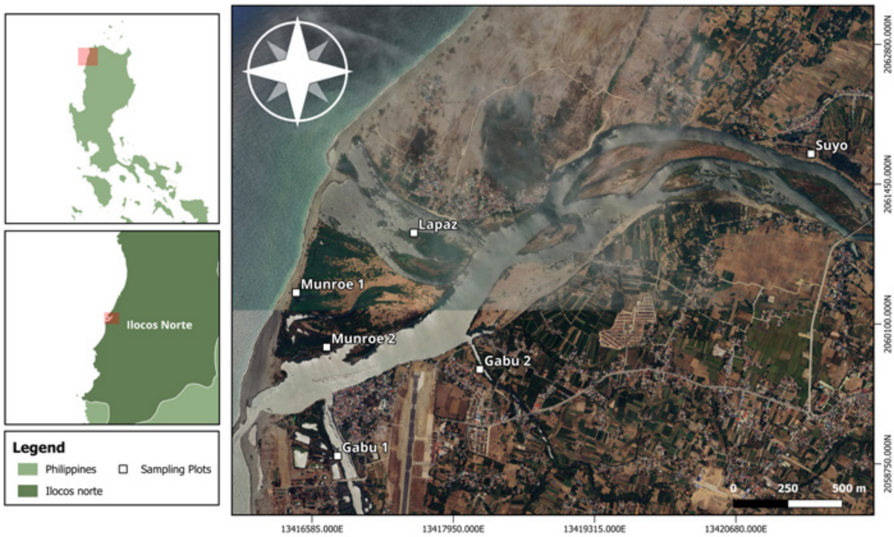

Figure 1. The map of sampling stations along Padsan River, Laoag City, Ilocos Norte, Philippines. The map was generated using QGIS version 3.36.2

of Ilocos Norte (PGIN). Permissions and necessary approvals were obtained from the appropriate authorities before commencing the study, and all research practices adhered to guidelines for ethical conduct in the field.

Vegetation Sampling

Two dominant ecological landscapes, riparian and coastal sand dunes, in the lower Padsan River basin were selected, each with three sampling stations for vegetation sampling. The selection of sampling stations was based on the observable characteristics of each identified landscape, including the type of substrate, zonation, and presence of vegetation. The coastal dune areas are located towards the seaward zone, while riparian areas are in the riverbanks towards the landward zone and river tributaries.

Three sites were selected in the coastal dune: Munroe 1, Munroe 2, and La Paz. Munroe 1 and 2 sites are located on the beachfront and side of Munroe Island, respectively (Fig. 2a, 2b). Munroe Island is a small coastal landform forming into a delta in the river mouth of Padsan. This island lies between the Lapaz and Gabu sites fronting the West Philippine Sea and splits the river into two small channels. Small ponds were also observed in Munroe. Moreover, the Lapaz site is in Brgy. Lapaz, adjacent to Munroe Island and west of Brgy. Suyo (Fig. 2c). The construction of a small port (known as "Free port" to locals) serves as access to the sea for locals and a docking area for boats. A dike was also constructed on this site to prevent severe flooding. Munroe and Lapaz sites are part of the LaPaz coastal dune in Laoag City, which is dominated by sandy substrate (Hesp 2004). Thorn bushes, herbs, grasses, and patches of beach forest trees characterize coastal dune vegetation. Additionally, multiple sandbars formation is dominated by mats of grass and sedge vegetation. In the riparian area, three sites were established: Suyo, Gabu 1, and Gabu 2. The Suyo site is located inwardly near the bypass bridge of Laoag City (Fig. 2d). Gabu 1 and 2 are small tributaries of the lower Padsan River in Brgy. Gabu Norte and Gabu Sur (Gabu 1) and Brgy. Cavit (Gabu 2) (Fig. 2e, 2f). For the uniformity of site coding, the small tributary in Brgy. Cavit is referred to as "Gabu 2". These sites are characterized by sandy-muddy to clay substrate and dominated by landward forest trees, grasses, and sedges thriving along riverbanks. In Gabu 1, planted mangroves such as *Rhizophora* spp., human settlers, and fish cages were observed. The Riparian area is converted into residential areas with houses interspersed between remnants of vegetation.

A nested quadrat was used for vegetation sampling to inventory the plant species and determine its composition, diversity, and vegetation structure in the two landscapes. Quadrats were

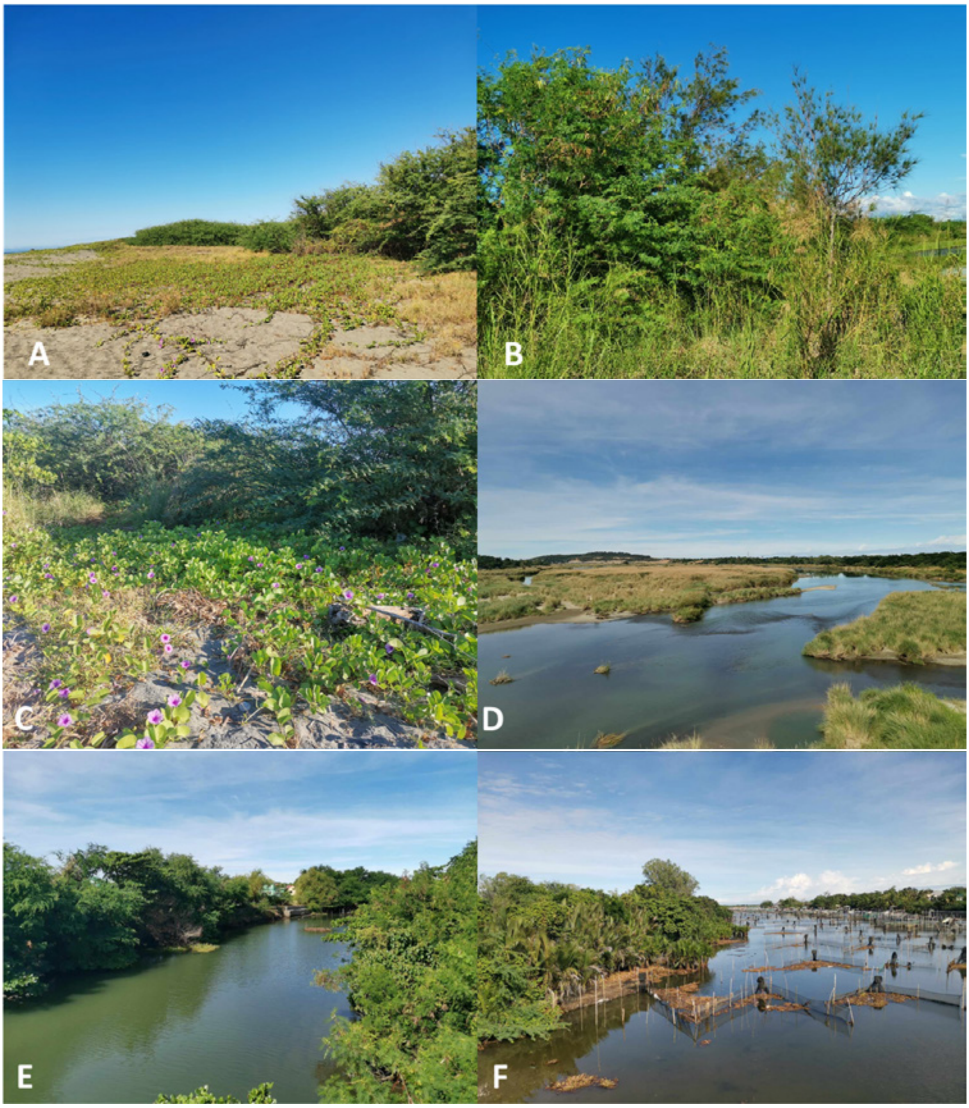

Figure 2. The sampling sites in the lower Padsan River basin a) Munroe 1 and b) Munroe 2 sites in Munroe Island, c) Lapaz, d) Suyo, e) Gabu 1 in Gabu Sur/Norte and f) Gabu 2 in Brgy. Cavit

randomly established in areas with sufficient vegetation cover. In each station, three (3) 10 m x 10 m fixed area nested quadrats were established for trees with a diameter at breast height (DBH) ≥10cm. Smaller quadrats measuring 5 x 5 m were established for shrubs, saplings, and poles, while 1 m x 1 m for herbaceous plants <1 cm tall. All species of flora inside the plot were identified, counted, and measured. Vegetation parameters such as diameter at breast height (DBH), basal area (BA), and tree height were recorded. The DBH taken 1.3 m above the ground was measured using tape. The DBH and BA were calculated based on the formulae given by English et al. (1997). A Global Positioning System device (Garmin GPSMAP 64sc) was used to determine the location of each plot. Random meander sampling was also done between plots to enrich the data on species richness and create a comprehensive list of species accounts in the lower river basin.

Documentation and Identification of Plants

Plant species were identified to the lowest taxon possible using the taxonomic keys, protologues, comparison of types, and publications from floras and monographs (Merrill 1926; Brummitt 1992; Madulid 2000; Regrario et al. 2017; Giesen et al. 2006; Primavera et al. 2004; Melana and Gonzales 2000; and Primavera and Sadaba 2012). Websites such as philippineplants.org (Pelser et al. 2011) and Plants of the World Online (POWO 2022) were also utilized. Documentation of diagnostic features (i.e., flowers, fruits, leaves, and roots) was conducted. Residency status, invasiveness, and conservation status were determined using the Global Invasive Species Database (Invasive Species Specialist Group 2015), IUCN Red List of Threatened Species (IUCN 2023), and list of Philippine threatened plant species by the Department of Environment and Natural Resources (DENR) Administrative Order 2017-11 (DENR 2017).

Data Analysis

The biodiversity indices used in the study are species richness, abundance, Shannon diversity, Pielou's evenness, and species dominance index. The abundance of trees was used to compute the biodiversity attributes of flora in the sampling sites. Paleontological Statistics Software package (PAST) version 4 was used to calculate the biodiversity indices in this study (Hammer et al. 2001).

Data ordination techniques using non-metric multidimensional scaling (nMDS) and cluster analyses were used to visualize the community structure of plants based on the tree abundance. The analysis generated dendrogram and nMDS plots for visualization. Analysis of similarities (ANOSIM) was done to test similarities and differences in plant community structure between the two landscapes. This procedure supports the generated dendrogram and ordination of the plant community structure evaluation. A similarity percentages (SIMPER) analysis was used to determine the significant contributions of plants to the dissimilarity of community structure. PRIMER 6 software was used to analyze the community structure of trees (Clarke and Warwick 2001; Clarke and Gorley 2006).

3 Results and Discussion

Composition of Plants

The study revealed 82 plant species from 41 families and 80 genera in the riparian and coastal sand dune landscapes of Lower Padsan River, Ilocos Norte (Table 1). Of these, 79 species were angiosperms, two pteridophytes, and only one gymnosperm. In the coastal sand dune, the common trees include *Prosopis juliflora* (Candaroma), *Casuarina equisetifolia* (Agoho), *Terminalia cattapa* (Talisay), *Acacia mangium* (Mangium), and *Leucaena leucocephala* (Ipil-Ipil). The dominant herbaceous plants were *Spinifex littoreus, Panicum repens, Ipomoea pes-caprae,* and *Canavalia maritima*. These species colonize open areas, sandbars, coastal flats, bushland, and thickets in the mouth of the Padsan River basin.

The riparian vegetation consists of mixed tree species growing along riverbanks, such as *Gmelina arborea* (Gmelina), *Samanea saman* (Acacia), *Eucalyptus globulus* (Bagras), *Calophyllum inophyllum* (Bitaog), and *P. juliflora*. Five mangrove species are found in Gabu 1 and 2, the small tributaries of the lower Padsan River, including *Rhizophora mucronata, Rhizophora apiculata, Nypa fruticans, Acrostichum aureum,* and *Acrostichum speciosum*. Mats of grass and sedges also thrive in the sandbars along river floodplains, including *Arundo donax, Cyperus compactus,* and *Saccharum spontaneum*.

The plant species richness in riparian areas is generally higher than in coastal dune landscapes. Across sampling locations, Gabu 2, one of the tributaries of the Padsan River, contains the highest number of species (n=37), followed by Suyo (n=35) and Lapaz (n=33). Both sites in Munroe Island had the lowest number of species, particularly on the beachfront (Munroe 1; 18 species). As to plant life forms, results revealed that trees dominate the riparian and coastal dune areas with a total of 34 species, followed by herbs (17 species), vines (13 species), and grasses (9 species; Fig. 3). These growth habits are present in all sampling sites in Padsan River.

The Padsan River holds much lower species richness and diversity compared to other river basins in the country (Malabrigo et al. 2014; Lubos et al. 2016; Sarmiento et al. 2017; Sarmiento et al. 2022), and forest ecosystems found in higher elevations of the Cordillera Mountains in

Table 1. The species richness, residency status, and occurrences of flora in the riparian and coastal sand dune habitats of the lower Padsan River basin

Family	Species	Residency Status	Common Name	Riparian			Coastal Sand Dune		
				G1	G2	SY	M1	M2	LP
Acanthaceae	*Ruellia tuberosa* L.	IT			/	/			
Amaranthaceae	*Amaranthus spinosus* L.	IT / IV	Kalunai	/				/	/
	Celosia argentea L.	IT		/					
	Buchanania arborescens (Blume) Blume	NT	Balinghasai			/			
	Mangifera indica L.	IT	Manga	/	/				
Apiaceae	*Centella asiatica* (L.) Urb.	NT							/
Apocynaceae	*Tabernaemontana pandacaqui* Lam.	NT					/		
Araceae	*Colocasia esculenta* (L.) Schott	NT							/
Arecaceae	*Cocos nucifera* L.	NT	Niyog	/	/	/			/
	Nypa fruticans Wurmb	NT / IV	Nipa	/	/		/		
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob.	IT / IV	Hagonoy	/		/			
	Elephantopus tomentosus L.	IT	Elepante		/				
	Mikania micrantha Kunth	IT / IV	Mote mote		/	/		/	/
	Sphagneticola trilobata (L.) Pruski	IT / IV						/	
	Synedrella nodiflora (L.) Gaertn.	IT			/	/			/
Bignoniaceae	*Dolichandrone spathacea* (L.f.) Seem.	NT	Tiwi	/					
Calophyllaceae	*Calophyllum inophyllum* L.	NT	Bitaog	/	/				
Cannabaceae	*Trema orientale* (L.) Blume	NT	Hanabiong		/				
Caricaceae	*Carica papaya* L.	IT	Papaya			/			
Casuarinaceae	*Casuarina equisetifolia* L.	NT / IV	Agoho					/	/
Combretaceae	*Combretum indicum* (L.) DeFilipps	NT					/		/
	Terminalia catappa L.	NT	Talisay	/	/	/	/	/	/
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br.	IT					/	/	/
Cucurbitaceae	*Luffa cylindrica* (L.) M.Roem.	IT	Wild upo	/	/	/	/		/
	Melothria pendula L.	IT					/	/	/
Cyperaceae	*Cyperus compactus* Retz.	NT							/
Ebenaceae	*Diopyros* sp.	NT		/					
Euphorbiaceae	*Euphorbia pulcherrima* Willd. ex Klotzsch	IT	Poinsettia		/				
	Jatropha gossypiifolia L.	IT / IV		/			/		/
	Macaranga tanarius (L.) Müll.Arg.	NT	Binunga			/			
	Melanolepis multiglandulosa (Reinw. ex Blume) Rchb. & Zoll.	NT	Alum		/	/			
	Ricinus communis L.	IT / IV	Tangan tangan			/			
Fabaceae	*Acacia mangium* Willd.	IT / IV	Mangium	/		/		/	
	Canavalia maritima Thouars	NT	Pataning dagat					/	
	Centrosema pubescens Benth.	IT				/			
	Clitorea ternatea L.	IT	Blue ternate		/				
	Derris trifoliata Lour.	NT			/			/	
	Gliricidia sepium (Jacq.) Kunth	IT	Mansanitas			/			/
	Leucaena leucocephala (Lam.) de Wit	IT / IV	Ipil ipil	/	/	/	/	/	/
	Mimosa pudica L.	IT / IV	Makahiya		/				
	Pithecellobium dulce (Roxb.) Benth.	IT	Kamatsili	/	/	/			

Notes: Sampling sites (G1=Gabu 1, G= Gabu 2, M1=Munroe 1, M2=Munroe 2, LP=Lapaz, SY=Suyo); / =presence of species; Residency Status (IT=Introduced Species, NT=Native Species, IV=Invasive Species)

Table 1. The species richness, residency status, and occurrences of flora in the riparian and coastal sand dune habitats of the lower Padsan River basin (continuation)

Family	Species	Residency Status	Common Name	Riparian			Coastal Sand Dune		
				G1	G2	SY	M1	M2	LP
	Pongamia pinnata (L.) Pierre	NT	Bayok	/	/	/		/	
	Prosopis juliflora (Sw.) DC.	IT / IV	Candaroma	/	/		/	/	/
	Pterocarpus indicus Willd.	NT	Narra			/			
	Samanea saman (Jacq.) Merr.	IT / IV			/	/			
	Sesbania grandiflora (L.) Poir.	IT	Katurai						/
Flagellariaceae	*Flagellaria indica* L.	NT	Uwag		/				
Lamiaceae	*Gmelina arborea* Roxb. ex Sm.	IT	Gmelina			/			
Lecythidaceae	*Barringtonia acutangula* (L.) Gaertn.	NT	Potat	/	/				
Malvaceae	*Kleinhovia hospita* L.	NT	Bitan ag	/		/		/	/
	Sida acuta Burm.fil.	IT	Wireweed		/	/		/	/
	Sterculia foetida L.	NT					/		
	Hibiscus tiliaceus L.	NT	Malibago		/				/
Meliaceae	*Azadirachta indica* A.Juss.	IT	Neem tree	/	/	/			
	Swietenia macrophylla G.King	IT	Mahogany	/					
Moraceae	*Ficus septica* Burm.fil.	NT				/			
Moringaceae	*Moringa oleifera* Lam.	IT	Malunggay						/
Myrtaceae	*Eucalyptus globulus* Labill.	IT	Bagras	/		/			
Passifloraceae	*Passiflora foetida* L.	IT / IV						/	
Petiveriaceae	*Rivina humilis* L.	IT			/				
Phyllantaceae	*Breynia cernua* (Poir.) Müll.Arg.	NT	Turog	/	/	/			
	Glochidion lutescens Blume	NT		/			/		
Piperaceae	*Piper aduncum* L.	IT / IV	Buyo buyo						/
Poaceae	*Arundo donax* L.	IT / IV	Talahib	/	/	/		/	/
	Bambusa vulgaris Schrad. ex J.C.Wendl.	IT / IV	Kawayan		/	/		/	/
	Dactyloctenium aegyptium (L.) Willd.	NT	Crowfoot grass				/	/	/
	Eleusine indica L.	IT		/		/	/		
	Imperata cylindrica (L.) Raeusch.	IT	Cogon		/	/		/	/
	Panicum repens L.	IT / IV		/				/	
	Saccharum spontaneum L.	NT		/	/	/	/	/	/
	Spinifex littoreus (Burm.f.) Merr.	NT		/		/	/		/
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	IT / IV	Water hyacinth		/				
Pteridaceae	*Acrostichum aureum* L.	NT	Palaypay		/				
	Acrostichum speciosum Willd.	NT	Palaypay	/					
Rhamnaceae	*Ziziphus jujuba* Mill.	IT / IV							/
Rhizophoraceae	*Rhizophora apiculata* Blume	NT	Bakhaw lalaki	/					
	Rhizophora mucronata Poir.	NT	Bakhaw babae	/					
Rubiaceae	*Morinda citrifolia* L.	NT	Apatot	/	/		/	/	
	Nauclea orientalis (L.) L.	NT	Bangkal			/			
Taccaceae	*Tacca leontopetaloides* (L.) Kuntze	NT							/
Verbenaceae	*Lantana camara* L.	IT / IV	Baho baho		/	/			
	Vitex rotundifolia L.f.	NT / IV	Beach vitex		/		/		
No. of Species	**82**			**33**	**37**	**35**	**18**	**23**	**33**

Notes: Sampling sites (G1=Gabu 1, G= Gabu 2, M1=Munroe 1, M2=Munroe 2, LP=Lapaz, SY=Suyo); / =presence of species; Residency Status (IT=Introduced Species, NT=Native Species, IV=Invasive Species)

Northern Luzon, Philippines (Malabrigo 2013; Batuyong et al. 2020; and Napaldet 2023). Plant richness is associated with ecological and growth limiting factors such as species-specific habitat requirements, type of substrate, physicochemical properties, and other habitat characteristics of dune and riparian ecosystems (Carboni et al. 2010; Šilc et al. 2017; Pielech and Czortek 2021; Peilech 2021; and Anbarashan et al. 2022).

Riparian ecosystems are recognized for their high plant species richness and diversity (Naiman and Décamps 1997; Peilech 2021). Riparian diversity is not evenly distributed in rivers but responds to the spatial gradients in the riparian zone from the springs towards river mouths (Ward 1989; Peilech 2021), with the highest diversity in middle river reaches than in river mouths (Nilsson et al. 1989). Several factors can affect riparian diversity and richness, including hydrological and disturbance regimes, light availability, habitat productivity, water flow, soil moisture, erosion, accumulation rates, and other factors (Larsen et al. 2019; Pielech and Czortek 2021; and Peilech 2021).

In coastal sand dune landscapes, the plant species documented in this study were also found in other areas in the tropics (Miththapala 2008; Anbarashan et al. 2022). Sand dune plants thrive in regions characterized by high temperatures, strong winds, and intense waves. These conditions often result in unstable anchorage for the plants, leading to the desiccation of plant tissues and breakage (Packham and Willis 1997; Miththapala 2008). The sand remains loose and porous in this environment, constantly altering the substrate. As an adaptation, plants near the shoreline develop sideways-growing roots and shoots that lie close to the ground. This growth pattern results in a dense mat on the surface, as seen in species like *I. pes-caprae* and *S. littoreus*. As one moves further inland to more stable dunes, plants adopt a more upright growth posture. Also, due to temperatures rising to 50°C, sand dune plants tend to exhibit xeromorphic characteristics by having a very thick outer layer of leaves and often reduced leaves to spiny projections like *S. littoreus* (Packham and Willis 1997; Miththapala 2008).

Family Fabaceae is the most represented plant family with 14 species (17%), followed by Poaceae (10%), Asteraceae (6%), Malvaceae (6%) and Euphorbiaceae (5%) (Table 1). The rest of the plant families comprise ≤ 2% species each. Fabaceae, commonly known as legumes, bean, or pea family, is the third-largest plant family of terrestrial plants with various growth habits, can fix nitrogen, and can adapt to adverse habitat conditions. The Poaceae, or the grass families, include bamboo, perennials, and annual plants. These families have been considered pioneer species with a wide range of ecological amplitude and can adapt to denuded and newly formed sandy habitats. Several studies have also found dominance of Poaceae, Fabaceae, and Asteraceae families in sand dune vegetation in the tropics (Rao and Sherieff 2002; Rodriguez et al. 2011; and Anbarashan et al. 2022) and lowland tropical rivers and riparian ecosystems (Mligo 2017, Sarmiento et al. 2017; and Sarmiento et al. 2022). In the study area, representative species of Poaceae and Fabaceae often form homogenous cover along with the riparian and coastal areas.

Prosopis juliflora (Candorama) is the most dominant tree species, comprising 29% of the entire tree population (Fig. 4). This species is present in five sampling stations and is most abundant in Munroe Island and Lapaz and grows along with specialized sand dune plants, *I. pes caprae* and *S. littoreus*. It forms dense thornbushes and thickets on dry coastal dune habitats. The species are also encroaching and mixing with the riparian forest

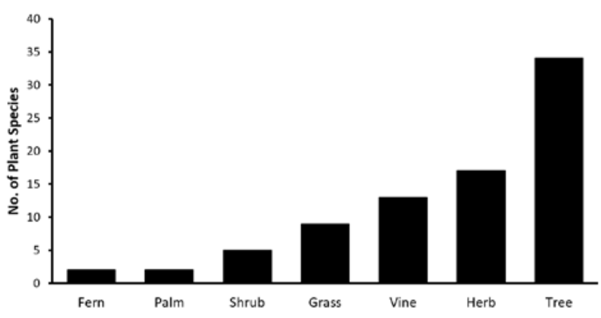

Figure 3. The species richness of plant life forms in the Lower Padsan River Basin

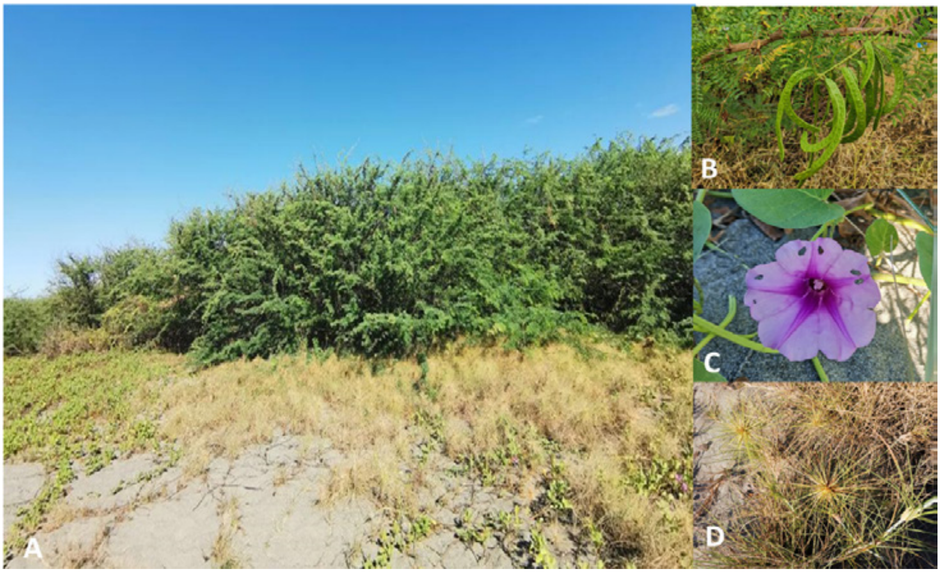

Figure 4. The coastal sand dune areas of Munroe Island are dominated by invasive b) *Prosopis juliflora* and specialized sand dune plants, c) *Ipomoaea pes caprae* , and d) S*pinifex littoreus*

in the tributaries of the Padsan River. *P. juliflora* is a salt-tolerant, nitrogen-fixing small tree or shrub plant reaching 3-8 m tall and native to the Neotropics; however, it is widely spread and thoroughly naturalized in the Philippines (Primavera and Sadaba 2011). It is considered one of the world's worst invasive species due to its aggressive behavior, broad ecological amplitude, and ability to outcompete native vegetation rapidly, which needs to be eradicated (Invasive Species Specialist Group 2015).

Ecological status

As to residency status, 52% of plants are introduced species, 48% are native species, and 27% are invasive species (Fig. 5). Of the invasive species, 23% are both introduced and invasive, and only 4% are both native and invasive species. The higher percentage of introduced species and occurrence of invasive species are associated with ecological and disturbance factors in sand dunes and riparian habitats of the Lower Padsan River.

Different kinds and degrees of disturbances are found to increase alien species and decrease native species in dune areas (Salgado et al. 2022) and riparian landscapes (Renöfält et al. 2005; Stępień et al. 2019). In the downstream of Padsan River, several observed anthropogenic disturbances are likely linked to the increase in introduced and invasive species, like *P. juliflora*. In some studies, the dominance of *P. juliflora* is linked with human activities and failed conservation strategies, which in turn replace native species in dune habitats of Cuddalore, India (Anrabashan et al. 2022).

Tree diversity and structure

The lower Padsan River basin exhibits moderate tree diversity (H' = 2.7), with Shannon diversity indices ranging from 0.89 to 2.43 across different sites. Specifically, the riparian areas located inwardly (Gabu 1 and 2 and Suyo) contain higher tree diversity, richness, abundance, and evenness. Moreover, the coastal dune areas (Lapaz, Munroe 1 and 2) showed higher tree dominance but lower diversity, species richness, abundance, and evenness (Table 2). Among the sampling sites, Suyo, located near the Laoag bypass bridge, has the highest tree diversity (H'=2.43) and species richness (n=15) and lowest dominance (0.11). Conversely, Munroe 1, located on the beachfront of Munroe Island, has the lowest diversity of trees (H'=0.89) attributed to its higher dominance (0.60) and lower species richness (n=6). The homogenous stands of *P. juliflora* contributed to the high dominance of the site. The diversity trend across sites from highest to lowest is as follows: Suyo>Gabu 2>Gabu 1>Lapaz>Munroe 2>Munroe 1.

The structural features of trees in the study area were calculated and presented in Table 3.

The total stand basal area was 18 m^2 ha^{-1}, a mean DBH of 13 cm, and a mean height of 8.6 m. Among the sampling sites, riparian areas in Gabu 1 and 2 and Suyo had the highest mean DBH, stand basal area, and mean height. The largest trees in the sites with the highest DBH are *S. saman, E. globulus, G. arborea, Pithecellobium dulce, Sterculia foetida, C. inophyllum* (Fig. 6a). The tallest trees with highest mean height are *E. globulus, S. saman, G. arborea, A. mangium, T. catapa and C. inophyllum* (Fig. 6b).

Results suggest that the riparian areas had bigger and taller trees, located mainly in the landward and small tributaries of the river. Landward riparian areas are favorable for tree growth, likely due to high freshwater and nutrient inputs, various substrate types (muddy, clay, and sandy), and protection from wave and wind actions. The presence of trees in riparian ecosystems is essential, as they plays a vital role in maintaining river health by reducing sediment transport and channel degradation, strengthening riverbank stability, regulating flood, and sequestering significant amounts of carbon (Pasion et al. 2021).

Community Structure of Trees

The Bray-Curtis cluster analysis and non-metric multidimensional scaling showed two major grouping patterns at 30% similarity based on tree abundance (Fig. 7). The sampling sites of Gabu 1, 2, and Suyo formed a single cluster, while Munroe 1, 2, and Lapaz as another cluster. This grouping pattern showed that plant community composition varies significantly between coastal dunes and riparian landscapes. The clustering of sampling

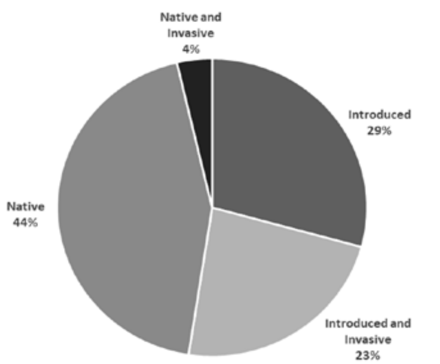

Figure 5. Residency status of plant species in the Lower Padsan River Basin

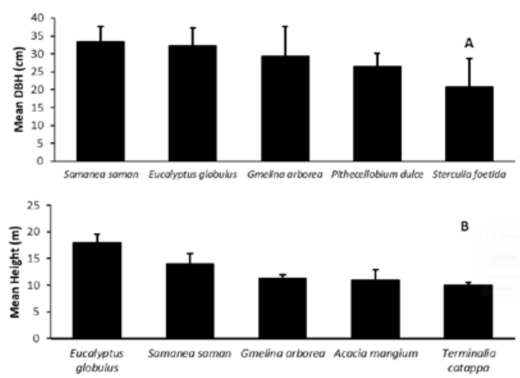

Figure 6. The top five trees with the highest a) mean diameter at breast height (DBH; cm) and b) mean total height (m). Error bars indicate the standard error of the mean (SEM)

Table 2. The plant diversity indices in the sampling sites of the Lower Padsan River

Diversity Indices	Riparian			Coastal Sand Dune			Overall
	Gabu 1	Gabu 2	Suyo	Lapaz	Munroe 1	Munroe 2	
Species Richness	10	12	15	10	6	4	33
Abundance	52	47	43	34	39	39	255
Species dominance	0.16	0.15	0.11	0.27	0.60	0.38	0.12
Shannon Weinner Index	2.01	2.11	2.43	1.68	0.89	1.10	2.7
Pielou's Evenness	0.74	0.69	0.76	0.54	0.41	0.75	0.43

Table 3. The tree diameter at breast height (DBH), height, and stand basal area in the Lower Padsan River Basin. The mean ± standard error of the mean (SEM) for height and DBH are shown

Tree Structural Features	Riparian			Coastal Sand Dune		
	Gabu 1	Gabu 2	Suyo	Lapaz	Munroe 1	Munroe 2
Mean DBH (cm)	14.1±2.5	16.1±2.7	15.3±2.5	4.19±1.7	10.6±0.9	12±2.0
Mean Height (m)	9.3±0.7	8.7±0.3	11.2±0.7	6.2±0.2	6.1±0.2	8.2±0.3
Stand Basal Area (m^2 ha^{-1})	3.36	5.82	5.77	0.29	1.47	1.33

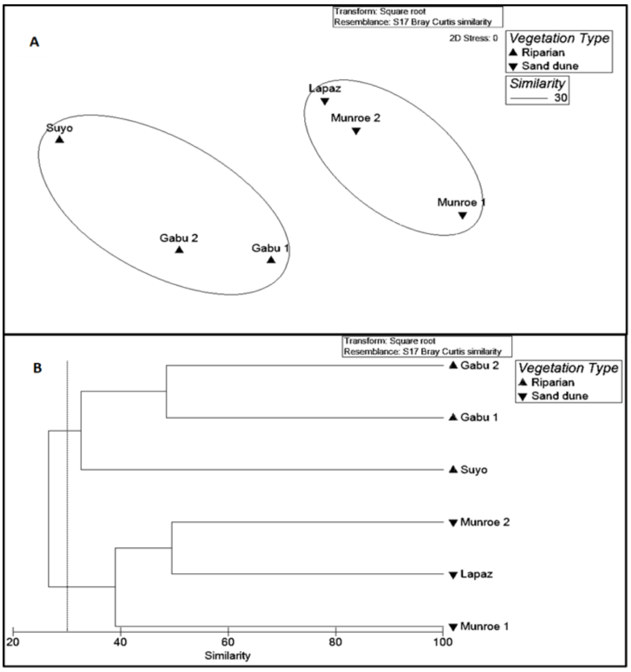

Figure 7. The multivariate exploratory analysis shows the a) nMDS plot and b) cluster dendrogram of sampling sites constructed based on the Bray Curtis Similarity Index

sites within a group indicates a higher similarity of plant communities sharing similar species composition. Conversely, clustering of sampling sites in between groups indicates lower species similarity.

Analysis of similarities (ANOSIM) test indicated significant dissimilarity (ANOSIM Global R=0.7, $p<0.05$) of tree communities between riparian and coastal dune environments in the Padsan River, supporting the grouping patterns found in cluster analysis and nMDS. ANOSIM pairwise comparison showed higher dissimilarity (Anosim R closer to 1) of plant communities between Suyo vs Munroe Island and Gabu 2 vs Munroe Island. In contrast, the comparison between Gabu 1 vs 2 and Gabu 2 vs Suyo showed higher similarities in plant communities (ANOSIM R closer to 0).

Similarity percentages (SIMPER) analysis showed that coastal dune is characterized by the dominance of *P. juliflora* with 68% contribution, while the riparian zone is a mixed tree community with the highest percentage contributions of *L. leucocephala* (24%), *P. dulce* (17%) and *T. catappa* (15%). In each site, the species with the highest contributions are the following: Suyo (*Kleinhovia hospita*), Gabu 1 (*C. inophyllum*), Gabu 2 (*Pongamia pinnata*), Lapaz (*P. juliflora*), Munroe 1 (*P. juliflora*), Munroe 2 (*P. juliflora*). Moreover, *P. juliflora* contributed the highest percentage contributions (10%) to the dissimilarity between riparian and coastal dune vegetation. The higher percentage of contributions indicates the dominance of species, thereby shaping the community similarity or dissimilarity and structure of plants in the lower Padsan river basin.

The spatial heterogeneity of plant communities in the ecological landscapes of the lower Padsan River basin is likely associated with environmental factors such as the type of substrate, topography, and water flow. Previous studies showed that factors such as water flow, soil characteristics, topography, groundwater fluctuations, and landscape type influence the distribution and composition of plants in riparian areas (Fu et al. 2021; Zu et al. 2022). Soil conditions and topography are crucial in shaping plant community distributions and characteristics, influencing riparian vegetation's type, quantity, and quality (Zhao et al. 2020).

4 Conclusion and Recommendations

The coastal sand dune and riparian landscapes of the lower Padsan River basin are home to 82 plant species belonging to 80 genera and 41 families. Of these, 52% of plants are introduced species, 48% are native species, and 27% are invasive species. Riparian zones in landward areas contain higher diversity.

Given the scarcity of published data and the existing threats to important landscapes in the Padsan River basin, our data provide crucial baseline information for science-based interventions such as the development of management and conservation strategies and long-term monitoring of the anthropogenic impacts on biodiversity and ecosystem health of the river. These efforts are essential for maintaining the vital functioning of the river ecosystem as human economic activities, such as dredging, progress downstream in the Padsan River, Ilocos Norte. In-depth studies investigating the effects of environmental factors on the distribution and abundance of coastal sand dunes and riparian plants in the Padsan River Basin are recommended.

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution

AA Along spearheaded the conceptualization of the study, data curation, formal analysis, and the writing and editing of the manuscript. DRF Orboc and LB Calagui provided technical inputs for the writing and revision of the manuscript. All authors participated in the data collection and approved the final version of the article.

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Hymenopteran Fauna of Andanan Watershed Forest Reserve in Caraga Region, Philippines

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ABSTRACT

The hymenopteran fauna plays a crucial role in the ecosystem, serving as primary pollinators and acting as biological controls essential in the interrelationships in the community. This study assessed various groups of Hymenoptera occurring in Andanan Watershed Forest Reserve from collected samples through sweeping, light trapping, and opportunistic sampling. A total of 36 species of hymenopterans were identified, belonging to 30 genera, 20 subfamilies, 11 families, and four superfamilies. One genus of Scoliidae – *Phalerimeris*, with one species, *P. aurulenta*, and a single species of *Liacos* – *L. semperi,* are reported in the Philippines for the first time, while the sphecine wasp *Isodontia* is a new record to Mindanao island. Formicidae is the most abundant family comprising 40% of all the collected individuals. Other groups with significant numbers include the families Apidae and Vespidae. Additional families present in the area include social apoid bees Halictidae and solitary bees Megachilidae. Predatory apoid wasps Crabronidae and Sphecidae, predatory vespoid wasps Pompilidae, Mutillidae, Scoliidae, and the parasitoid wasps Ichneumonidae were also reported. Anthropogenic activities and human interventions are also observed in the area, which may pose threats to the diversity of hymenopteran fauna in the forest reserve.

Keywords: *bees, wasps, ants, new records, checklist, Philippines*

1 Introduction

Hymenoptera is one of the largest insect taxa that include certain groups that are social and consist of several well-organized family units engaging in a variety of complex tasks within the colony, while others are solitary in habit, and some have evolved to be parasitoid to other insects (Sharkey et al. 2012). Hymenopterans play various roles in the ecosystem, serving as primary insect pollinators for flowering plants, fruit-bearing trees, and agricultural crops. In the food web, they are important components for the diet of birds, fishes, and other small animals. According to Choate & Drummond (2011), hymenopterans also serve as biological control agents by feeding on phytophagous arthropods, and have shown that some species are used in ecological studies due to their complexity and suitability in habitat requirements (Dauber et al. 2003). Favorably occurring in tropical forests, hymenopterans have been recorded to tolerate anthropogenic activities (Sobrinho & Schoereder 2007; Mondal & Rojo 2017). However, despite their tolerance, certain groups are still experiencing global declines (Uno et al. 2010) as their nesting behaviors and development are significantly altered due to forest degradation (Samejima et al. 2004).

The Philippines has been studied for hymenopteran diversity in the past decade due to its wide range of possible habitats (General & Alpert 2012). New research has also contributed to the knowledge of Philippine Hymenoptera by describing new species (Kojima 1982; Fernandez

2006; Sorger & Zettel 2011; General 2018; Zettel et al. 2018; and Koch & General 2019), implying the diverse community of this group in the archipelago.

The Andanan Watershed Forest Reserve is a protected forested area under Proclamation No. 734, S. 1991 (PENRO Agusan del Sur 2020), situated in Sibagat and Bayugan in the Caraga region of northeastern Mindanao. There is limited information on the insect fauna of this area, such as lepidopterans (Domine & dela Cruz 2020) and odonatans (Guerzon et al. 2023). There is no information yet on hymenopterans that can inform the area's need for forest management and conservation practices. The result of this study will serve as a preliminary report of hymenopteran fauna for species inventory and ecological monitoring in the future.

2 Materials and Methods

The Andanan Watershed Forest Reserve is a secondary forest that spans alternating lowland and mountainous areas in the Caraga region of northeastern Mindanao. The forested section is characterized by slopes and ridges along its riparian area. Fruit-bearing trees such as *Lansium parasiticum* (Osbeck), Sahni & Bennet (lanzones), and *Artocarpus odoratissimus* Blanco (marang) are observed in certain parts of the area. Flowering plants like *Wedelia, Odontonema, Areca, Ficus,* and *Nauclea* are scattered around the area. The forest reserve boasts a moderately dense canopy cover. The ground is also covered with leaf litter, fallen twigs, and decaying logs. Large to medium boulders are observed alongside the river, and various types of soils, ranging from clay to loam, play a vital role for certain species of bees and wasps. The riparian zone features a dense combination of shrubs, ferns, and grasses. Pebbles and cobbles can be found in some areas along the stream, with rocks covered by moss and algae. Arthropods and other insects, such as spiders and larvae of lepidopterans, coleopterans, and hemipterans, were also observed in the Andanan Watershed Forest Reserve.

The Andanan Watershed Forest Reserve also contains patches of cultivated lands. Certain areas within the reserve have been dedicated to agricultural crops. Furthermore, a few residential areas have been observed near the riparian zone, featuring ornamental flowering shrubs that attract some pollinators to these plants.

One collection site each was established in three different barangays – Calaitan (8.7927°N, 125.7789°E; 209.1 masl), Berseba (8.8552°N, 125.8007° E; 219.7 masl), and Santo Niño (8.8451°N, 125.7871°E; 261.7 masl) (Fig. 1) of Bayugan City, Agusan del Sur. Various tributaries along the Andanan River interconnect the riparian zones along the three sites. Ocular habitat observations were documented using a digital camera for photos and videos, while the coordinates were recorded using a Global Positioning System (GPS) receiver.

The specimens were collected by sweeping and handpicking for an eight-hour sampling effort. During nighttime, light trapping was also utilized. Moderately large samples were placed in specimen boxes with phenol and then pinned and labeled properly, while smaller individuals were placed in ethyl alcohol. All taxa were identified and validated by hymenopterists specializing in certain taxonomic groups. The field collection took place from July to September 2019.

This study was granted with the gratuitous permit number R13-2021-33 issued by DENR Region XIII Butuan City.

3 Results and Discussion

Table 1 lists all hymenopteran groups collected in Andanan Watershed Forest Reserve. A total of 36 species were identified, representing 30 genera, 20 subfamilies, 11 families, and four superfamilies.

The superfamily Apoidea (Fig. 2, species composition: 39%) comprises a large group of hymenopterans, generally including bees and apoid wasps. This group is behaviorally diverse, encompassing both eusocial species (Apidae and Halictidae) and solitary bees (Megachilidae), along with specific groups of apoid wasps (Sphecidae and Crabronidae). Eusocial bees, mostly pollenivores, are valuable pollinators in natural habitats for flowering plants and agricultural crops. On the other hand, sphecoid and digger wasps are obligate predators and kleptoparasites of other wasps (Schmid-Egger 2011).

Another cosmopolitan superfamily, Vespoidea (Fig. 2, species composition: 19%), is also present in Andanan Watershed Forest Reserve. This group includes a wide range of both eusocial

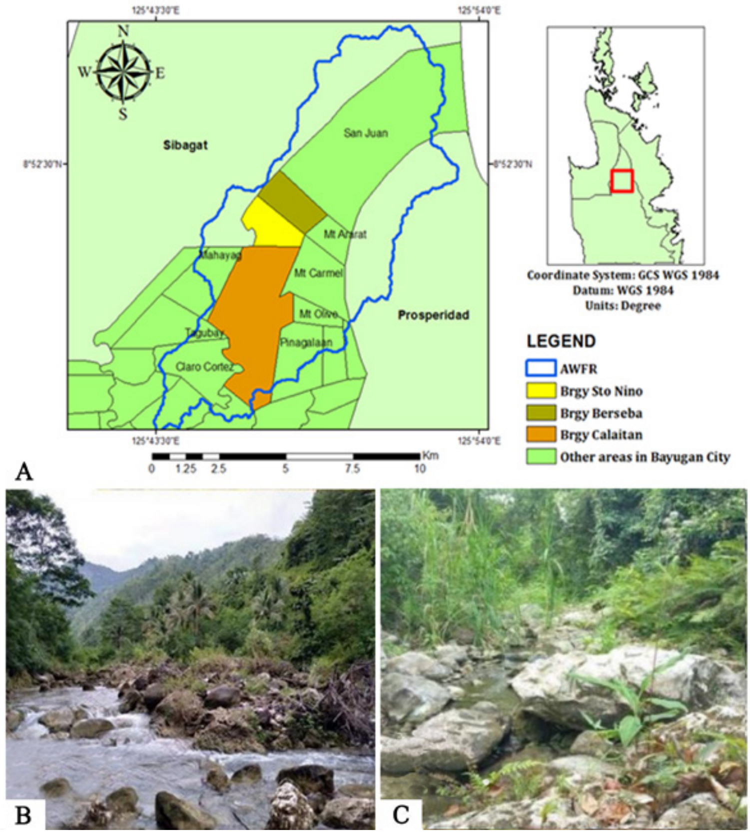

Figure 1. (A) Location map delineating the Andanan Watershed Forest Reserve boundary (in blue: AWFR) and the three collections sites of the study (Calaitan, Berseba, and Sto. Niño); (B–C) tributaries of Andanan River showing the riparian system and vegetation of the area close to forest margin

wasps (vespine wasps and paper wasps) and solitary wasps (potter wasps, scoliid wasps, and spider wasps). Most members of vespine wasps are essential pollinators for various fruits and crops, while some are employed as biological agents to control larvae pests such as caterpillars (Mahmood et al. 2012). Other members of this large group, such as scoliid wasps, act as parasitoids to beetle larvae (Augul, 2016), while pompilid wasps are predators of spiders (Waichert et al. 2012).

Obligate parasitoid wasps belonging to the superfamily Ichneumonoidea (Fig. 2, species composition: 2%) have been observed in the area. This group is obligate endoparasitic, inserting their eggs directly into the host larva through their sharp ovipositors. This evolutionary behavior has proven successful, turning them into effective bio-control agents against insect pests. Lastly, the largest group, Formicoidea (Fig. 2, species composition: 40%), includes an abundant community of ants recorded in Andanan Watershed Forest Reserve. This group comprises diverse genera of ants and is primarily observed near their nest sites, contributing to their prevalence in the collection. Since ants are the most successful social insects, they have become the most species-rich and ecologically dominant among all social insects (Johnson et al. 2013). They can perform vital functions in many terrestrial environments (Chen et al. 2013).

A total of 195 hymenopteran individuals were recorded in Andanan Watershed Forest Reserve. Seventy-eight belong to Formicoidea, and 77 are Apoidea, making these two superfamilies the most abundant groups in the area, constituting 40% and 39%, respectively. On the other hand, Vespoidea accounted for 37 individuals, comprising 19% of the total numbers, while Ichneumonoidea was the

Table 1. Checklist of Hymenoptera in Andanan Watershed Forest Reserve. New records indicated: *genus in the Philippines; **species in the Philippines; ***genus in Mindanao

Superfamily	**Family**	**Subfamily**	**Species**
Apoidea	Apidae	Apinae	*Amegilla* sp.
			Apis breviligula
			Apis nigrocincta
			Thyreus wallacei
		Xylocopinae	*Xylocopa ghilianii*
			Xylocopa flavonigrescens
	Crabronidae	Crabroninae	*Larra* sp.
	Halictidae	Nomiinae	*Nomia (Curvinomia) iridescens*
			Nomia (Maculonomia) sp.
	Megachilidae	Megachilinae	*Megachile* sp.
	Sphecidae	Sphecinae	*Isodontia* sp. ***
			Sphex sp.
		Sceliphrinae	*Sceliphron caementarium*
			Sceliphron laetum
Formicoidea	Formicidae	Ectatomminae	Genus undetermined
		Formicinae	*Camponotus* sp.
			Colobopsis sp.
			Polyrhachis bihamata
			Polyrhachis ignota
			Polyrhachis sp.
		Myrmicinae	*Carebara diversa*
			Myrmicaria sp.
			Solenopsis geminata
		Ponerinae	*Odontomachus* sp.
Ichneumonoidea	Ichneumonidae	Ophioninae	*Enicospilus* sp.
Vespoidea	Mutillidae	Mutillinae	*Trogaspidia* sp.
	Pompilidae	Ceropalinae	*Irenangelus* sp.
		Pepsinae	*Hemipepsis* sp.
	Scoliidae	Scoliinae	*Liacos semperi* **
			Phalerimeris aurulenta *
	Vespidae	Eumeninae	*Delta pyriforme*
			Phimenes curvatus
			Rhynchium atrissimum
		Polistinae	*Ropalidia flavobrunnea*
		Stenogastrinae	*Eustenogaster spinicauda*
		Vespinae	*Vespa tropica*

fewest, with only three individuals collected. The family Formicidae is the most observed group due to the area's diverse vegetation and leaf litter covering the ground, providing an ideal habitat for ant colonies. Apoid bees of the family Apidae, including honeybees and related groups, show a significant number in the area. Since pollination is a key component in the integrity of terrestrial ecosystems, hymenopteran pollinators, including bees (Kremen et al. 2007), play crucial roles in plant reproduction (Potts et al. 2009).

Similarly, the numbers of vespid wasps (Vespidae) were relatively high. Eusocial wasps, particularly certain groups of Polistinae and

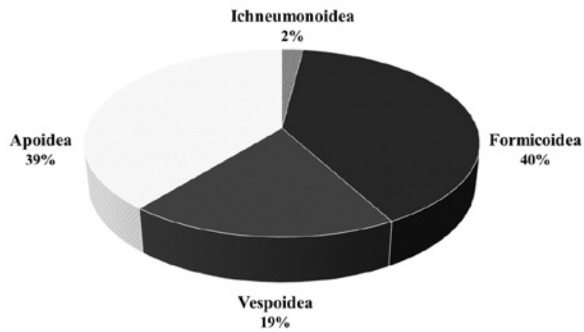

Figure 2. Superfamily composition and relative abundance of hymenopterans recorded in Andanan Watershed Forest Reserve, comprising 11 families

Vespinae, thrive as colonies, while others like Eumeninae and Stenogastrinae are solitary in nature. Although most vespid species are predatory, their occurrence is usually associated with specific arthropods in the area, serving as their prey. Some studies have reported that vespid wasps prefer tropical forests with extreme canopy shades (Bawa 1990; Steffan-Dewenter et al. 2006), a characteristic of certain sections in the forest reserve.

The superfamily Apoidea comprises one of the largest groups of hymenopterans. Apidae, one of the most common groups, includes honeybees, carpenter bees, and bumblebees plays a vital role as a key pollinator for fruit trees and flowering plants. Some groups within Apidae are utilized worldwide for honey production (Van Klink 2016). In Andanan Watershed Forest Reserve, two subfamilies are reported: Apinae and Xylocopinae. One notable group is the genus *Thyreus* (Fig. 3G), known as a kleptoparasite to *Amegilla* (Fig. 3F) (Lieftinck 1968). Two species of honeybees from the genus *Apis* were also reported (Figs. 3A and 3B). Solitary bees, such as carpenter bees from the genus *Xylocopa* (Figs. 3H and 3I), are also recorded in the area. These large bees typically build their nests in burrows and dead wood and are considered essential pollinators for several cultivated and wild plant species (Prashanta & Belavadi 2017). Family Halictidae, including *Nomia* (Figs. 3D and 3E), a typical sweat bee common in the Philippines (Cockerell 1919), and the leaf-cutter bees *Megachile* (Fig. 3C) of family Megachilidae are also documented. According to Baltazar (1996), most species of *Megachile* are parasites of larvae and pupae of other insects. However, it is not certain whether the individual collected from the area is parasitic or non-parasitic. Sphecoid groups of Apidae are also collected in the Andanan Watershed Forest Reserve, including sphecid wasps (Sphecidae) and sand wasps (Crabronidae). One notable crabronid wasp, *Larra* (Fig. 3J), is a predator of a wide range of insects and spiders (Bohart & Menke 1976). On the other hand, *Isodontia, Sphex,* and *Sceliphron* exhibit diverse nesting habits in the ground and use various insects as food for their offspring. *Isodontia* (Fig. 3K) is a new record in Mindanao, while digger wasp *Sphex* (Fig. 3N) and mud daubers *Sceliphron* (Figs. 3L and 3M) are commonly found and considered invasive species, particularly in Europe (Ćetković. al. 2011). Certain species of these wasps even prefer nesting near anthropogenic disturbances (Fateryga & Kovblyuk 2014).

Formicoidea comprises the largest and most diverse hymenopterans in Andanan Watershed Forest Reserve, encompassing various ant groups and widely distributed across tropical ecosystems (Coleman & Wall 2015). In the Philippines, the taxonomy of this group has been developed by several hymenopterists (Baltazar 1996; Calilung 2000; General & Alpert 2012; General & Buenavente 2017; and Mondejar & Nuñeza 2022). Four subfamilies are recorded in the area: Ectatomminae, with one individual with an undetermined genus (Fig. 4D); Formicinae; Myrmicinae; and Ponerinae. Three genera of formicine ants were collected in the area: *Camponotus* (Fig. 4G), *Colobopsis* (Fig. 4A), and *Polyrhachis* (Figs. 4H, 4I and 4J). *Polyrhachis*, distinguished by spines on its pronotal and mesonotal areas, generally includes one of the largest species of Philippine ants. Myrmicine ants of the genera *Carebara* (Fig. 4F), *Myrmicaria* (Fig. 4B), and *Solenopsis* (Fig. 4C) were also

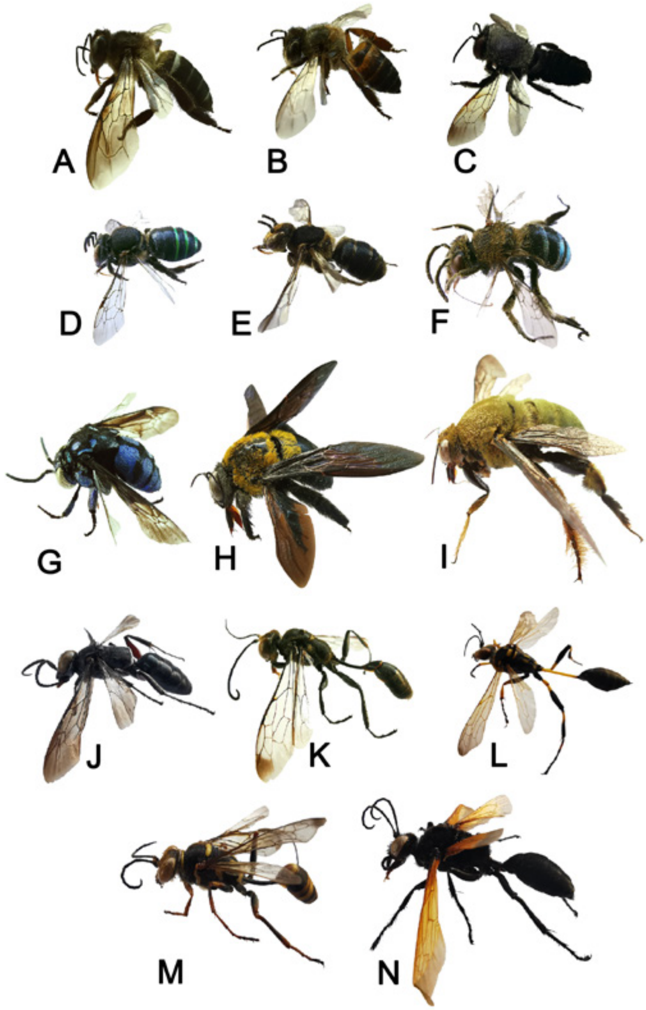

Figure 3. Superfamily Apoidea including apoid bees (A) *Apis breviligula*; (B) *Apis nigrocincta*; (C) *Megachile* sp.; (D) *Nomia (Curvinomia) iridescens*; (E) *Nomia (Maculonomia)* sp.; (F) *Amegilla* sp.; (G) *Thyreus wallacei*; (H) *Xylocopa ghilianii*; (I) *Xylocopa flavonigrescens*; and apoid wasps (J) *Larra* sp.; (K) *Isodontia* sp.; (L) *Sceliphron caementarium*; (M) *Sceliphron laetum*; (N) *Sphex* sp.

collected and are the most abundant among all ants in the area. The genus *Odontomachus* (Fig. 4E) is a ponerine ant remarkable for its long head and strong, elongated jaws, used for grasping prey. This group, locally known as "hantik", is mainly found in the ground or climbs on plant foliage to hunt prey (General & Alpert 2012).

One genus of ichneumonoid wasp from the superfamily Ichneumonoidea is reported in the Andanan Watershed Forest Reserve. Members of *Enicospilus* (Fig. 4K) are parasitoid wasps targeting other insect taxa, usually at their larval stages.

In the superfamily Vespoidea, four families are reported in the area. A species of velvet ant, *Trogaspidia*, belonging to the family Mutillidae, was collected and represented by male (Fig. 5A) and female (Fig. 5B) individuals. Pompilidae, commonly known as spider wasps, are also recorded with two genera – *Irenangelus* (Fig. 5G), known as a kleptoparasite of other pompilid wasps (Barthelemy, 2014), and *Hemipepsis* (Fig. 5F), known to feed on tarantula spiders in the tropics. One genus of Scoliidae – *Phalerimeris*, with one

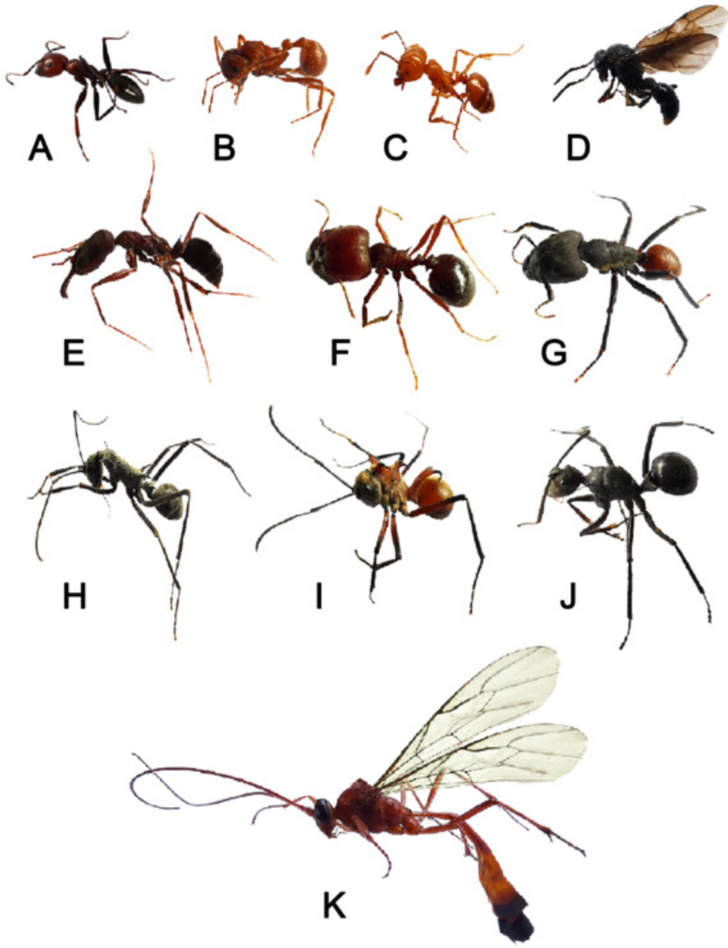

Figure 4. Superfamilies Formicoidea (A) *Colobopsis* sp.; (B) *Myrmicaria* sp.; (C) *Solenopsis geminata*; (D) Ectatomminae Undetermined Genus; (E) *Odontomachus* sp.; (F) *Carebara diversa*; (G) *Camponotus* sp.; (H) *Polyrhachis ignota*; (I) *Polyrhachis bihamata*; (J) *Polyrhachis* sp.; and Ichneumonoidea (K) *Enicospilus* sp.

species *P. aurulenta* (Fig. 5C: male) and (Fig. 5D: female), and a single species of *Liacos* – *L. semperi* (Fig. 5E), are reported in the Philippines for the first time. Vespidae is the most diverse group with eusocial and solitary representative subfamilies among all the vespoid families. In Andanan Watershed Forest Reserve, Eumeninae, Polistinae, Stenogastrinae, and Vespinae were recorded. Three genera of subfamily Eumeninae, also known as potter wasps, are identified. These include *Delta* (Fig. 5H), whose nests are often found attached to building walls using mud (Yamane 1990), as well as *Phimenes* (Fig. 5J) and *Rhynchium* (Fig. 5I). Polistine wasps, also known as paper wasps, are the only eusocial vespid wasps recognized in the area. One genus is *Ropalidia* (Fig. 5K), the most diverse social wasps in the tropics. Another subfamily is Stenogastrinae, also known as hover wasps, with one species, *Eustenogaster* – *E. spinicauda* (Fig. 5L), observed in the area. This species was described by Saito & Kojima (2007) using various specimen types from Samar, Leyte, Surigao and Bukidnon. Lastly, the genus *Vespa* of the subfamily Vespinae are true hornets distributed in the Oriental region. The species *V. tropica* (Fig. 5M) was first recorded in Sulu by Bequaert (1936), suggesting its dispersal route from the Indonesian archipelago through Borneo.

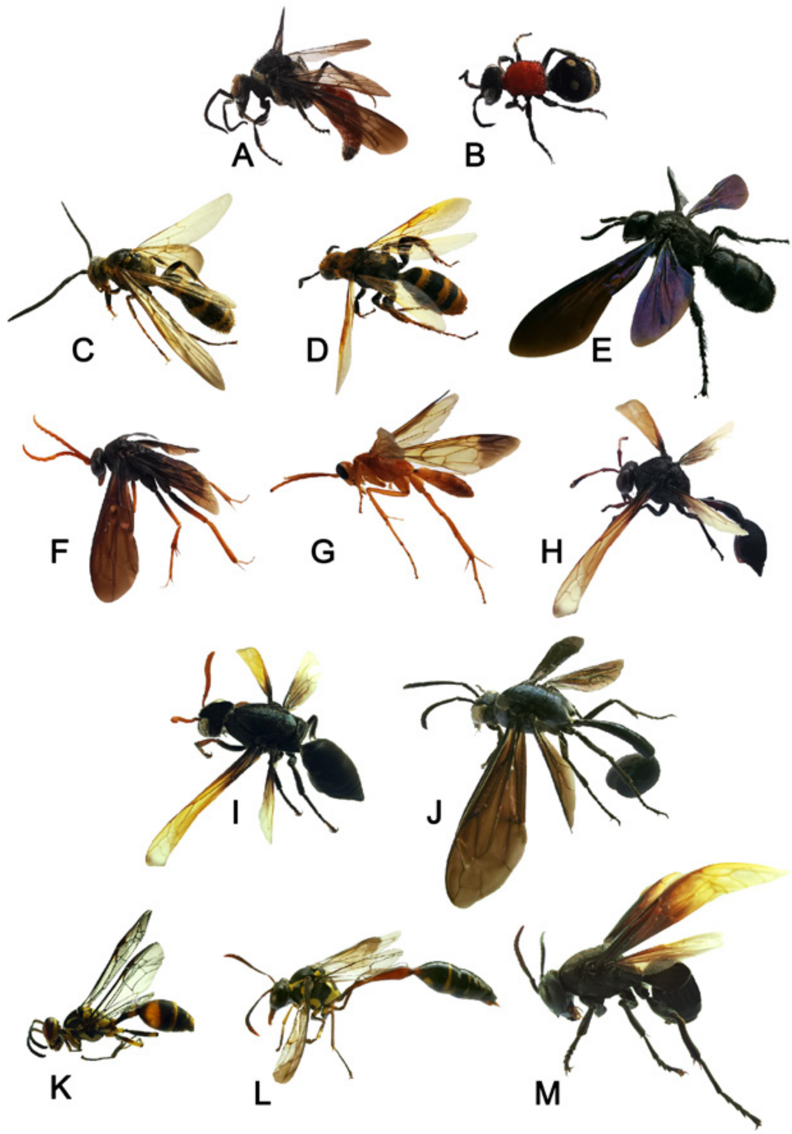

Figure 5. Superfamily Vespoidea (A) *Trogaspidia* sp. [male]; (B) *Trogaspidia* sp. [female]; (C) *Phalerimeris aurulenta* [male]; (D) *Phalerimeris aurulenta* [female]; (E) *Liacos semperi*; (F) *Hemipepsis* sp.; (G) *Irenangelus* sp.; (H) *Delta pyriforme*; (I) *Rhynchium atrissimum*; (J) *Phimenes curvatus*; (K) *Ropalidia flavobrunnea*; (L) *Eustenogaster spinicauda*; (M) *Vespa tropica.*

4 Conclusion and Recommendations

Various techniques have inherent biases that favor different species of hymenopterans. For example, certain active groups at night may be more effectively captured through light trapping, while ground-dwelling hymenopterans are better sampled using pitfall traps, and active flyers are more advantageously captured with Malaise traps. Using all of these collecting methods is encouraged to capture an area's wider spectrum of hymenopteran biodiversity. Research on insect fauna, particularly this large and diverse group of Hymenoptera, encourages future researchers to delve into the taxonomy and ecological studies, potentially discovering new records in protected areas with high demands for conservation. The hymenopteran checklist in Andanan Watershed Forest Reserve is the first inventory study in the area, serving as a guide for future ecological assessment and biomonitoring in the forest reserve.

Andanan Watershed Forest Reserve listed 36 species of hymenopterans belonging to 11 families. The hymenopteran community in this area is supported by forested and riparian ecosystems, which may also pose threats, such as potential deforestation and agricultural expansion, that lead to habitat fragmentation. Nevertheless, actively working to preserve the forested and riparian sections is highly encouraged. Furthermore, a more comprehensive and standardized collection effort is recommended to generate more panoramic baseline information on hymenopterans in the forest reserve.

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution

Geneva Sabuero contributed to the conceptualization, collection of resource materials, and the original drafting of the manuscript. Nick Anthony Burias was involved in the conceptualization and contributed to the writing through review and editing. Ian Niel dela Cruz participated in the conceptualization, collection of resource materials, and writing through review and editing, as well as providing supervision. All authors approved the final version of the manuscript.

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