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A Socio-Ecological Approach to Managing Plant Invasion in Pangdan River, City of Naga, Cebu, Philippines

NADELA, John Vincent B.(1); BACOMO, Genevieve I.(2); CARREON, Eden Marie C.(3); ANGUB, Florence A.(4); NUÑEZ, Kian S.(5); GARCES, Jake Joshua C.(6)

(1) 0009-0008-5309-5492; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. vincentnadela30@gmail.com.
(2) 0009-0006-5882-7926; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. genevievebacomo@gmail.com.
(3) 0009-0002-3599-4407; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. edenmariecarreon@gmail.com .
(4) 0009-0009-0046-540X; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. florenceangub33@gmail.com.
(5) 0009-0003-1667-4253; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. kianzenunksn123@gmail.com .
(6) 0000-0003-1080-0557; Cebu Normal University. Osmeña Blvd, Cebu City, 6000 Cebu, Philippines. garcesjj@cnu.edu.ph .

ABSTRACT

Plant invasion threatens the ecological functions and biodiversity of riparian ecosystems. Various management strategies are proposed to preserve its ecological vitality; however, several challenges are observed in many management efforts. This study adopted a socio-ecological approach to understand the riparian landscape along the Pangdan River, City of Naga, Cebu Island, Philippines. Using the Belt Transect-Quadrat Method, ecological components, i.e., biological indices, and climatic and edaphic parameters were assessed; semi-structured interviews among stakeholders were also employed to gather social and historical data. Results showed a gradient in plant diversity, with upstream having higher native plant richness (N=67.57%) and downstream displaying the lowest native plant richness (N=5.41%). Light intensity and temperature emerged as key factors shaping plant communities, with both native and alien species richness declining as these factors increased. Soil properties within the examined range had minimal independent effects on plant diversity. Historical analysis revealed the prevalence of anthropogenic activities, i.e., quarrying, artisanal mining, and the introduction of invasive plants. The documented decrease in plant diversity and the prevalence of alien species raise concerns about the river's ecosystem health. Providing valuable baseline data and understanding the current state of the riparian zone is crucial for developing effective management strategies in riparian ecosystems.

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RESUMO

A invasão de plantas ameaça as funções ecológicas e a biodiversidade dos ecossistemas ribeirinhos. São propostas diversas estratégias de gestão para preservar a sua vitalidade ecológica; no entanto, são observados vários desafios em muitos esforços de gestão. Este estudo adotou uma abordagem socioecológica para compreender a paisagem ribeirinha ao longo do rio Pangdan, cidade de Naga, ilha de Cebu, Filipinas. Através do Método Belt Transect-Quadrat, foram avaliados componentes ecológicos, ou seja, índices biológicos e parâmetros climáticos e edáficos; entrevistas semiestruturadas entre as partes interessadas foram também utilizadas para recolher dados sociais e históricos. Os resultados mostraram um gradiente na diversidade de plantas, com a montante a apresentar uma maior riqueza de plantas nativas (N = 67,57%) e a jusante a apresentar a menor riqueza de plantas nativas (N = 5,41%). A intensidade da luz e a temperatura surgiram como factores-chave que moldam as comunidades vegetais, com a riqueza de espécies nativas e exóticas a diminuir à medida que estes factores aumentavam. As propriedades do solo dentro do intervalo examinado tiveram efeitos independentes mínimos na diversidade das plantas. A análise histórica revelou a prevalência de atividades antropogénicas, nomeadamente, extração, mineração artesanal e introdução de plantas invasoras. A diminuição documentada da diversidade vegetal e a prevalência de espécies exóticas levantam preocupações sobre a saúde do ecossistema fluvial. Fornecer dados de base valiosos e compreender o estado actual da zona ribeirinha é crucial para o desenvolvimento de estratégias de gestão eficazes nos ecossistemas ribeirinhos.

Keywords:
espécies de plantas exóticas, índices bióticos, espécies de plantas invasoras, ecossistemas ribeirinhos, abordagem socioecológica

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Introduction

Riparian areas, hosting native plants (NPs) and alien plants (APs) provide vital ecological roles and services (i.e., water filtration, bank stabilization, and habitat provision) that maintain improved water quality, flood control, and recreational opportunities (Singh et al., 2023). Even so, riparian zones are recognized as some of the most delicate ecosystems on the planet, vulnerable to a variety of human-caused threats such as habitat modification, removing vegetation for farming, grazing, foot traffic, and urban growth, which are often accompanied by, or resulted in the proliferation of APs (Singh et al., 2021).

In fact, tropical regions are not left aside as plant invasion has also become a cause of global concern; tropical regions of Southeast Asia are no exception. However, despite the urgent need to combat the prevalence of invasive alien plants (IAPs) in the region, specifically the Philippines, acknowledge the limited studies on databases and economic costs that focus on IAPs and its management, underscoring a growing global concern (Shrestha et al., 2022). These gaps must be addressed, and site-specific research must be conducted to determine the impacts of IAPs on a riparian ecosystem. This is important in designing a local effective management plan for a plant-invaded landscape.

Nature-based solutions (NbS) have been a promising approach that allows nature to manage ecosystems in dealing with biological invasion, ecological degradation, and biodiversity loss (Seddon et al., 2020). However, despite the recognized efforts of promoting NbS, the concept has gaps that need to be addressed. These challenges include (1) the lack of comprehensive knowledge and data on NPs and APs and their distribution patterns, (2) limited funding and resources for management efforts, (3) and the need for greater public awareness and participation in management projects. Indeed, the need for prioritizing tools with precision, automation, and cost-effectiveness to improve management strategies, despite limited resources and context-specific challenges (Stein et al., 2022). Stakeholder interviews are valuable for understanding underlying beliefs and dynamics in these contexts (Kariuki et al., 2021). In developing countries, where data is often lacking, improvisation is essential. Effective monitoring and evaluation require distinct approaches, with the interpretation of results guiding management decisions and the design of monitoring frameworks.

The Pangdan River in the City of Naga has been found to have covered biodiverse NPs and APs (i.e. *Cocos nucifera, Zea mays, Mangifera indica, Artocarpus heterophyllus*, and *Leucaena leucocephala*) in its riparian zones that have been observed to lack data assessment regarding its vegetation cover and water quality (Department of Environment and Natural Resources-Environmental Management Bureau 7 [DENR-EMB 7], 2021). Consequently, it is necessary to assess the site's plant species' biological and ecological status using a variety of biotic indicators and important characteristics. Sustainable efforts of collaborating public-private agencies for the rehabilitation of the Pangdan River are ongoing, and the current update focuses on the water quality status and the causes of such results (DENR-EMB 7, 2023).

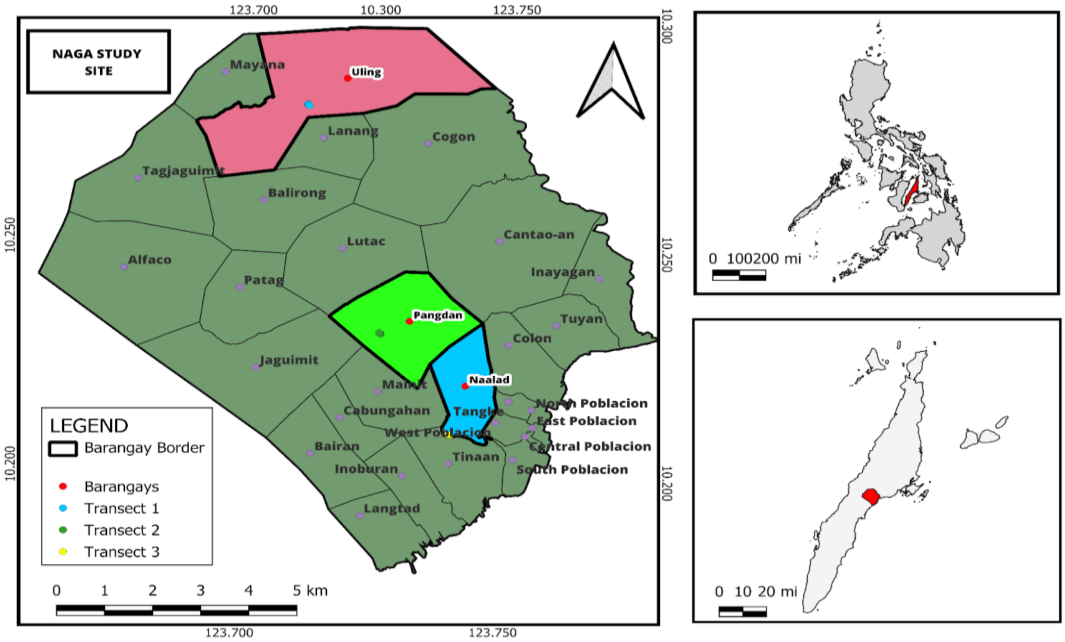
The recent meeting on March 8, 2023, focused on collaborative actions by public-private agencies, including water quality monitoring, information dissemination, waste management, educational campaigns, and infrastructure support (DENR-EMB 7, 2023). This study aims to enhance strategic planning by integrating an interdisciplinary mixed-method approach to address challenges in plan execution (Muhammad et al., 2022). This study aims to characterize ecological scales and trends, collect historical data, and develop questionnaires on knowledge, perception, and social values related to NPs and APs. This will inform effective management planning for the Pangdan River in Naga City, Cebu Island, Philippines.

Materials and Methods

The City of Naga, derived from the term "narra" because of the abundance of Narra trees, is considered as one of the major energy producers (e.g., Apo Cement Corporation, and other businesses) in Cebu Island, Philippines (City Government of Naga & City Planning and Development Office, 2016). Additionally, employment opportunities in commercial buildings, tourist attractions, and food production are provided to the people by the said businesses and establishments. It has a total land area of 102,018,400 m² and is situated along Cebu's southern shore (Fig.1).

Figure 1.

Geographical location of the study area in Pangdan river, City of Naga, Cebu Island, Philippines



At these coordinates, the elevation is believed to be 34.3 meters above mean sea level (masl). The riparian river, called Pangdan, lies approximately between the latitude 10° 11' 43" N and the longitude of 123° 45' 18" E, with a total length of 16,760 m. The Pangdan River runs alongside the three barangays of Naga City. These barangays are Barangay Uling (Site 1), Barangay Pangdan (Site 2), and Barangay Naalad (Site 3), which correspond to the upstream, midstream, and downstream sections of the river, respectively (Fig.1).

Based on researchers' observations, Barangay Uling has higher population densities compared to Barangay Pangdan and Naalad due to factors including favorable topography and land for agriculture and development, historical settlement patterns near water sources, and more favorable environmental conditions. With the increasing settlements in each site, increased habitat alteration (i.e., deforestation, agricultural, industrial processes) might disrupt NPs in natural ecosystems creating an ideal condition for IAPs to flourish.

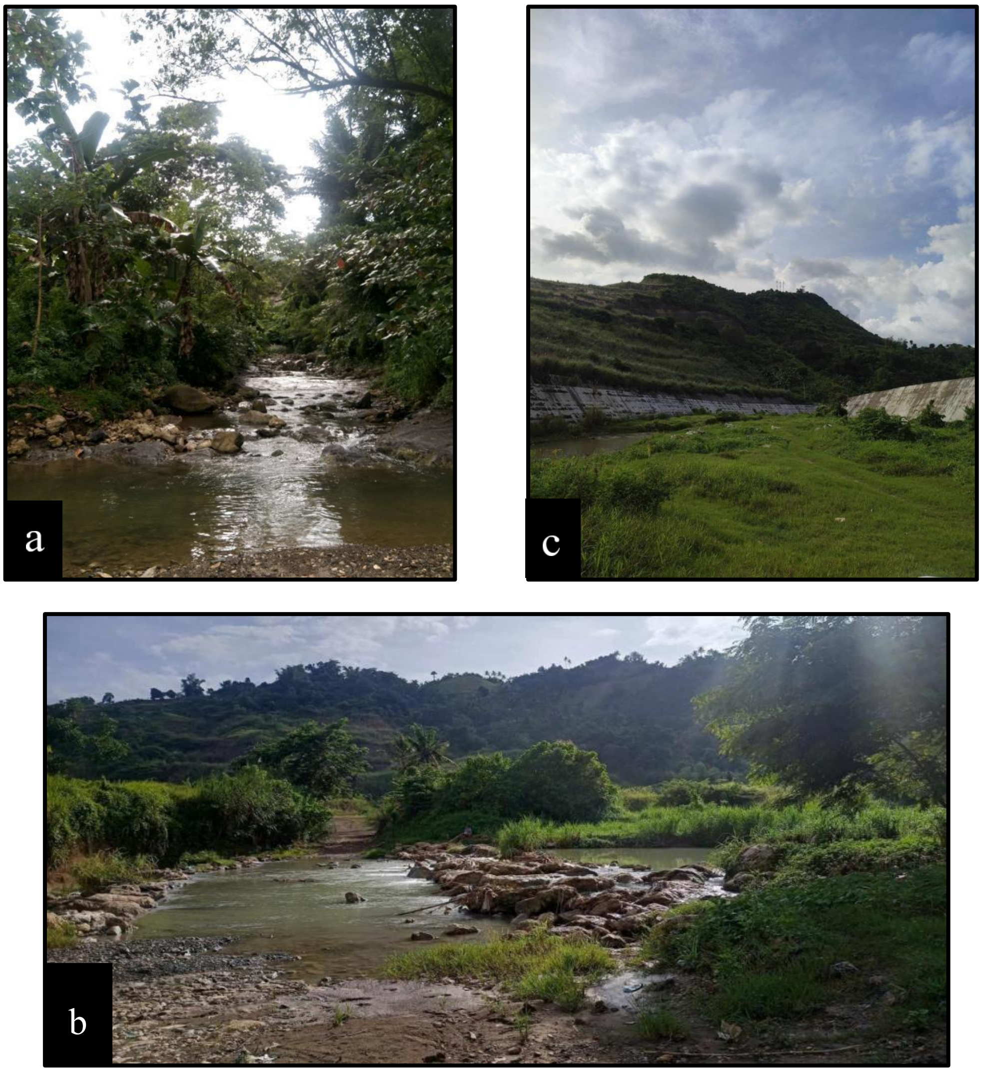
S1 is located upstream supported by a diverse array of plants (Fig. 2a). The water is clean and refreshing, originating from the nearby mountains. Abundant greenery filled the area, including mango, coconut, and bamboo trees, along with ferns and mosses thriving in the humid environment. S2 is the midstream, indicating a place that is relatively established, with human activities well pronounced.

The turbidity in this reach is slightly high and attributed to natural factors, and those from the upstream sections. This section is a mix of natural vegetation and human interventions. Other than mango and coconut trees, residents often cultivate a variety of other fruits and decorative plants that were imported from other nearby regions. The area is relatively open due to the absence of a canopy in the riparian zone, resulting in full exposure to sunlight (Fig. 2b). S3, identified as the downstream section of the river, is characterized by turbid water, primarily due to the accumulation of sediments and minerals deposited along the river's course (Fig. 2c).

During the catastrophic landslide in September 2018, debris and a large volume of mud overwhelmed the area, particularly Barangay Naalad leading to its accumulation into the Pangdan river (Lagmay et al., 2020). Consequently, it has become more prone to pollution and destruction. This study is the first to investigate biological invasions in riparian ecosystems using a mixed-method approach of du Plessis et al. (2021). The study was carried out in Pangdan River, City of Naga, Cebu Island, Philippines during the wet season from October 2023 to January 2024.

Figure 2.

Riparian zones. (a) S1: Barangay Uling; (b) S2: Barangay Pangdan; (c) S3: Barangay Naalad

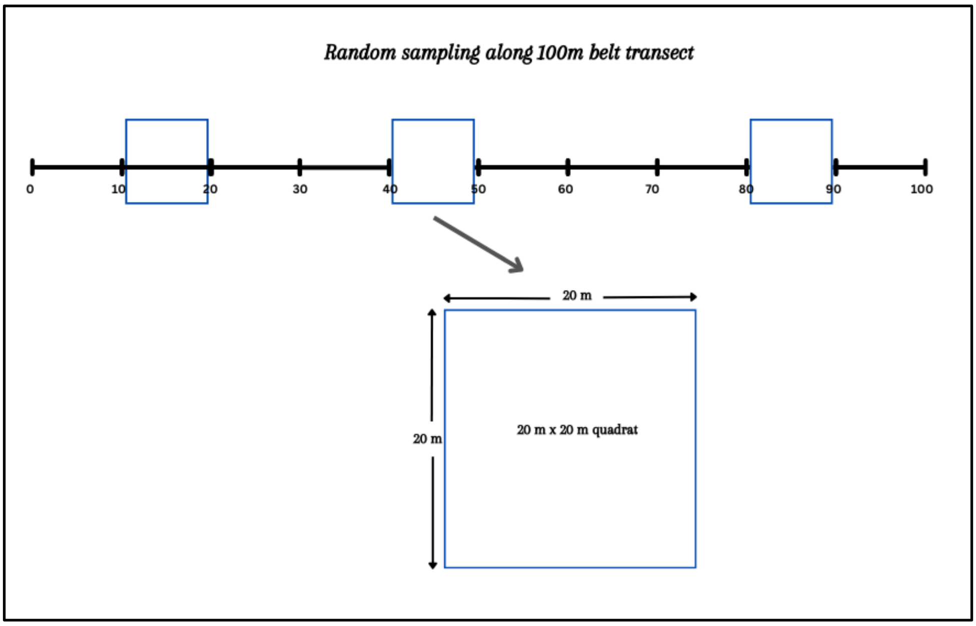


Vegetation sampling, identification, and verification

To comprehensively assess the vegetation of both NPs and APs within the site, representative cover samples were taken from upstream (S1), midstream (S2), and downstream (S3) areas. A belt-transect quadrat method was utilized in each river section shown in Fig. 3 (Pei et al., 2023). Within each 100-m belt transect, three (3) 20 m x 20 m quadrats with 20 m intervals were laid along the three sections, totaling nine quadrats overall.

Figure 3.

Belt-transect quadrat layouts per river section

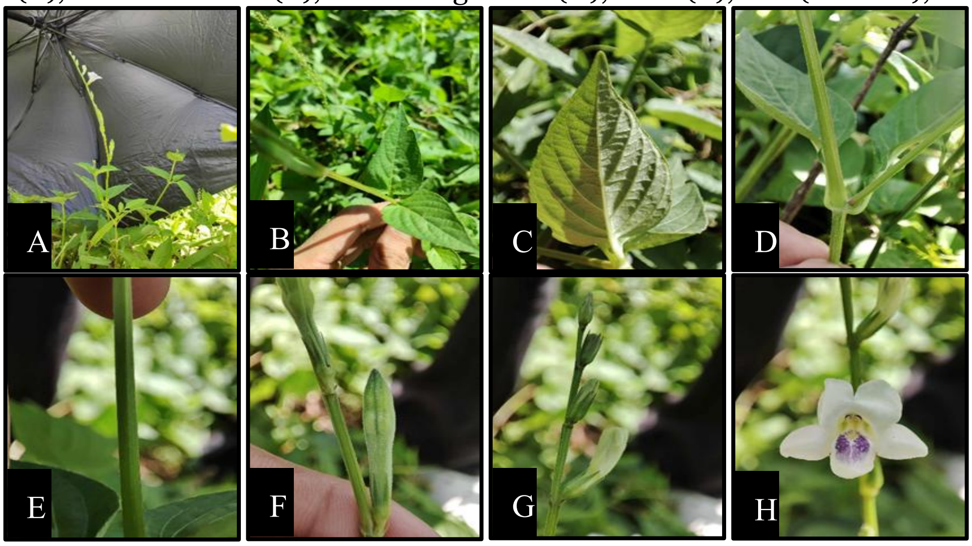


Plants were identified to their species level based on the references by Madulid (1995) and Zamora & Co (1986). The scientific names, taxonomic classification such as families, their conservation and ecological status were also identified and verified using trusted literatures such as the Co's Digital Flora of the Philippines (www.philippineplants.org), Plants of the World Online (POWO) (https://powo.science.kew.org), and International Plant Names Index (IPNI) (https://www.ipni.org). Moreover, the Plant Ecosystem Services (PES) of the plants gathered in the study site were evaluated based on the description by the local villagers and referenced existing literature on ecosystem services linked to each plant species.

While there was no collection of plant specimens, photo documentation of keys was taken following the method described in Matt Walters "Plant Photographs and Captions for Identification". Detailed photographs were taken of each plant capturing the following keys: (a) habit, (b) branch, (c) stem, (d) leaf (abaxial and adaxial surfaces, (e) leaf type, (f) phyllotaxy, (g) leaf attachment, (h) surface details, (i) leaf bud, (j) stipule, (k) flower (flower bud and type of inflorescence), (l) fruits and (m) seeds, as shown in Fig. 4.

Figure 4.

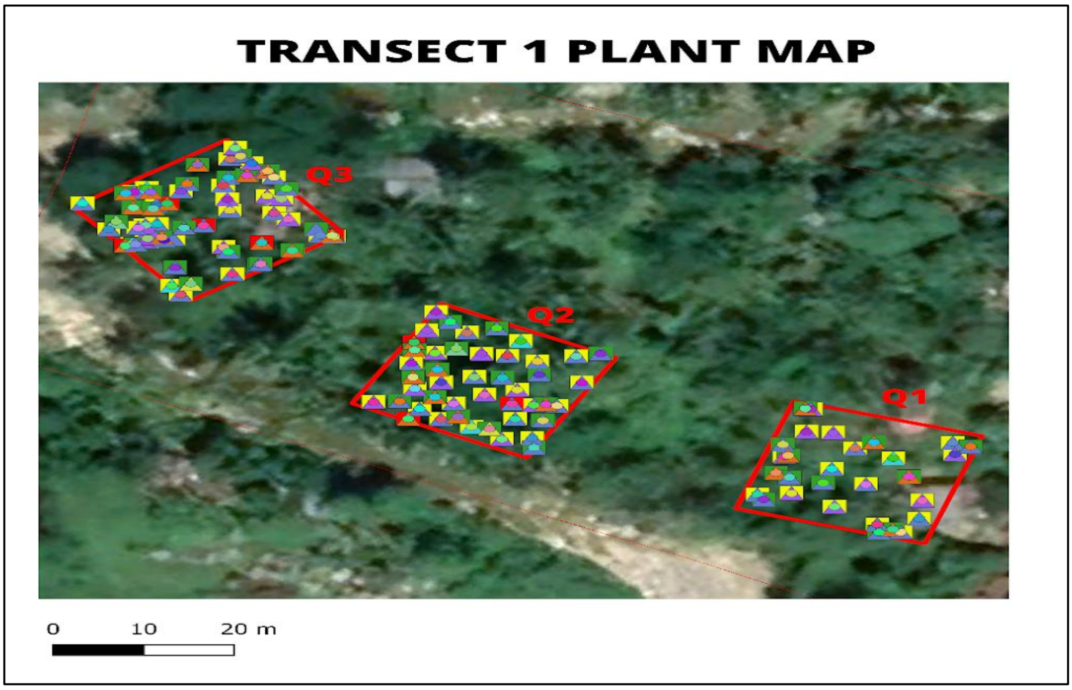
Sample photo documentation of a plant present in the area—General view (A), adaxial surface (B), abaxial surface (C), leaf arrangement (D), stem (E), bud (F and G), flower (H).

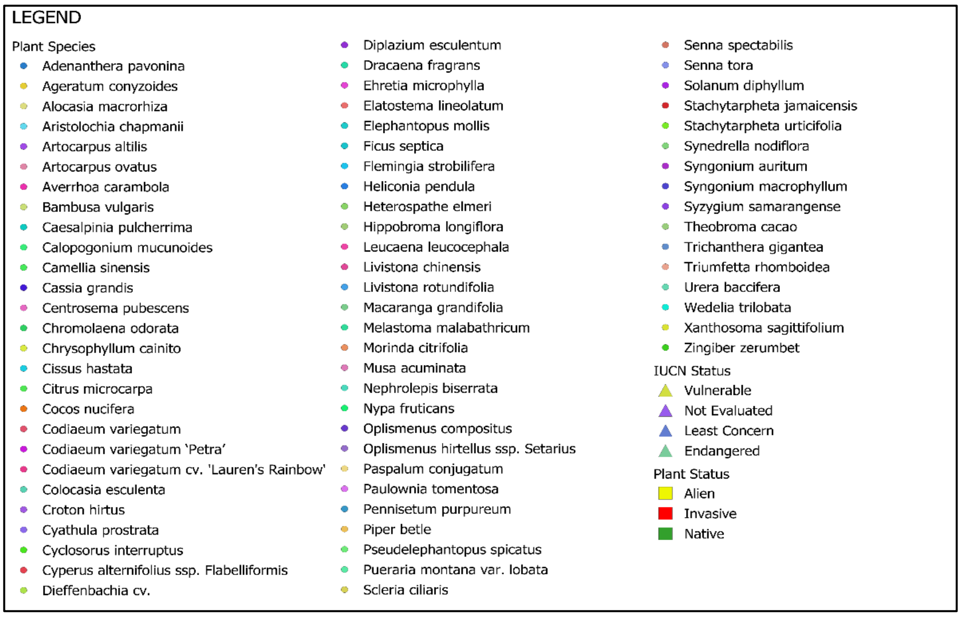


These details were compiled into a single file for each plant, which was then labeled and assigned a tag number for easier identification. Finally, a checklist of information about the plant, location, and general details were documented in a data sheet. A separate list was created for each plant, detailing its individual count, conservation status, and economic and medicinal uses. Permits were obtained from the barangay and DENR acknowledged that no plant samples were collected.

Figure 5.

Spatial Map of Plant Distribution in Transect 1

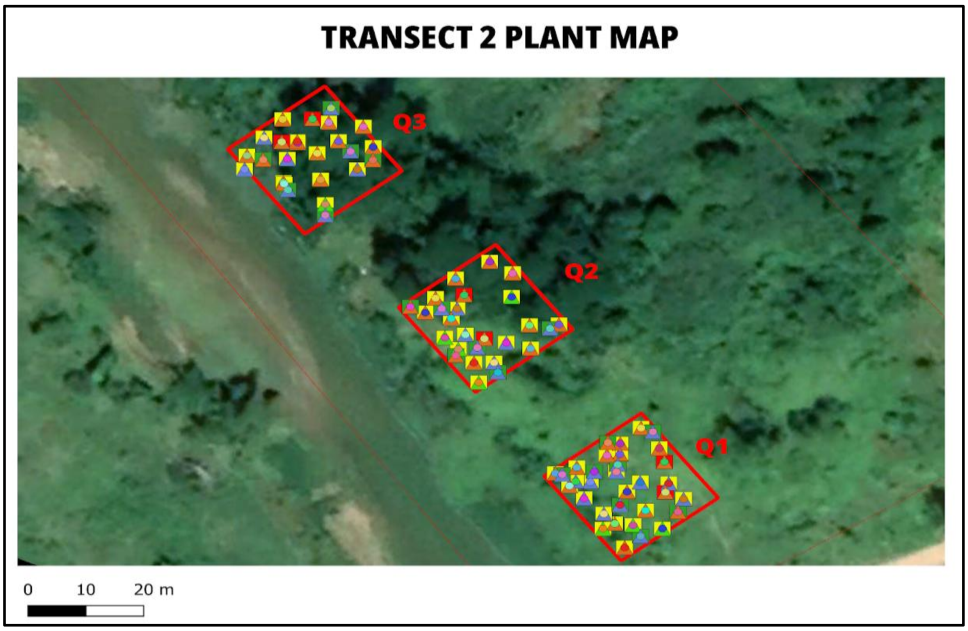


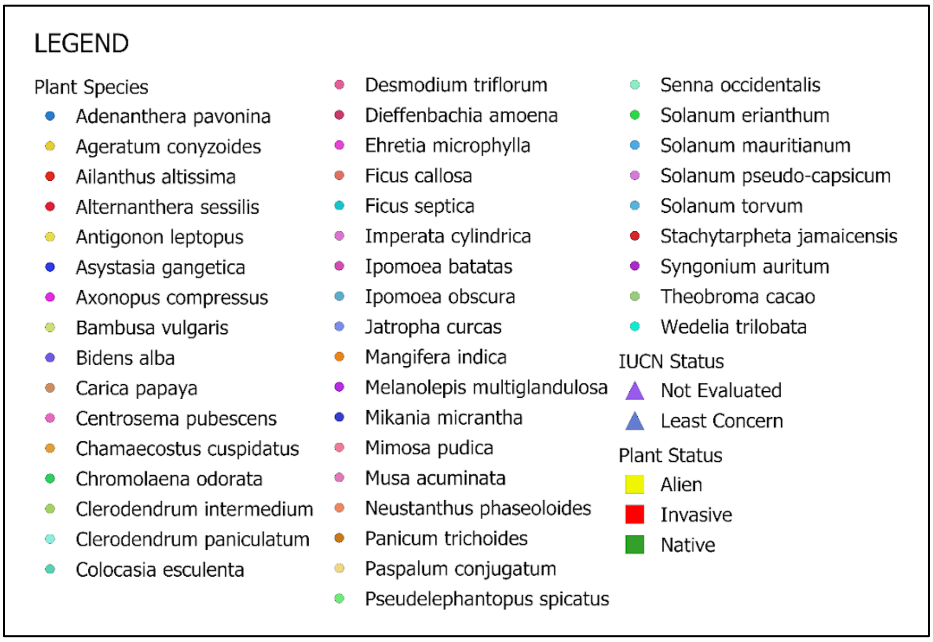


Note: primary data, 2024

Figure 6.

Spatial Map of Plant Distribution in Transect 2

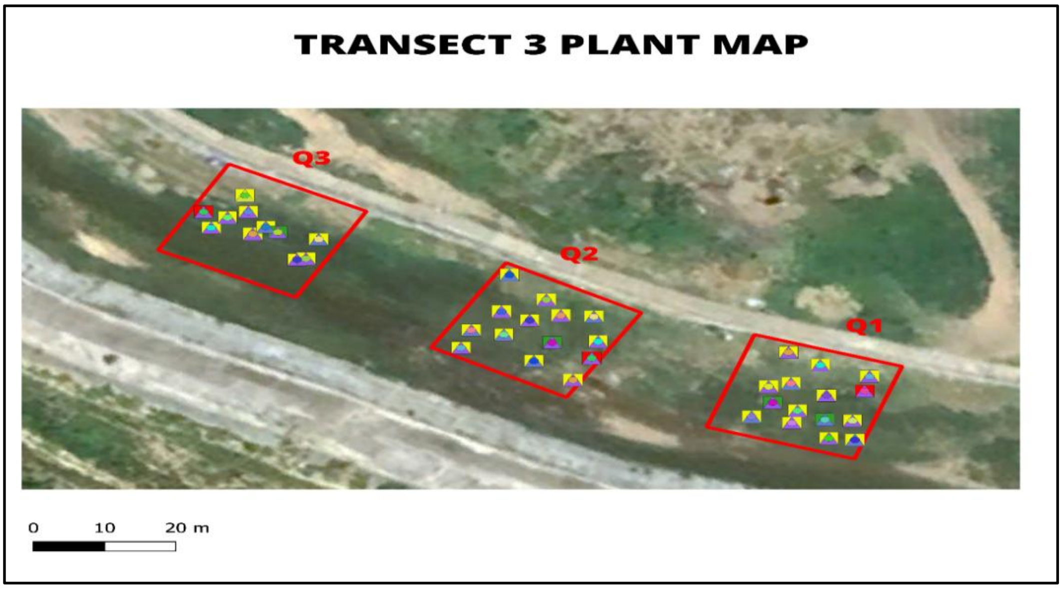


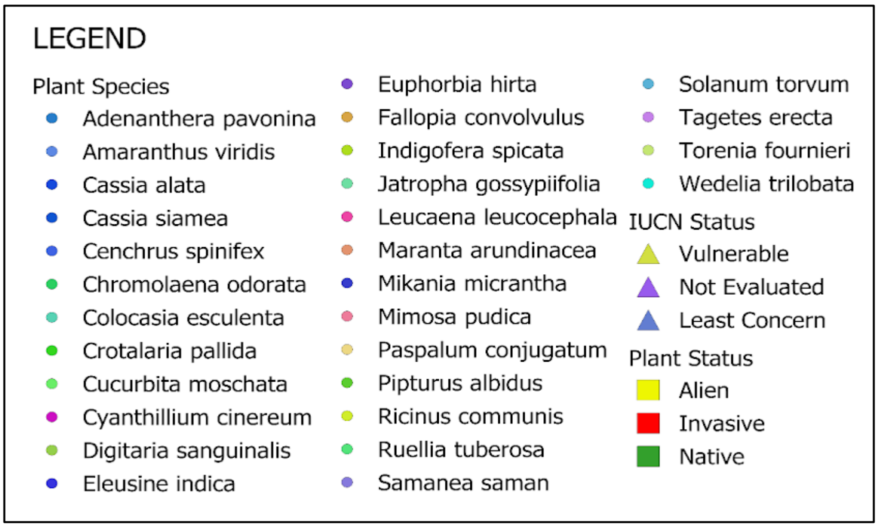


Note: primary data, 2024

Figure 7.

Spatial Map of Plant Distribution in Transect 3





Note: primary data, 2024

Vegetation Analyses

In examining the vegetation comprising both APs and NPs within the area, calculations for species richness, abundance, diversity, and evenness were conducted utilizing the prescribed formulas delineated by Garces et al. (2022):

(1) Species richness= number of species found in each quadrat (Eq. 1)
where *NP* is the number of NPs found in each site, and *AP* is the number of APs found in each site

(2) Species abundance

$$x = \frac{total\ number\ of\ alien\ plant\ species\ (APs) found}{sum\ of\ total\ species\ found} \times 100$$

$$x = \frac{total\ number\ of\ native\ plant\ species\ (NPs) found}{sum\ of\ total\ species\ found} \times 100 \quad \text{(Eq. 2)}$$

(3) Shannon-Wiener Index (H'). The Shannon-Wiener Index assumes that all species within the region are adequately represented in the randomly selected samples. This index considers both species richness and the proportion of species within the area, with values spanning from 0 to 4. A value of zero indicates minimal diversity, typified by a singular taxon dominating the community.

$$H' = \sum_{i=1}^{s} \frac{ni}{N} ln \frac{ni}{N} \quad \text{(Eq. 3)}$$

where ni is the number of individuals, N represents the total number of species, while s refers to the number of species encountered, and ln is a natural logarithm.

(4) Simpson's Diversity Index (D). The Simpson Diversity Index serves as a dominance metric, evaluating the diversity of prevalent species within a given area. It quantifies the probability that two randomly chosen members of a community belong to different species. It is presumed that an increase in the index (D) corresponds to a decrease in evenness. D ranges from 0 to 1, denoting no diversity at 0 and infinite diversity at 1 (Fitrian et al., 2017).

$$D = \sum_{i=1}^{s} (Pi)^2 \quad \text{(Eq. 4)}$$

Where *Pi* refers to the proportion of individuals of the i^{th} species, and s is the number of species encountered.

(5) Species Evenness (Pielou's Evenness Index). The calculation of the relative abundance of various species within a specific area is determined through the

utilization of the PE Index. An area that has a higher overall species diversity is considered to have a more even distribution. The evenness index is defined between 0 to 1. A perfect evenness is reflected by a value of 1, while as it decreases to 0, the relative abundances of the species are not evenly distributed

$$PE = \frac{H}{ln\ (S)} \qquad \text{(Eq. 5)}$$

where H is the Shannon-Wiener Index, ln is a natural logarithm, and S is the total number of species.

Moreover, in interpreting the calculated indices, the value category based on Fernando (1998) and Rosalina et al. (2023) were used as a reference.

Table 1.

Interpretation of Calculated Indices adapted from Fernando Biodiversity Scale, 1998

Relative Values	Shannon Index	Evenness Index
Very High	3.5 and above	0.75 - 1.00
High	3.0 - 3.49	0.5 - 0.74
Moderate	2.5 - 2.99	0.25 - 0.49
Low	2.0 - 2.49	0.15 - 0.24
Very Low	1.9 and below	0.05 - 0.14

Table 2.

Interpretation of Dominance Index adapted from Rosalina et al. (2023)

Dominance Index
0.00 < D < 0.50 = Low dominance
0.50 < D < 0.75 = Medium dominance
0.75 < D < 1.00 = High dominance

Ecological sampling collection

Two important ecological parameters were recorded and analyzed: (1) Climatic factors, including relative humidity (RH), light intensity, and temperature (2) Edaphic factors, including pH, nitrogen (N), phosphorus (P), and potassium (K). Samples were collected from each site and carried out at a consistent time of day. Climatic factors were measured using a handheld ExTech EN300 Environmental Meter (Property No. 15-200-095). Soil sampling collection and preparation process carefully adhered to the guidelines established by the Bureau of Soils and Water Management (2020) for analysis.

Statistical analyses

One-way Analysis of Variance (ANOVA) was utilized to ascertain significant differences among ecological parameters. The ANOVA test was done independently. Differences among means were found to be significant when $p \leq 0.05$. A simple regression analysis was performed to determine the relationship of ecological parameters and the biological composition which were represented by their species richness and abundance, shown in Eq. 6.

$$Y = \beta 0 + \beta 1 X1 + \varepsilon \qquad \text{(Eq. 6)}$$

where Y is the dependent variable, β0 is a constant term, β1 is the regression coefficient, X1 is the independent variable, and ε is the error term.

Data collection for Historical Context of the Area

Both primary and secondary data collection were employed in exploring the historical context of the riparian landscape in the City of Naga, Philippines. This approach aimed to provide insights into the social-ecological and environmental dynamics of the landscape through time. This included learning the dynamics of the ecosystem and determining the changes of the plant species composition in the riparian landscape. Primary data were collected through residents or community elders, who had been in the area for at least ten years or more, through key informant interviews to inquire about their perceptions of changes in riparian landscape over time. Employing a snowball sampling technique, a total of ninety (90) households were interviewed across all four sites. Respondents were purposefully chosen according to the number of households adjacent to a river and their proximity to occurrence of riparian vegetation (Replan et al., 2023).

Researchers utilized a semi-structured interview guide to ensure the collection of all relevant information. An open-ended interview questionnaire, available in both English and Cebuano, was prepared to facilitate comprehensive responses. The survey questions were adapted from du Plessis et al. (2021) and Garces (2019) with minor modifications. The survey was conducted December 2023 to January 2024. Each interview was anticipated to last 20-25 minutes. Informed consent was obtained for review by the CNU Ethics Review Board (CNU-ERB).

The secondary data were gathered from historical sources. Researchers used supplemental maps, images, official records, and other documents to obtain secondary data on the trend of the chosen river from the past and alterations within the riparian ecosystem throughout its temporal progression. These sources were accessed through online repositories, spatial software (QGIS), and municipal/barangay archives.

Historical Context Analyses

The approach employed in analyzing the qualitative data was based on the thematic analysis defined by Braun & Clarke (2008). The audio recordings were transcribed verbatim and anonymized to ensure data familiarity. Relevant quotes were extracted to provide contextual information. The empirical data were then compared with other sources, including historical records or archival documents. Subsequently, interpretations and conclusions were visualized and contextualized. This data was subsequently integrated with online QGIS maps to analyze the relationships and patterns between identified themes and geographic features, offering a spatial perspective on the findings.

Results and Discussion

A total of 8,427 plant individuals belonging to 45 different taxonomic families and 121 plant species were encountered across the established transects at Pangdan River wherein 36 (29.75%) were NPs and 85 (70.25%) were APs (Table 4). The list of individuals together with their respective family, plant life form, IUCN status, ecological status, as well as their presence and absence in each transect were presented in Table 3. It is important to note that there were five (5) species well established in all sites which are mainly APs, and one regarded as an IAP. *Chromolaena odorata*, commonly known as Siam weed or Hagonoy by the locals, is a significant but one of the most problematic perennial herbs in the world and one of the top five IAPs in the Philippines (Kone et al., 2021). While a highly adaptable weed, it poses, however, a significant fire hazard during dry season, as its dried stems become flammable and can contribute to wildfires. Thus, despite its above-ground die-off, weeds regenerate quickly forming dense cover in the subsequent rainy season (Uwalaka & Muoghalu, 2021).

Table 3.

Checklist of the floral diversity encountered across study sites and their respective family, life form, IUCN status and ecological status

Taxa Family	Plant Species	Plant Life Form	IUCN Status	Ecological Status	Site 1	Site 2	Site 3
Acanthaceae	*Asystacia gangetica*	Herb	Not Evaluated	Alien	-	*	-
	Ruellia tuberosa	Shrub	Not Evaluated	Alien	-	-	*
	Trichanthera gigantea	Tree	Least Concern	Alien	*	-	-
Amaranthaceae	*Altemanthera sessilis*	Herb	Least Concern	Native	-	*	-
	Amaranthus viridis	Herb	Not Evaluated	Alien	-	-	*
	Cyathula prostrata	Herb	Not Evaluated	Native	*	-	-
Anacardiaceae	*Buchanania arborescens*	Tree	Least Concern	Native	*	-	-
	Mangifera indica	Tree	Data Deficient	Alien	-	*	-
Araceae	*Alocasia macrorhiza*	Herb	Not Evaluated	Native	*	-	-
	Colocasia esculenta	Herb	Least Concern	Native	*	*	*
	Dieffenbachia amoena	Shrub	Not Evaluated	Alien	-	*	-
	Dieffenbachia cv.	Herb	Data Deficient	Alien	*	-	-
	Syngonium auritum	Vine	Not Evaluated	Alien	*	*	-
	Syngonium macrophyllum	Vine	Not Evaluated	Alien	*	-	-
	Xanthosoma sagittifolium	Herb	Not Evaluated	Alien	*	-	-
Arecaceae	*Cocos nucifera*	Tree	Least Concern	Native	*	-	-
	Heterospathe elmeri	Shrub	Endangered	Native	*	-	-
	Livistona chinensis	Tree	Least Concern	Alien	*	-	-
	Livistona rotundifolia	Tree	Least Concern	Native	*	-	-
	Nypa fruticans	Tree	Least Concern	Native	*	-	-
Aristolochiaceae	*Aristolochia chapmanii*	Vine	Not Evaluated	Alien	*	-	-
Asparagaceae	*Dracaena fragrans*	Shrub	Least Concern	Alien	*	-	-
Asteraceae	*Ageratum conyzoides*	Herb	Least Concern	Alien	*	*	-
	Bidens Alba	Herb	Not Evaluated	Alien	-	*	-
	Chromolaena odorata	Shrub	Not Evaluated	Invasive	*	*	*
	Cyanthillium cinereum	Herb	Not Evaluated	Native	-	-	*
	Elephantopus mollis	Herb	Not Evaluated	Invasive	*	-	-
	Mikania micrantha	Vine	Not Evaluated	Alien	-	*	*
	Pseudelephantopus spicatus	Herb	Not Evaluated	Alien	*	*	-
	Synedrella nodiflora	Herb	Least Concern	Alien	*	-	-
	Tagetes erecta	Herb	Not Evaluated	Alien	-	-	*
	Wedelia tribolata	Herb	Not Evaluated	Alien	*	*	*
Athyriaceae	*Diplazium esculentum*	Fern	Least Concern	Native	*	-	-
Byttneriaceae	*Theobroma cacao*	Tree	Not Evaluated	Alien	*	*	-
Campanulaceae	*Hippobroma longiflora*	Herb	Not Evaluated	Alien	*	-	-
Caricaceae	*Carica papaya*	Tree	Data Deficient	Alien	-	*	-
Convolvulaceae	*Ipomoea batatas*	Vine	Data Deficient	Alien	-	*	-
	Ipomoea obscura	Subshrub	Least Concern	Native	-	*	-
Costaceae	*Chamaecostus cuspidatus*	Herb	Not Evaluated	Alien	-	*	-
Cucurbitaceae	*Cucurbita moschata*	Vine	Not Evaluated	Alien	-	-	*
Cyperaceae	*Cyperus alternifolius ssp.*	Bulb	Least Concern	Alien	*	-	-

					Site		
	flabelliformis						
	Scleria ciliaris	Subshrub	Least Concern	Native	*	-	-
Ehretiaceae	*Ehretia microphylla*	Shrub	Not Evaluated	Native	*	*	-
Euphorbiaceae	*Codiaeum variegatum*	Shrub	Least Concern	Alien	*	-	-
	Codiaeum variegatum ‘Petra’	Shrub	Least Concern	Alien	*	-	-
	Codiaeum variegatum cv. 'Lauren's Rainbow'	Shrub	Least Concern	Alien	*	-	-
	Croton hirtus	Herb	Not Evaluated	Alien	*	-	-
	Euphorbia hirta	Herb	Not Evaluated	Alien	-	-	*
	Jatropha curcas	Tree	Least Concern	Alien	-	*	-
	Jatropha gossypiifolia	Shrub	Least Concern	Alien	-	-	*
	Macaranga grandifolia	Shrub	Vulnerable	Native	*	-	-
	Melanolepsis multiglandulosa	Tree	Least Concern	Native	-	*	-
	Ricinus communis	Shrub	Not Evaluated	Alien	-	-	*
Fabaceae	*Adenanthera pavonina*	Tree	Least Concern	Alien	*	*	*
	Caesalpinia pulcherrima	Shrub	Least Concern	Alien	*	-	-
	Calopogonium mucunoides	Herb	Not Evaluated	Invasive	*	-	-
	Cassia alata	Shrub	Least Concern	Alien	-	-	*
	Cassia grandis	Tree	Least Concern	Alien	*	-	-
	Cassia siamea	Tree	Least Concern	Alien	-	-	*
	Centrosema pubescens	Subshrub	Not Evaluated	Alien	*	*	-
	Crotalaria pallida	Shrub	Not Evaluated	Alien	-	-	*
	Desmodium triflorum	Herb	Not Evaluated	Native	-	*	-
	Flemingia strobilifera	Shrub	Not Evaluated	Native	*	-	-
	Indigofera spicata	Shrub	Not Evaluated	Native	-	-	*
	Leucaena leucocephala	Shrub	Least Concern	Invasive	*	-	*
	Mimosa pudica	Subshrub	Least Concern	Alien	-	*	*
	Neustanthus phaseoloides	Subshrub	Not Evaluated	Native	-	*	-
	Pueraria montana var. lobata	Vine	Not Evaluated	Native	*	-	-
	Samanea saman	Tree	Least Concern	Alien	-	-	*
	Senna accidentalis	Herb	Least Concern	Alien	-	*	-
	Senna spectabilis	Tree	Least Concern	Alien	*	-	-
	Senna tora	Herb	Least Concern	Native	*	-	-
Heliconiaceae	*Heliconia pendula*	Herb	Not Evaluated	Alien	*	-	-
Lamiaceae	*Clerodendrum intermedium*	Shrub	Least Concern	Native	-	*	-
	Clerodendrum paniculatum	Shrub	Not Evaluated	Alien	-	*	-
Linderniaceae	*Torenia fournieri*	Herb	Not Evaluated	Alien	-	-	*
Marantaceae	*Maranta arundinacea*	Herb	Not Evaluated	Alien	-	-	*
Melastomataceae	*Melastoma malabathricum*	Shrub	Not Evaluated	Native	*	-	-
Moraceae	*Artocarpus altilis*	Tree	Not Evaluated	Alien	*	-	-

					Site		
	Artocarpus ovatus	Tree	Not Evaluated	Native	*	-	-
	Ficus callosa	Tree	Not Evaluated	Native	-	*	-
	Ficus septica	Tree	Least Concern	Native	*	*	-
Musaceae	*Musa acuminata*	Herb	Least Concern	Native	*	*	-
Myrtaceae	*Syzygium samarangense*	Tree	Least Concern	Alien	*	-	-
Nephrolepidaceae	*Nephrolepis biserrata*	Fern	Least Concern	Native	*	-	-
Oxalidaceae	*Averrhoa carambola*	Tree	Not Evaluated	Alien	*	-	-
Paulowniaceae	*Paulownia tomentosa*	Tree	Least Concern	Alien	*	-	-
Piperaceae	*Piper betle*	Vine	Not Evaluated	Native	*	-	-
Poaceae	*Axonopus compressus*	Grass	Least Concern	Alien	-	*	-
	Bambusa vulgaris	Grass	Not Evaluated	Invasive	*	*	-
	Cenchrus spinifex	Grass	Not Evaluated	Alien	-	-	*
	Digitaria sanguinalis	Grass	Not Evaluated	Alien	-	-	*
	Eleusine indica	Grass	Least Concern	Alien	-	-	*
	Imperata cylindrica	Grass	Least Concern	Native	-	*	-
	Oplismenus compositus	Grass	Least Concern	Native	*	-	-
	Oplismenus hirtellus ssp. setarius	Grass	Not Evaluated	Native	*	-	-
	Panicum trichoides	Grass	Least Concern	Alien	-	*	-
	Paspalum conjugatum	Grass	Least Concern	Alien	*	*	*
	Pennisetum purpureum	Grass	Least Concern	Alien	*	-	-
Polygonaceae	*Antigonon leptopus*	Vine	Not Evaluated	Alien	-	*	-
	Fallopia convolvulus	Vine	Not Evaluated	Alien	-	-	*
Rubiaceae	*Morinda citrifolia*	Tree	Not Evaluated	Native	*	-	-
Rutaceae	*Citrus microcarpa*	Tree	Not Evaluated	Alien	*	-	-
Sapotaceae	*Chrysophyllum cainito*	Tree	Least Concern	Alien	*	-	-
Simaroubaceae	*Ailanthus altissima*	Tree	Not Evaluated	Alien	-	*	-
Solanaceae	*Solanum diphyllum*	Shrub	Least Concern	Alien	*	-	-
	Solanum erianthum	Shrub	Least Concern	Alien	-	*	-
	Solanum mauritianum	Shrub	Not Evaluated	Alien	-	*	-
	Solanum pseudo-capsicum	Shrub	Not Evaluated	Alien	-	*	-
	Solanum torvum	Shrub	Not Evaluated	Alien	-	*	*
Sparmanniaceae	*Triumfetta rhomboidea*	Shrub	Not Evaluated	Alien	*	-	-
Theaceae	*Camellia sinensis*	Shrub	Data Deficient	Alien	*	-	-
Thelypteridaceae	*Cyclosorus interruptus*	Fern	Least Concern	Native	*	-	-
Urticaceae	*Elatostema lineolatum*	Subshrub	Not Evaluated	Alien	*	-	-
	Pipturus albidus	Shrub	Not Evaluated	Alien	-	-	*
	Urera baccifera	Shrub	Least Concern	Alien	*	-	-
Verbenaceae	*Priva lappulacea*	Herb	Least Concern	Alien	*	-	-
	Stachytarpheta jamaicensis	Shrub	Least Concern	Alien	*	*	-
	Stachytarpheta urticifolia	Herb	Not Evaluated	Alien	*	-	-
Vitaceae	*Cissus hastata*	Shrub	Not Evaluated	Native	*	-	-

					Site		
Zingiberaceae	*Zingiber zerumbet*	Herb	Data Deficient	Alien	*	-	-

Site 1	47 Alien	26 Native
Site 2	31 Alien	12 Native
Site 3	26 Alien	3 Native

***, Presence; -, Absence**

The Fabaceae family emerged as the most species-rich, containing nineteen species, followed by Poaceae with eleven. A total of 6 NPs and 13 APs were identified out of the nineteen species in the family Fabaceae. Notably, two IAPs were present, that is, *Calopogonium mucunoides* (Calapo) found in S1 and *Leucaena leucocephala* (Ipil-ipil) present in both S1 and S3. Conversely, the family Poaceae had a distribution of 3 NPs and 8 APs, with one identified IAP, which is, *Bambusa vulgaris* (Kawayan killing) introduced in both S1 and S2. The dominance of the Fabaceae family is likely attributed to the preference of nearby households for cultivating leguminous and medicinal plants near their homes. This stands in contrast to the second most prevalent family, Poaceae (grasses).

The high abundance of grasses likely stems from their multifaceted roles in the area. Grasses serve as essential food crops for humans, as well as providing grazing land for both livestock and wild herbivores. Several plant families had an equal number of species with Asteraceae and Euphorbiaceae each contributing ten. However, the family Asteraceae also harbored two IAPs, particularly, *Chromolaena odorata* (Hagonoy), established across all three sites and *Elephantopus mollis* (Elephant's foot) present only in S1. In essence, it is worth mentioning that there were generally five distinguished IAPs from all sites to wit: *Chromolaena odorata*, *Elephantopus mollis*, *Calopogonium mucunoides*, *Leucaena leucocephala*, and *Bambusa vulgaris*.

Table 4.

Biodiversity indices from the three sites (S1, S2, and S3) of Pangdan River, City of Naga, Cebu sland, Philippines.

	N	n	H'	D	PE	% abundance
Site 1	73	2447	3.15	0.0746	0.73	50.34
Site 2	43	3765	2.61	0.1184	0.69	29.66
Site 3	29	2215	2.037	0.1771	0.60	20
TOTAL:	**145**	**8427**				**100**

Surprisingly, *Bidens alba*, another member of the Asteraceae family, emerged as the most abundant species recorded, with 944 individuals found only at S2. The three most dominant families, Fabaceae, Poaceae, and Asteraceae are often linked to human impacted habitats, reflecting a similar level of human-caused disturbances between the studied areas. Three species each were recorded in the Acanthaceae, Amaranthaceae, Urticaceae, and Verbenaceae families. Five other families, Anacardiaceae, Convolvulaceae, Cyperaceae, Lamiaceae, and Polygonaceae, each contributed two species. The Araceae and Moraceae families had seven and four species, respectively. The remaining 28 families were represented by a single species each. The high number of plant families identified reflects high floristic biodiversity in the riparian area. This diversity, combined with the presence of both APs and NPs, highlights the importance of these landscapes for conservation and management efforts.

The Pangdan River exhibited a diverse array of plant life forms, with shrubs (32 spp.) being the most dominant group, followed by herbs (31 spp.), trees (27 spp.), grasses (11 spp.), vines (10 spp.), subshrubs (6 spp.), ferns (3 spp.), and a single bulb species. There was a dominance of herbaceous and shrub species, many of which were weeds, including the five identified IAPs in this study. Moreover, the APs prevailed in number more than the NPs in each category, except for all the native ferns (N=3).

Following the International Union for Conservation of Nature (IUCN) Red List Categories, two of the 36 NPs were classified as threatened, where *Heterospathe elmeri* is Endangered and *Macaranga grandifolia* were listed as Vulnerable. *Heterospathe elmeri*, an endemic palm species belonging to family Arecaceae and locally distributed in Camiguin, Negros, and Mindoro, Philippines, is valued for its nuts, which serve as betel substitutes (Njue et al., 2016). These palms are characterized as erect, undergrowth species that thrive in dense, humid forests.

They are distinct from other Philippine species of *Heterospathe* due to its broad, elongate-ovoid fruits. Unfortunately, *H. elmeri* was only assessed globally in 2019, and there has been no updated comprehensive national assessment of threatened Philippine flora since the issuance of DENR Administrative Order (DAO)-2007. On the other hand, *M. grandifolia*, commonly known as the Giant Macaranga, is Vulnerable due to a range of factors contributing to its diminishing numbers.

The primary concern centers on habitat loss, a consequence of deforestation driven by agricultural expansion, logging activities, and infrastructure development, all of which have significantly reduced suitable habitats. This flora is frequently exploited for its edible uses in the Philippines, owing to its versatile properties. Traditionally, various parts of the plant, including its leaves, bark, and twine, have been utilized for various purposes. The leaves have been used as a remedy for swollen bellies, utilized as food wrappers, and are consumed by birds when ripe. Moreover, the bark-derived twine has been used for crafting fishing spears, while the wood has found diverse practical applications. This multifunctional aspect of *M. grandifolia* underscores its significance as a valuable resource for food, medicine, and practical uses in the Philippines.

In terms of species richness, S1 had the highest number of plant species summed up to 73 and consisted of 47 (64.28%) APs and 26 (35.62%) NPs. Followed by S2, wherein out of the 43 plant species, 31 (72.09%) were APs and 12 (27.91%) were NPs. Meanwhile, S3 had the lowest number of plant species where 26 (89.66%) APs and 3 (10.34%) NPs for a total of 29 plant species. Evidently, the plant species richness in all sites was dominated by APs compared to NPs, wherein APs are the ones contributing much to the diversity within and across the three study sites. Higher levels of documented anthropogenic disturbances at S1 likely correlate with the proliferation of alien species, thereby explaining the greater abundance of APs in the area.

S1 exhibited the highest species richness (N=73), accounting for 50.34% of the total abundance across all three sites (Table 4). In contrast, S2 recorded a lower species richness (N=43) with a relative abundance of 29.66% while S3 had the lowest species richness (N=29) comprising 20% of the total richness of the three sites. This highlights the great diversity of plant species in upstream riparian zones compared to midstream and downstream. Remarkably, the abundance of plant individuals is highest in S2 than in S1 and S3 (S2: n= 3765; S1: n= 2447; S3: n= 2215).

The observed abundance of riparian plant species in S2 can be attributed to two key factors: (1) limited canopy cover and (2) river channel width (Novoa et al., 2018). The sparse canopy allows for increased sunlight penetration, creating a more favorable environment for the growth and development of riparian flora. The higher abundance of flora is likely due to the open nature of the water body, resulting from the presence of settlements, built-up areas, and roads.

The highest Shannon index was recorded in S1 (H'= 3.15) while S2 showed a moderate diversity (H'= 2.61), and S3 revealed the lowest diversity (H'= 2.037), emphasizing the adverse impact of flow regulation on riparian plant community diversity and composition. This pattern implied the loss of keystone species and subsequent increased susceptibility to disturbances in both ecosystems. Consistently high values were observed across all sites for the PE index. S1 exhibited the highest evenness (PE = 0.73), followed by S2 at PE = 0.69 and S3 at PE = 0.60. These results thus indicate that although dominance varies per site, the relative distribution of species abundance remains comparatively even throughout the Pangdan River.

Across the three sites, variations in ecological parameters were observed, highlighting diverse conditions within the study area (Table 5). There was an observed diminishing RH values from upper upstream stations to lower downstream stations (60–39). As altitude decreases, the atmospheric pressure increases, which leads to a rise in temperature through compression of air molecules. Warmer air has a higher capacity to hold moisture, leading to a decrease in relative humidity (Ortiz & Torres, 2020). Furthermore, the variation in light intensity across three sites could have been attributed to the dominance of plant life forms. S1 and S2 were primarily composed of trees (S1=24.66%; S2=17.65%) and shrubs (S1=26.03%; S2=23.52%) that provide greater shading, reducing the amount of light penetration across the riparian surface. Meanwhile, S3 dominated by herbs (S3=28.57%) allows greater intensity of light to be distributed to smaller plants.

In line with the trend of light intensity across the three sites, the trend on temperature variation gradually decreases from upstream to downstream. Attributing to their differences in elevation, S1 experiences low air pressure, which results in a cooler temperature. In contrast, S3 is more exposed to higher light intensity and less shading.

The data on edaphic parameters gathered on the three sites (S1, S2, and S3) of selected areas across the riparian of Pangdan River at the City of Naga, Philippines, revealed compelling patterns, which interpretations relate to variations in attributes of spatial, geomorphic, vegetation, and the anthropogenic practices occurring across all areas. The expected low-level pH in the upstream region, in agreement with most factors considered to interpret the soil property results for the parameter pH in the study of Pei et al. (2023) on assessing land use activities influence as an indicator of biodiversity loss in riparian vegetation.

Adapting the criteria from the sufficiency ranges in the soil as outlined by Quattrocchi (2018), a neutral soil pH range between 6.6 to 7.3 is suggested. The results of the study indicate that S1 has the lowest pH, with subsequent sites exhibiting higher. The pH variation observed among S2, which has a higher pH than S3, may be attributed to the historical quarry activity and previous banana plantations in the upstream and midstream areas. These agricultural management practices may have negatively impacted the soil pH, consequently affecting other soil properties critical for plant health (Rai & Singh, 2020).

The extensive history of quarrying operations in the vicinity of S1 may contribute to the alkaline soil conditions observed from the quarry discharge downstream during rainy events, progressively raising the pH of the soils in the S2 and S3 regions. The values of the three sites fall in the very strongly alkaline category significantly hinders plant growth, possibly decreasing essential nutrients such as N and P, along with K availability (Replan et al., 2023).

Table 5.

Means of the ecological parameters (mean ± SE) at all the respective sampling Site 1: City of Naga, Cebu Island, Philippines. Barangay Uling, Site 2: Barangay Pangdan, and Site 3: Barangay Naalad of Pangdan River.

Ecological Parameters		Means		
		Site 1 Uling	**Site 2 Pangdan**	**Site 3 Naalad**
Climatic Parameters	RH (%)	81.33±2.02	77.51±3.03	75.41±1.47
	Light Intensity (μmol/s/m^2)	22.27±3.36	60.54±12.00	167.19±29.45
	Temp (°C)	30.12±0.60	30.63±0.46	32.23±0.17
Edaphic Parameters	Soil pH	8.07±0.42	8.71±0.01	8.42±0.15
	Nitrogen (mg/L)	0.17±0.04	0.11±0.00	0.09±0.03
	Phosphorus (mg/L)	9.24±6.42	3.54±0.33	8.56±2.30
	Potassium (mg/L)	112±12.82	119±25.53	80±27.99

Note: primary data, 2024

Table 6.

Multiple Linear Regression analysis of Biological Variables and Multiple Ecological variables

Variables	**Significance level $p < 0.05$**				**Regression coefficient (β)**			
	Native		**Alien**		**Native**		**Alien**	
	N	**n**	**N**	**n**	**N**	**n**	**N**	**n**
Relative humidity	0.013	0.006	0.260	0.597	1.801	58.167	2.107	-23.816
Light intensity	0.007	0.003	0.137	0.421	-0.089	-2.847	-0.106	1.692
Temperature	0.055	0.013	0.102	0.356	-4.597	-166.535	-5.094	123.735
Soil pH	0.166	0.090	0.368	0.084	-10.913	-393.428	-9.287	661.272
Nitrogen	0.081	0.015	0.212	0.158	98.944	3817.814	93.786	-4199.63
Phosphorous	0.951	0.663	0.601	0.168	-0.037	-7.822	-0.385	-38.467
Potassium	0.339	0.285	0.295	0.984	0.097	3.294	0.133	-0.105

Nutrient availability in riparian zones differs among the different stream regions due to variations in factors like soil composition, water flow patterns of the river, land utilization, and inputs from nearby areas. Typically, N levels are elevated in upstream areas due to inputs from terrestrial sources, while downstream regions may exhibit lower concentrations because of water flow dilution and microbial processes (Liu et al., 2022), as reflected by the decreasing N concentrations from S1 to S3 (0.17 mg/L, 0.11 mg/L, and 0.09 mg/L respectively). The N concentration based on sufficiency ranges in the soil of Landon (2014), S1 and S2 falls in the low category, while S3 falls at very low, which may be influenced by the rate of N uptake and organic matter content from the diversity of plant species (Table 5), along with other anthropogenic disturbances present across all studied sites. Specifically, S1 recorded a total of 95 anthropogenic occurrences, while S2 documented 221 occurrences, in contrast to the relatively lower count of 22 occurrences in S3.

The data indicates a noticeable decline in P and K concentrations across the three sites, a trend suggesting potential factors influencing the distribution in these riparian areas. According to Landon (2014), for P sufficiency among the three sites, S1 and S3 fall into the moderately low category and S2 is classified as low. Meanwhile for K content, S1 and S3 are categorized as sufficient, and S2 falls under the "sufficient +" category. Upstream areas situated on geological formations naturally rich in K-bearing minerals may contrast with downstream areas lacking such geological features, and ongoing weathering and erosion processes could facilitate the gradual downstream movement of K over time.

The notable lower P concentration in S2 compared to S3 and the highest level of K recorded at S2, could be linked to the history of banana cultivation in the area as banana plants have high nutrient requirements for production. According to Leonel et al. (2020), most P absorption of banana plants occurs three to nine months after planting, which may have affected the P concentration in the area. Despite being significantly diminished, the thriving presence of banana cultivation in S2 (Table 3) could explain the elevated K levels observed at this S2. The results indicate that continuous cropping with or without adequate replenishment can gradually impact the readily accessible P and K reserves in the soil over time.

Table 6 provides regression coefficients and significance levels for native and alien species richness (N) and abundance (n) in response to various climatic parameters. RH exhibited significant differences on NP richness (β= 1.801; p= 0.01) and NP abundance (β= 58.167; p= 0.006). Meanwhile, RH exhibited no significant differences on AP richness (β=2.107; p= 0.260) and AP abundance (β= 23.819; p= 0.60).

These results suggest a positive relationship between relative humidity and richness for native species. The riparian study site lies within a tropical region characterized by consistently high humidity, particularly during the wet season. Given the conducive environmental conditions, it is no surprise that the area is suitable for the thriving of various plant species. Higher relative humidity means greater opportunities for flora, regardless of native and alien in their growth and proliferation.

Light intensity also was one of the significant factors controlling the richness and abundance of native species: p = 0.007, β = -0.089, and p = 0.003, β = -2.847, respectively. Therefore, both its coefficients were negative, leading to a lesser richness and overall number of native species with increasing light intensity. The alien species showed less sensitivity to light intensity, where no significant relation was observed with either richness (p = 0.137) or abundance (p = 0.421). NPs compared to APs are less resilient to changes within their habitat. This explains the negative relationship between light intensity and native species as they are more sensitive to light variation (Liu et al., 2022). The adaptability of APs to environments where native species struggle to inhabit (Liu et al., 2022).

In addition, the negative relationship between light intensity and AP richness suggests a pattern of succession. S3 having the highest light intensity entails that an early succession is ongoing. This is supported by the low-lying plant life forms observed in the area (herbs= 28.57%; shrubs= 25%) (Swanson et al., 2010). Despite S3 having the lowest AP richness compared to other sites, the dominance of alien plant species (89.66%) is significantly higher than its native plant richness (10.34%) highlighting the role APs as pioneer species and stabilizer of disturbed environments during its early succession (Ballesteros et al., 2021).

Temperature had a negative effect on NPs abundance ($p = 0.013$, $\beta = -166.535$) and richness borderline ($p = 0.055$, $\beta = -4.597$), implying that at higher temperatures, the abundance of the respective NP decreases. This points to the observation that the sites with higher richness have lower temperatures (~30°C), whereas S3 reaches up to a higher temperature at 32° and has a lower richness. This suggests that temperatures within this range might promote optimal growing conditions for a wider variety of plant species, particularly trees, which can contribute to higher overall species richness (Swanson et al., 2010; Ballesteros et al., 2021). Areas with high species richness were often partially dominated by trees, further supporting this connection.

In the terms of edaphic parameters, soil pH, N, P, and K have all been observed to lack significant relationships with both NPs and APs richness or abundance. This is evidenced by their high p-values. Thus, soil pH gave no meaningful effect in species diversity and abundance, showing that the acidity or alkalinity of the soil in the riparian ecosystem plays an insignificant role. While borderline significant for the richness of APs with $p = 0.015$ and $\beta = 3817.814$, N concentration did not have a significant effect on the richness of NPs. There are no significant effects of P and K concentrations on either group. These results might indicate that soil properties do little to affect plant diversity in the study area and that other factors, such as climatic conditions and disturbances, may play a more important role.

Several factors considered influential in affecting the abundance and richness of vegetation along riparian areas, including both natural disturbance regimes and anthropogenic disturbances observed along the Pangdan River stretch. Notable anthropogenic disturbances, such as quarrying, historical banana farming, and runoffs from piggeries and poultry farms— particularly prevalent in upstream and midstream regions— are documented as contributors to the alteration of riparian vegetation.

Historical context of Pangdan river

The term *Pangdan* was primarily derived from the abundant Pangdan plant in the barangay ultimately naming the main river as the Pangdan river. The territory was found to be historically owned by Spanish Hacienderos during the pre-World War II which was predominantly utilized for agricultural purposes. The diversity of their upland agriculture reflected a mosaic of root crops, vegetables, corn, bananas, coconut palms, various fruit trees (such as mango, jackfruit, star apple, and guyabano), and woody vegetations like ipil-ipil (used for fuelwood) and madre de cacao trees. With the advent of industrialization, significant changes in both the landscape and population were quantifiable. Concurrently, the economic landscape evolved with the establishment of various businesses, including mines and quarries, within the city of Naga. Among them were barangay Uling (July-August 2001) and Pangdan (2000; May-December 2003) with an estimated landfill of 15,000 and 600,000 respectively. The expansion of the urban areas, construction of factories, and conversion of agricultural lands into residential or quarry sites encroached upon the natural habitat, reducing the habitat availability for NPs and contributing to the proliferation of IAPs. Moreover, natural disturbances like typhoons played a role in modifying the river landscape such as the Typhoon Odette in 2021. Presently, the APO Land and Quarry Corporation (ALQC) had established three quarry sites around the City of Naga. Two quarry sites located near the study area, Langtad and Pangdan, respectively have 192 ha and 84 ha of contract area (Mines and Geoscience Bureau [MGB], 2024).

Table 7.

Semi-structured questionnaire results of the respondents living along the riparian zone

Questions	General Answers	Percentage (%) of respondents who answered
Awareness of invasive plant species	Aware	7.78
	Not aware	92.22
Influential factors in invasive plant spread	Planting of IPS	17.78
	Purchasing/trading of IPS	45.55
	Discarding IPS	36.67
Advocating for strict land management practices	Agrees	80
	Disagrees	20
Clearing initiatives and programs for IPS around riparian areas	None	100
Personal initiatives to combat invasive plant spread	None	100

Note: primary data, 2024

The current research explored the understanding of stakeholders, their views, and the significance of IPS in the riparian zones of three barangays characterized as S1, S2, and S3 across the Pangdan River (Table 7). The survey covered 90 participants whose age groups ranged from young adults to seniors who lived close to these areas and held major responsibility for the decision-making and activities taking place there. Based on the results, five general themes were made to merge these reflections and make recommendations through a framework in Fig. 9 constructed from a socio-ecological systems perspective.

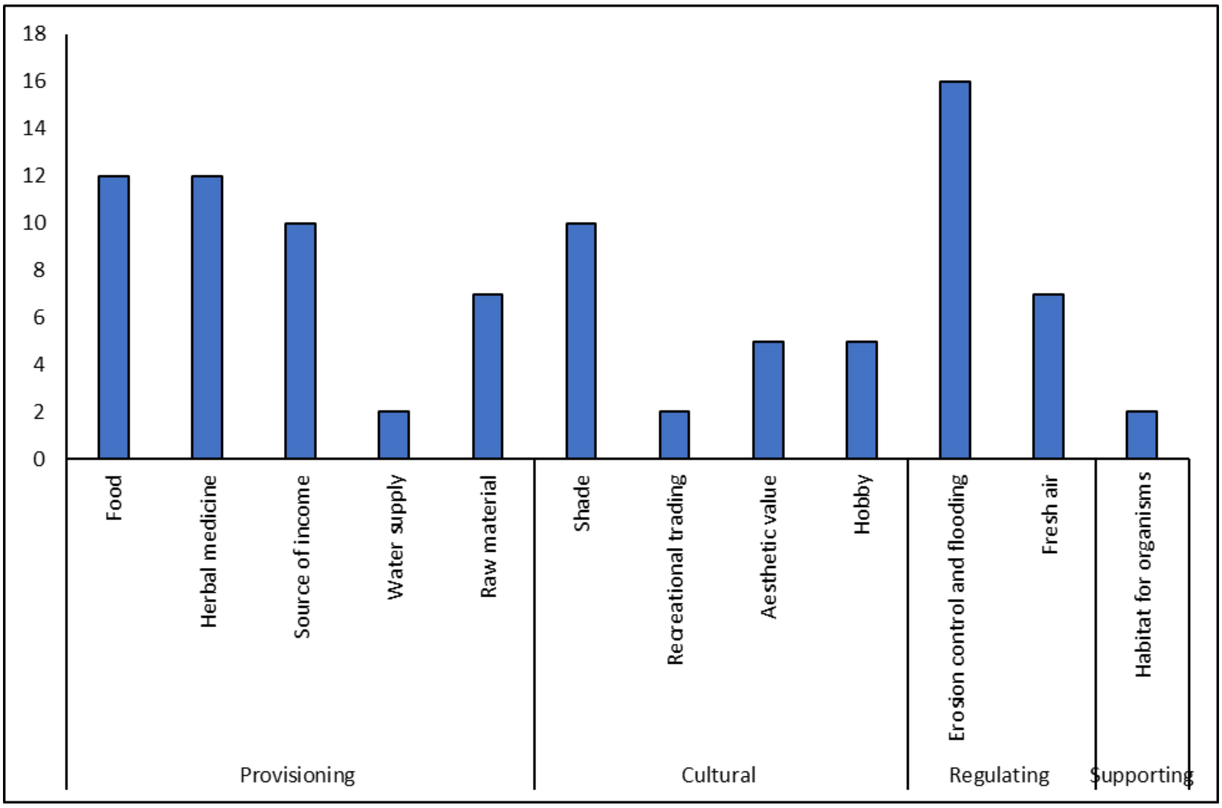
IPS pose one of the most serious threats to ecosystems globally, causing damage to the ecological environment, removing NPs, altering natural processes, and disrupting ecosystems. Effective IPS management strategies depend on perceived resources and properties that predispose a plant to be invasive. Upon investigation of the three barangays along the Pangdan River, information obtained from 90 respondents revealed low awareness regarding the distinction between NPs and IPs. Majority (92.22%) were unable to differentiate between the two, while only 7.78% demonstrated awareness. The raised awareness should act as a catalyst for further education and outreach efforts. Additionally, respondents who demonstrated awareness about IPS exhibited a greater understanding of the ecological dynamics associated with plant invasiveness, including their origin, modes of introduction, unnatural growth rates, and subsequent impacts on the environment.

Humans are active participants in the introduction of IPS. The study identified three primary factors contributing to their prevalence in the riparian area. Purchasing or trading (45.55%) is the leading pathway for IP spread, followed through discarding (36.67%), and finally by planting (17.78%). Distinguishing whether these means of introductions were deliberate or accidental is unclear and challenging to evaluate. However, it was explicitly stated that there was an observed increase of trading and purchasing activities during the COVID-19 pandemic. Restricting human movement for over two years will significantly affect propagule pressure, potentially altering the course of biological invasions. Additionally, given that the

Philippines is a center of agricultural activity, it is understandable that residents engage in cultivation for either consumption or aesthetic purposes. The familiarity with IAPs and viewing them positively as potential resources contribute to adaptation to the invaded environment (Garces, 2023).

Figure 8.

Identified ecosystem services provided by IPS



Note: primary data, 2024

In terms of advocating for strict land management practices, a substantial majority (80%) favors this initiative, indicating a perceived value in the preservation and regulation of land use (Hasan et al., 2020). The respondents opposing strict management (20%) asserted possible areas of concern or contention warranting further exploration. The reason for their passive approach to land management demonstrated a complicated interaction between variables, including the dynamics of land ownership and attitudes toward short-term versus long-term sustainability. The connection between corporate interests and community livelihoods is highlighted by Apo Cement's anticipated purchase of property, underscoring the necessity of fair and open land management systems.

The absence of dedicated clearance projects and personal initiatives aimed at removing IPS from the riparian region indicates a potential lack of environmental management practices in the area. Although the implementation of weekly Saturday clean-up drives demonstrates that efforts are being made to actively maintain riparian ecosystems, the overall effectiveness of these initiatives in mitigating the impact and spread of IPS remains uncertain due to the lack of focused interventions.

Riparian buffers in urban and exurban areas offer a range of ecosystem services like those in rural settings, including the provision of shade, shelter, and food for aquatic life, wildlife habitat, economic resources, and aesthetic enhancement, thereby diversifying landscapes visually, expanding recreational opportunities, and safeguarding against flood damage. These services are further divided into provisioning, cultural, regulating, and supporting services. The provisioning services include direct use of ecosystems by humans, such as food, medicines, and raw materials. Cultural services refer to the non-material benefits to society, including recreation, spirituality, tradition, and aesthetics. Regulating services aid in the natural regulation of processes and include air and water purification. Supporting services include all functions that underlie and support the other three, such as soil formation and primary production. Thus, the data presented through the detailed breakdown of Fig. 8 are invaluable in explaining the wide range of ecosystem services and the importance of the percentage contributions to human well-being from such diverse sources.

The knowledge that IPS is harmful to any ecosystem and the fact that these species continue to fulfill ecosystem functions poses an important question– are these IPs passengers or drivers of change in degraded ecosystems. A challenging idea was further given by Richardson et al. (2007) that if humans are components of ecosystems, then plant species that have been intentionally or unintentionally introduced by humans into many ecosystems worldwide are just as natural as what we conventionally call native. They questioned the traditional distinction between the NPs and APs and restored a functional consideration rather than focusing on a balance in structures and composition only.

The percentages of each ecosystem service category illustrate how closely human well-being relates to the health of the ecosystem. It is crucial to recognize and understand the value of these services for informed decision-making and sustainable resource utilization. While the human well-being aspects of an IPS may be beneficial to some extent to the ecosystem, their negative effects also need to be considered, such as the displacement of native species, interference with natural processes, and reduction of biodiversity. Consideration of the data limitation, skewness, impact subjectivity, and long-term effects of an invasive species' criticality makes it complex to align entirely. In decision-making, a cost-benefit analysis should be applied to analyze this information before deciding whether to act against it.

The role of stakeholders is important in understanding and developing management strategies for plant-invaded riparian ecosystems as their involvement provides different insights that are more applicable in a site-specific context. Stakeholders such as residents, farmers, and LGUs are greatly affected by such invasions especially in terms of compromising their ecosystem services, livelihoods, and the overall human health (Novoa et al., 2018). The crafted management plan centered on stakeholder engagement, acknowledging their vital role in addressing invasive species challenges (Richardson et al., 2007; Novoa et al., 2018).

Stakeholder identification depends on the target species being prioritized. For example, *C. odorata* are severely widespread in each section of Pangdan river. To make preventive actions, adaptive management involves stakeholders who have experienced the benefits and costs of the conflict species and those that might be affected amidst management intervention ensuring that the varied expectations and values of the society and stakeholders were incorporated in the management plan. Lacking awareness of residents (92.22%) on IAPs proliferation near river areas suggests expanding engagement to other stakeholders, such as professionals, can help raise awareness about IAPs and foster collaborative decision making. Stakeholders need to be categorized to prioritize those with the most significant influence on the management strategy.

In fact, a common approach for stakeholder prioritization is the impact-influence matrix (Rai & Singh, 2020). This method, also known as stakeholder mapping, categorizes stakeholders into four groups: "Key players" with high influence and impact, "Context setters" with high influence but low impact, "Subjects" with high impact but low influence, and the

"Crowd" with low influence and impact. Key players include residents near the river, farmers, and barangay officials. On the other hand, context setters consist of private organizations, CENRO, and municipal officials. Science-based assessment is imperative to evaluate the plant communities within the riparian zone along Pangdan river. This includes utilizing established methods to identify the status of each plant species either as Native Plants (NPs), IAPs, or Other Alien Plants (OAPs).

Once the key stakeholders are selected, the engagement process follows. At this stage, initial objectives for the IAP management plan can be developed, taking the context of the plan should be considered. Primary unveiling and exploring stakeholder perceptions and awareness levels regarding IAPs facilitate a comprehensive analysis of stakeholders' subjective views and attitudes towards the proposed management strategies. This approach enhances understanding, mitigates conflicts of interest, and ultimately leads to a shared objective for the draft strategy (Novoa et al., 2018). This process can be effectively achieved through open dialogue, allowing all participants to share their perspectives and engage meaningfully, thereby promoting social learning and information exchange. Furthermore, public involvement in decision-making fosters a sense of trust and establishes partnerships among stakeholders.

Since the goal of this strategy provides a basis for managing IAPs across different sites, a different engagement process may need to be carried out. This process can also be aimed at promoting early detection of emerging IAPs, although they may not be widespread in some sites, still rapid response management for controlling them is needed (Novoa et al., 2018). A more specific example of a management goal in Pangdan riparian zone may be (1) increasing the dominance of native species and reduction of IAPs, (2) providing stricter policies with regards to anthropogenic activities, (3) improving ecological functions, particularly on soil holding capacity and quality, leading to improved water quality, and (4) raising awareness about IAPs and encouraging stakeholder participation through education and outreach program.

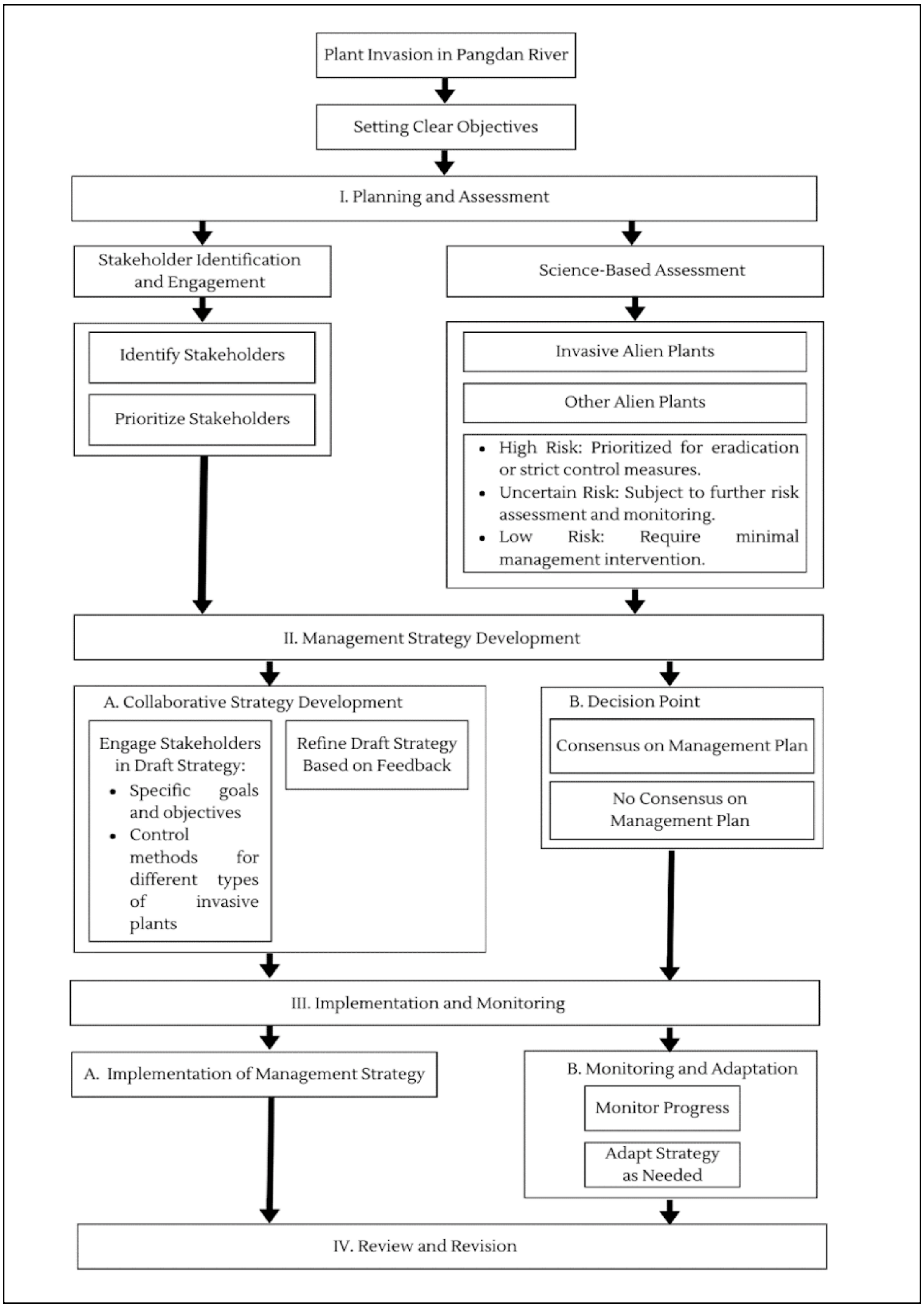
A defined control method for a specific target species not only ensures the effectiveness of management and recovery of ecosystems, but also minimizes the environmental, social, and economic costs underpinned. Such factors can be barriers to the implementation of control strategies (du Plessis et al., 2021).

Once the engagement process has been done, there is a need to reassess the level of engagement of the stakeholders to improve co-design, co-production, and co-implementation when it comes to decision making and management actions (Novoa et al., 2018). By doing this, they need to be made aware of the decisions and outcomes and in return, provide valuable feedback to arrive at a consensus in the plan.

1. If stakeholders reach consensus on the management plan, proceed to implementation.
2. If stakeholders cannot agree on a plan, explore alternative approaches such as mediation or arbitration.

Figure 9.

Framework for managing plant invasion through stakeholder engagement in Naga, Cebu Island, Philippines



Note: primary data, 2024

A formulated management strategy is only effective with successful implementation. This relies upon collaborative partnerships with stakeholders. These stakeholders should possess the capacity and resources to fund the plan. Furthermore, designating a project manager to oversee the entire process and ensure adherence to established timelines and objectives is crucial. Prior stakeholder engagement throughout the design phase can significantly reduce conflicts during implementation. However, unforeseen opposition may still arise during execution. In such scenarios, maintaining trust and mitigating conflict necessitates clear communication regarding the implemented actions.

Driven by the need for environmentally friendly solutions, the concept of NBS emerged within environmental science and species invasion management. The researchers suggest a NBS solution to combat the prevalence of plant invasion in riparian areas along Pangdan River. International organizations like IUCN and the World Bank actively promoted the NBS concept as they aimed to move beyond traditional engineering interventions. Moreover, NBS are defined as actions that protect, sustainably manage, and restore natural ecosystems, with the goal of addressing societal challenges effectively and adaptively. These solutions provide benefits for both human well-being and biodiversity (Haase, 2017).

The status of invasive plant populations and the effectiveness of control measures must be regularly monitored to ensure successful management of invasive species. The effectiveness of control attempts can be evaluated by long-term monitoring programs, which further assists in shaping the development of management strategies. Important insights can be obtained into how interventions affect the larger ecosystem and its processes by monitoring population changes before, during, and after interventions.

Continuous constant assessment, adaptation process, and regular reviews in the long term enable the identification of areas where the plan may need to be strengthened or refined. Regular evaluation of the management approach ensures effective control strategies and restoration projects, allowing for the integration of new scientific findings and environmental changes. This method also helps find and fix recurring problems by encouraging stakeholder collaboration and addressing concerns at regular review meetings. Following such evaluations, if changes are deemed required, the management strategy should be directly updated. This iterative process allows the plan to reflect the most recent knowledge, effectively address current challenges, and ultimately retain its efficacy in meeting its defined goals (Novoa et al., 2018).

Conclusions

This study investigated the influence of various environmental factors on plant diversity and community composition along the Pangdan River. Key findings revealed a gradient in biodiversity, with upstream sites exhibiting higher species richness (67.57%) and abundance (65.55%) of NPs. Downstream site displayed the lowest richness (5.41%), decreased abundance of (1.77%) NPs, and 2nd highest abundance (34.96%) of APs. Light intensity and temperature were identified as significant factors shaping plant communities. NPs preferred shadier environments, while some APs thrived in areas with higher light exposure. Both NPs and APs' richness declined with increasing temperature. Edaphic parameters within the studied range showed minimal independent effects on plant diversity. Limitations such as sample size (n=9) and exclusion of the dry season highlight the need for further research incorporating seasonal variations.

This would provide more accurate and reliable results regarding the relationship between ecological factors and plant communities. Historically, the Pangdan River supported a rich tapestry of native vegetation. However, the rise of industrialization and the increase of anthropogenic activities through time gradually altered the riparian landscape. This resulted in a large discrepancy between the NPs and APs ratio. The decline of NP diversity and the dominance of APs raise serious concerns about the health of the Pangdan River ecosystem. To address these issues, the study recommends a management strategy that integrates the concept of NbS and the engagement of various stakeholders with different degrees of impact and influence. Through this comprehensive recommendation, the NPs diversity, human well-being, and the overall functioning of the riparian ecosystem will be maintained.

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