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Research Article

Potential impacts of industrial tree plantation encroachment on tree species diversity and carbon storage in the riparian zones of Andanan Watershed Forest Reserve, Philippines

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Abstract

Riparian zones within watersheds serve as vital interfaces between terrestrial and aquatic ecosystems, supporting key ecological and environmental processes. Despite their critical importance, these ecosystems are increasingly threatened by human activities. This study evaluated tree species diversity and estimated carbon density in the riparian zones downstream of the Andanan River Watershed Forest Reserve through a systematic sampling method conducted across 12 plots. Two hundred and eighty-eight individual trees were recorded, encompassing 32 species from 17 families and 27 genera. The tree population included 19 native and 13 non-native species, with five native species endemic to the Philippines. Notably, eight species identified are listed on the Philippine or IUCN Red Lists of Threatened Species. The Shannon-Wiener Diversity Index (H’=2.76) indicated moderate species diversity, while the estimated carbon content was 83.15 ± 17.49 MgC ha^{-1}. Geographic Information System (GIS) and Remote Sensing (RS) analysis revealed that 1,525.305 hectares of the protected area, including approximately 729.07 hectares of riparian zones, have been converted into industrial tree plantations, leading to the displacement of natural forest species. These findings underscore the urgent need for policy interventions to restore a balance between natural and plantation species in protected areas, thereby preserving biodiversity, enhancing carbon sequestration and mitigating the impacts of climate change.

Keywords

carbon analysis, riparian zone, tree species diversity, ITP encroachment

Introduction

Riparian zones are vital interfaces between river channels and upland ecosystems, facilitating the exchange of energy, matter and biota (Gregory et al. 1991; Pusey and Arthington 2003; Casotti et al. 2015). These areas are amongst the most productive and biodiverse landscapes on Earth, recognised as one of the fifteen global terrestrial biomes. The term 'riparian' comes from the Latin '*riparius*,' meaning land adjacent to waterbodies (Naiman and Décamps 1997; Sunil et al. 2010). Riparian and riverine vegetation are dynamic systems that support high biological diversity (Tockner and Ward 1999; Chovanec et al. 2000), yet they are some of the most impacted habitats by human activities (Nilsson and Svedmark 2002). Although riparian zones occupy only a small portion of a watershed, they are critical habitats for wildlife, especially in agricultural regions where streamside habitats are rapidly disappearing. These zones perform essential functions, including stabilising stream-banks, preventing sedimentation, regulating water temperature, recharging groundwater and filtering pollutants from runoff (Baker et al. 2006). Protecting riparian zones is crucial for preserving biodiversity and sustaining ecosystem services, particularly in designated protected areas.

In the Philippines, protected areas are designated lands and waters of unique physical and biological significance. These areas are managed to enhance biodiversity and safeguard them from destructive human activities (Senga 2001; Mallari et al. 2016). Two key laws govern these protected areas: Republic Act No. 7586 - the National Integrated Protected Areas System (NIPAS) Act of 1992, and Republic Act No. 11038 - the Expanded NIPAS (E-NIPAS) Act of 2018. The Caraga Region in Mindanao is home to 12 protected areas, which play a critical role in biodiversity conservation and ecosystem services (Biodiversity Management Bureau 2024). These areas include the Agusan Marsh in Agusan del Sur, a globally significant wetland; the Tinuy-an Falls area in Surigao del Sur; Siargao Island in Surigao del Norte; and Puting Bato watershed in Cabadbaran City, Agusan del Norte.

The issuance of Executive Order (EO) 23 in 2011, which declared a moratorium on the cutting and harvesting of timber from the natural and residual forests, contributed to the expansion of Industrial Tree Plantations (ITPs) in the Philippines (Huesca 2016; Peras et al. 2020). Despite its good intentions, EO 23 led to unintended challenges. The logging ban increased the demand for timber, both in legal and illegal markets, shifting the pressure on to other types of forests, secondary growth areas and even mangroves (Guiang 2001; FAO/RECOFTC 2016). ITPs are increasingly being established in forest ecosystems and riparian zones across the Philippines (Catibog-Sinha and R. 2006; Mang and Brodie 2015; Causaren et al. 2017; Sarmiento et al. 2022). While these plantations can serve as effective carbon sinks, sequestering substantial amounts of atmospheric carbon, much of the stored carbon is released back into the atmosphere during harvest as the trees mature. The favourable conditions in riparian areas further boost growth and biomass productivity (Aishan et al. 2018, Dybala et al. 2018).

Tree species diversity in riparian zones, along with their capacity to store carbon, is crucial for maintaining the ecological integrity of these areas, especially in protected environments. However, the encroachment of industrial tree plantations can significantly impact both biodiversity and carbon storage. These plantations, often dominated by monocultures of fast-growing species, tend to displace native vegetation and disrupt the natural habitats of riparian species (Mang and Brodie 2015). This disruption can lead to a reduction in species richness and abundance, as well as a diminished carbon storage capacity in these critical ecosystems.

This study evaluated the impact of industrial tree plantation encroachment on tree species diversity and carbon storage within the riparian zones of the Andanan Watershed Forest Reserve (ARWFR), Philippines, by comparing the ecological characteristics of these zones in areas affected by plantation activities with those in unaffected natural habitats focusing specifically in the riparian zones of Claro Cortez and Calaitan in the downstream section of the of the watershed. In addition, GIS analysis was employed to determine the extent of ITP encroachment within the protected watershed. The findings aim to highlight the importance of conserving native tree species and maintaining ecological integrity in riparian zones within protected areas.

Materials and methods

Study area

The Andanan River and its surrounding areas were designated as a nature reserve, known as the Andanan River Watershed Forest Reserve (ARWFR), under Philippine Presidential Proclamation No. 734 on 29 May 1991. The watershed spans 15,097 hectares, extending from Sibagat to Bayugan City and encompasses eight barangays: Sta. Irene, Calaitan, Berseba, Sto. Niño, Mt. Carmel, Mt. Ararat, San Juan in Bayugan City and Barangay New Tubigon in Sibagat, Agusan del Sur. The riparian zones along the river are densely populated with trees, shrubs, ferns and grasses. Boulders and rocks are abundant along the riverbanks, sometimes obstructing water flow, with the river width varying from 5 to 10 m along its course.

The area is primarily classified as uplands, characterised by steep, sloping mountainous terrains with elevations ranging from 20 to 1,250 m above sea level. However, the downstream areas of the ARWFR, particularly in the barangays of Claro Cortez and Calaitan, feature flatter terrain with slopes of 0-50% and elevations between 30 and 550 m above sea level (Fig. 1).

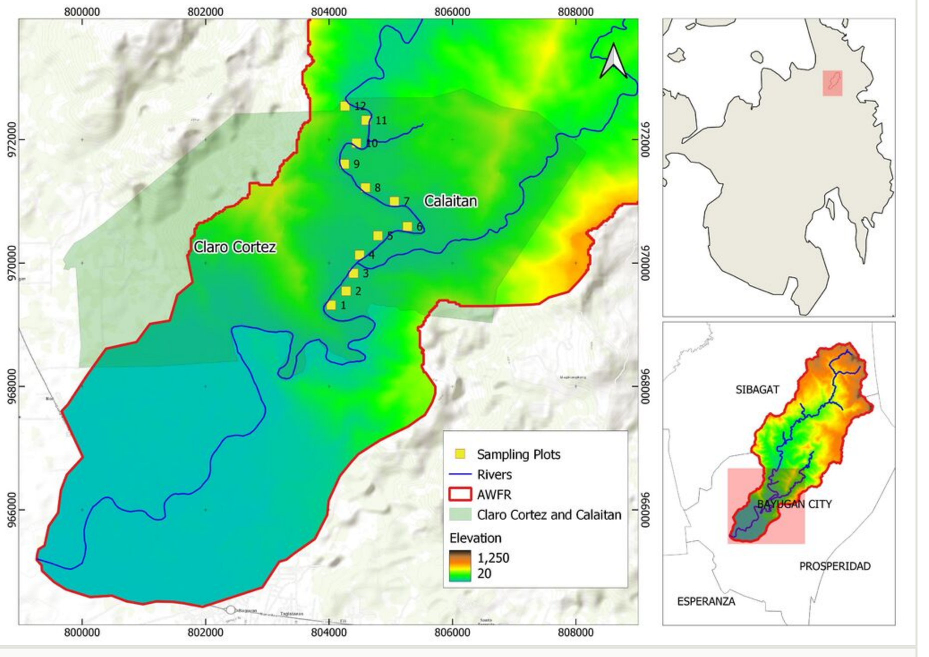

Figure 1.

Tree sampling stations established along a 5.6-km forest riparian zone within ARWFR, Claro Cortes-Calaitan section.

This study was conducted in riparian sections that serve as boundaries between the barangays of Claro Cortez and Calaitan. The river spans approximately 5.6 km and likely supports the most diverse vegetation within the watershed. The climate is classified as Type II under the Corona Climatological Classification, characterised by frequent rainfall, primarily due to the northeast monsoon and tropical cyclones. The soil in this area is classified as Camansa series, a clay loam soil well-suited for tree plantations and typically found in hilly, mountainous regions.

Data Gathering

A total of 12 sampling plots, each measuring 20 × 20 m, were established at intervals of approximately 250 m along the river. The plots were systematically arranged on alternating sides of the river, with three plots per setting, as illustrated in Fig. 1. This layout ensured a comprehensive sampling of the riparian vegetation on both riverbanks. All standing trees inside plots with a diameter at breast height (DBH) of ≥ 10 cm were identified and recorded. Tree DBH were taken at about 1.3 m from the ground using calibrated diameter tapes, while tree heights were measured using a laser rangefinder/

hypsometer. This approach allowed for an accurate assessment of tree species composition and abundance, contributing to the understanding of species distribution and dominance in the riparian zone.

Data analysis

The vegetation analysis was conducted using descriptive statistics to determine the relative density, relative frequency, relative dominance and the species importance value of each species in the area following the methodology of Mueller-Dombois and Ellenberg (1976), currently used in phytosocial studies (Gumiero et al. 2015; Sarmiento 2018, Kunwar et al. 2020).

Inventory data were entered into a spreadsheet and analysed using an Excel-based SIV Calculator developed by the authors for efficient and rapid analysis (Suppl. material 1). Tree species with the highest importance values were identified as the most dominant in the study area, with SIV ranks indicating the order of species within the riparian zone (Taylor et al. 1993, Kunwar et al. 2020, Azevedo de Melo et al. 2021). Additionally, key ecological parameters — species richness, dominance, diversity and evenness — were employed to provide a comprehensive assessment of the community structure. These metrics not only quantify the number of species present, but also reveal the relative abundance of each species, their dominance within the community and how evenly individuals are distributed across species. Together, they offer a nuanced understanding of the ecological balance and health of the ecosystem. The biodiversity scale developed by Fernando (1998) was applied to determine biodiversity levels, with the diversity index interpreted using the results from Shannon's Diversity Index. This approach allowed for a more precise evaluation of species distribution patterns and overall ecosystem diversity.

Biomass computation

For this study, the researchers used a non-destructive sampling technique following the generic allometric equations for the computation of biomass (AGB) as follows:

Biomass (aboveground), AGB = $0.066\,D^{2.59}$, *Ketterings et al. (2001)*;

Biomass (belowground), BGB = 20% AGB, *Pearson et al. (2017)*;

Total Plant Biomass = Biomass (aboveground) + Biomass (belowground).

We then computed the total carbon stock in each tree using the following equation,

$$TCS = (AGB + BGB) \times 0.5,$$

where 0.5 is the conversion factor, which indicates that the carbon content is assumed to be 50% of the total biomass following Takimoto et al. (2008) and Khan (2013). We converted the total carbon stock into hectares by dividing the cumulative sum of the carbon stock in each DBH class by the area (hectares).

GIS analysis

The extent of industrial tree plantation (ITP) encroachment within the protected areas was evaluated using published secondary data derived from GIS and remote sensing (RS) mapping technology (Escasio et al. 2023; Santillan 2023). A map produced by the Industrial Tree Plantation Research and Innovation Center, which identifies the locations of ITPs in Agusan del Sur based on satellite remote sensing, was georeferenced and used as an overlay for spatial analysis. The boundaries of the Andanan River Watershed Forest Reserve (ARWFR) were clipped from the georeferenced map and plantation areas within these boundaries were extracted using the raster calculator function in QGIS 3.34.14.

The study also utilised a dataset containing estimates of forest above-ground biomass for the year 2021, which was developed by Santoro and Cartus (2024). The data are derived from multiple Earth observation sources, including Copernicus Sentinel-1, Envisat's ASAR and JAXA's ALOS-1 and ALOS-2 satellites and were produced by the Biomass CCI team under the European Space Agency's Climate Change Initiative (CCI) programme. The dataset was employed as a reference to derive the carbon density. By using these biomass estimates in QGIS, the study was able to estimate the amount of carbon stored in the forested areas within the watershed. This approach provided a standardised and reliable basis for assessing carbon stocks, enabling a more comprehensive evaluation of the watershed's role in carbon sequestration and climate regulation.

Results and Discussion

Tree species diversity

A total of 292 individual trees were identified and recorded in the sampled riparian zones, representing 17 families, 27 genera and 32 tree species. Amongst these, 19 species were native to the region, while 13 were non-native. Of the native species, 16 were non-endemic and six were endemic to the area (Table 1). The majority of the surveyed plots contained more than 20 trees as shown in the individual rarefactions (Fig. 2) following Chao et al. (2014); however, the diversity values, measured using Shannon's Index, ranged from 'very low' to 'low.' This limited diversity is largely attributed to extensive riverbank clearing for industrial plantation and agricultural activities, as most of the plots were situated within Falcata plantations (*Falcataria falcata* J.W. Grimes and Barney), where monoculture practices dominate the landscape.

Several indigenous small-diameter tree species were documented in the riparian zones. The largest tree recorded onsite was a White Lauan (*Shorea contorta*) with a diameter at breast height (DBH) of 53.5 cm, followed by an Antipolo (*Artocarpus blancoi*) and a Smooth Narra (*Pterocarpus indicus* f. *indicus*). These species are capable of reaching heights of up to 50 m and diameters of up to 180 cm; however, no individuals of such dimensions were encountered during the survey, indicating possible anthropogenic impacts or a younger age class within the riparian areas. The Moraceae family exhibited the highest species richness, with eight species identified, followed by Fabaceae, Meliaceae and Malvaceae, each represented by three species.

The Shannon-Wiener Index (H') for the riparian zones, calculated using PAST 4.0, ranged from 1.153 to 2.372 (Table 2). Based on the diversity classification scheme by Fernando (1998), seven plots fell into the 'very low' diversity category, while the remaining five plots were classified as having 'low' diversity. Analysis of the species composition revealed that the top five plots with the highest diversity were characterised by a mix of native and fruit-bearing trees. In contrast, the plots with the lowest diversity were predominantly dominated by industrial tree plantation (ITP) species, such as *Falcataria moluccana* (Falcata), *Swietenia macrophylla* (Mahogany) and *Gmelina arborea* (*Gmelina*). A one-way ANOVA was performed to compare the effect of species composition on the diversity index (H'). The ANOVA results show that there was a significant difference between the groups (F (1,10) = 23.41, p = 0.001). The F-value of 23.41 suggests that the variation due to classification is much greater than the random variation (error).

Table 1.

List of species encountered and their ecological distribution.

Family name	Scientific name	Ecological Distribution
Anacardiaceae	*Mangifera indica*	Non-native
Anacardiaceae	*Koordersiodendron pinnatum*	Native
Anonaceae	*Annona muricata*	Non-native
Anonaceae	*Cananga odorata*	Native
Araliaceae	*Polyscias nodosa*	Non-native
Arecaceae	*Cocos nucifera*	Native
Bytheriaceae	*Theobroma cacao*	Non-native
Diptoracarpaceae	*Shorea contorta*	Native-Endemic
Fabaceae	*Falcataria falcata*	Non-native
Fabaceae	*Leucaena leucocephala*	Non-native
Fabaceae	*Pterocarpus indicus* f. *indicus*	Native
Lamiaceae	*Gmelina arborea*	Non-native
Lauraceae	*Litsea philippinensis*	Native-Endemic
Lythraceae	*Largestromia speciosa*	Native
Malvaceae	*Durio zibethinus*	Non-native
Malvaceae	*Ceiba pentandra*	Non-native
Malvaceae	*Diplodiscus paniculatus*	Native-Endemic
Meliaceae	*Sandoricum koetjape*	Native
Meliaceae	*Swietenia macrophylla*	Non-native

Family name	Scientific name	Ecological Distribution
Meliaceae	*Lansium parasiticum*	Native
Moraceae	*Artocarpus blancoi*	Native-Endemic
Moraceae	*Artocarpus heterophyllus*	Non-native
Moraceae	*Artocarpus odoratissimus*	Non-native
Moraceae	*Ficus balete*	Native-Endemic
Moraceae	*Ficus minahassea*	Native
Moraceae	*Ficus nota*	Native
Moraceae	*Ficus septica*	Native
Moraceae	*Broussonetia papyrifera*	Non-native
Sapindaceae	*Nephelium lappaceum*	Native
Sapindaceae	*Pometia pinnata*	Native
Urticaceae	*Pipturus aborescens*	Native
Verbenaceae	*Vitex parviflora*	Native

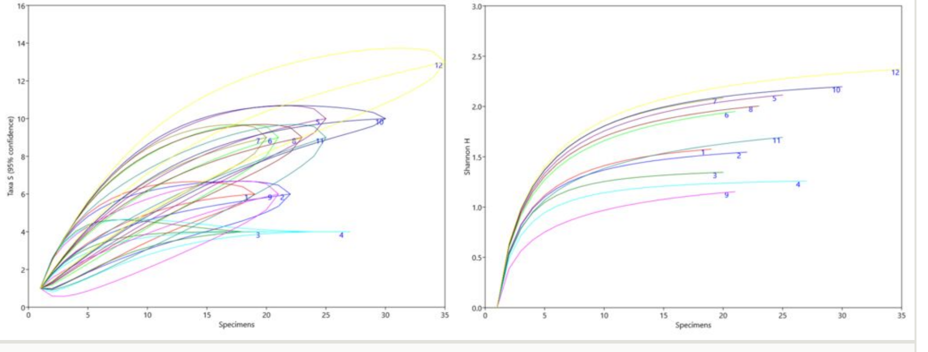

Figure 2.

Individual rarefaction curves generated in PAST 4.0, showing species richness (Left) and Shannon H Diversity Index (Right) as a function of the number of individuals in each sampling plot.

Table 2.

Summary of plant species composition, ecological structure and diversity indices per sampling plot.

Plot No.	Individuals	Richness	Dominance	Shannon's	Simpson's	Evenness
1	19	6	0.252	1.576	0.748	0.806
2	22	5	0.248	1.547	0.752	0.783
3	20	4	0.270	1.345	0.730	0.960
4	27	4	0.322	1.259	0.678	0.881
5	25	10	0.142	2.113	0.858	0.828
6	21	9	0.179	1.950	0.821	0.781

Plot No.	Individuals	Richness	Dominance	Shannon's	Simpson's	Evenness
7	20	9	0.135	2.085	0.865	0.894
8	23	9	0.157	2.005	0.843	0.825
9	21	6	0.469	1.153	0.531	0.528
10	30	10	0.122	2.197	0.878	0.899
11	25	9	0.277	1.693	0.723	0.604
12	35	13	0.107	2.372	0.893	0.825
Total	288	32	0.114	2.766	0.886	0.497

The overall diversity index (H') of 2.77 of the riparian section was relatively higher than the 1.07 recorded for the riparian zones along the Dikhu River in Nagaland, India (Leishangthem and Singh 2018). However, it was lower compared to the diversity indices reported for other Indian riparian forests, including 3.06 (Iqbal et al. 2012), 5.6 (Sunil et al. 2016), 2.19-2.92 (Burton et al. 2005) and 1.70-3.24 (Malabrigo et al. 2014) in the Philippines.

Simpson's Index, which measures the probability that two individuals randomly selected from a sample will belong to the same species, was also highest in Plot 12, further indicating a more balanced and diverse species composition. The Evenness Index, which reflects how evenly individuals are distributed amongst the species present, was highest in Plot 3, where no single species dominated the area. In contrast, Plot 9 exhibited the lowest values for both the Shannon-Wiener Index (H') and Simpson's Index (D), indicating minimal diversity and evenness. This plot was predominantly occupied by Falcata, a species often associated with monoculture practices that reduce overall biodiversity.

Species importance value

The data were organised and analysed using standard vegetation analysis methods to estimate the relative density, relative dominance and relative frequency for each tree species. These metrics were then used to calculate the Species Importance Value (SIV), which integrates a species' abundance, size and distribution within the study area. Species with high SIV scores demonstrate significant ecological dominance, density and frequency within the riparian zone.

As shown in Table 3, the three species with the highest SIV in the Claro Cortes-Calaitan riparian section are *Falcataria falcata* (75.537), *Cocos nucifera* (24.799) and *Gmelina arborea* (19.301). *F. falcata*, in particular, exhibits overwhelming dominance, reflecting its extensive presence and likely influence on the local ecosystem. *C. nucifera* and *G. arborea*, while less dominant than *F. falcata*, also play important roles in the riparian vegetation structure, contributing to the overall species composition and ecological dynamics of the area.

Table 3.

Top 15 tree species with the highest importance values.

Species	RDen	RFreq	RDom	SIV
Falcataria falcata	33.637	29.268	12.632	75.537
Cocos nucifera	12.916	6.620	5.263	24.799
Gmelina arborea	5.320	7.666	6.316	19.301
Artocarpus blancoi	8.400	4.878	4.211	17.489
Swietenia macrophylla	3.710	6.969	5.263	15.942
Smooth Narra	5.654	2.787	4.211	12.652
Artocarpus heterophyllus	3.075	3.833	5.263	12.171
Vitex parviflora	3.768	4.181	4.211	12.160
Durio zibethinus	2.161	3.136	4.211	9.507
Ficus nota	0.879	2.787	5.263	8.930
Theobroma cacao	2.091	3.484	3.158	8.733
Lansium domesticum	1.273	2.787	4.211	8.271
Litsea philippinensis	0.570	3.484	4.211	8.265
Mangifera indica	2.296	2.091	3.158	7.544
Artocarpus odoratissimus	2.500	2.091	2.105	6.695

Carbon storage capacity

The carbon density per sampling plot varied significantly, ranging from 20.18 to 148.56 MgC ha-1, with Plot 12 recording the highest value and Plot 1 the lowest (Table 4). The average carbon density in the study area was 83.15 ± 17.49 MgC ha^{-1}. This estimate is notably lower than the carbon density reported for the riparian zone of Pasonanca Natural Park in Zamboanga City, southern Philippines with 128.42 ± 39.04 MgC ha^{-1} (Pasion et al. 2021). Furthermore, our findings fall short of global estimates for tropical wet forests (146.00 MgC ha^{-1}) and tropical moist forests (179.00 MgC ha^{-1}) as reported by Keith et al. (2009). Additionally, they are lower than pantropical averages from Asia (185.00 MgC ha^{-1}) and Africa (196.00 MgC ha^{-1}) as documented by Slik et al. (2013).

Table 4.

Carbon Density Computation.

Plot No.	Species Composition	Total Biomass (Kg)	Carbon Density (MgC ha^{-1})
1	ITP	1,658.09	20.18
2	ITP	5,501.62	67.20
3	ITP	6,974.21	90.08

Plot No.	Species Composition	Total Biomass (Kg)	Carbon Density (MgC ha^{-1})
4	ITP	8,231.45	99.98
5	Mixed	6,739.58	80.41
6	ITP	6,695.18	81.31
7	Mixed	5,503.11	66.68
8	Mixed	4,882.24	57.33
9	ITP	9,005.79	104.44
10	Mixed	9,104.62	114.42
11	ITP	5,458.97	67.22
12	Mixed	12,125.14	148.56
Grand Mean		6,823.33	83.15

A one-way ANOVA was performed to evaluate the effect of species composition (ITP vs. Mixed) on the carbon density of the sampled plots. The analysis revealed no significant difference between the groups (F (1,10) = 0.87, p = 0.374), indicating that species composition did not have a significant impact on carbon density. Although most sampling plots were classified under the ITP category, the lack of significant difference may be attributed to the presence of ITP tree individuals within the mixed species composition plots, which contributed to the overlap in carbon density between the groups.

The ITP species dominated riparian areas under study has a computed overall carbon density lower than in other riparian zones dominated by natural and mixed trees species (Keith et al. 2009; Slik et al. 2013; Pasion et al. 2021; Sarmiento et al. 2022). The low carbon storage and density can be attributed to a combination of environmental, antrhopogenic and methodological factors. The study area's proximity to human settlements likely plays a significant role in reducing carbon storage. Human activities such as agriculture, logging, infrastructure development and land conversion can lead to habitat fragmentation, soil disturbance and vegetation loss. Additionally, the introduction of monoculture species or the removal of native vegetation for economic activities can further diminish the area's carbon sequestration capacity (Liu et al. 2018; Hlásny 2024).

To compare carbon density between industrial tree plantation (ITP) and non-ITP areas within the watershed, we randomly established GIS-generated sampling points in non-ITP areas. These points were strategically placed to enable direct comparison with ITP areas. The sampling points were used to extract raster values from a carbon desity raster (Fig. 3), which was derived from the above-ground biomass dataset obtained from The ESA Climate Change Inititative Open Data Portal (Santoro and Cartus 2024). The analysis revealed a significant contrast in carbon density between the two land-use types. The non-ITP areas exhibited a higher carbon density, with an average of 95.41 ± 26.85 MgC ha^{-1}, while the ITP areas had a considerably lower carbon density, averaging 38.14 ± 26.85 MgC ha^{-1}. These findings suggest that natural or non-ITP forested areas store significantly more carbon compared to plantation forests, which could be attributed to differences in species composition, forest age, management practices and overall biomass accumulation potential.

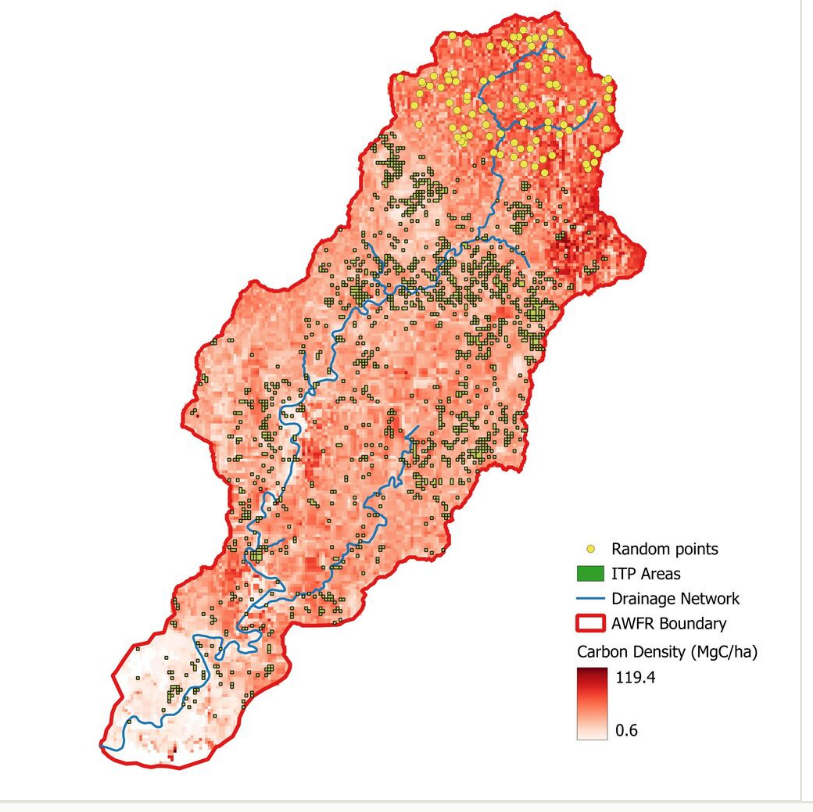

Figure 3.

Carbon density map showing the location of ITP areas and randomly generated plots in non-ITP areas of ARWFR.

Young forests are highly efficient at sequestering carbon because they are in a phase of rapid growth. During this stage, trees actively absorb carbon dioxide (CO_2) from the atmosphere through photosynthesis, using it to build biomass as they expand their roots, trunks and canopies. This period is marked by high carbon absorption rates as trees fill canopy gaps and capture more light, allowing for rapid increases in height and diameter.

However, as forests mature, their ability to absorb carbon diminishes due to various biological and ecological processes. The carbon sequestration rate depends on the average age and density of trees within a stand, with younger forests generally being more effective at capturing carbon (Yang et al. 2023). Despite their rapid growth, young forests face intense competition for light, nutrients and space, resulting in the death of some saplings. While the decomposition of these young trees releases some carbon back into the atmosphere, the amount is relatively small compared to what is absorbed during the growth phase. Understanding these dynamics is crucial for assessing the role of forests in carbon sequestration and their potential for climate change mitigation. The age structure and composition of forests play a significant role in determining their overall carbon storage capacity and long-term ecological impact.

Encroachment of ITP in Riparian Areas of ARWFR

Fig. 4 displays the Bray-Curtis Similarity Index as a similarity percentage between the sampling plots. This Index compares the relative abundances of the plots with a value of 0, indicating total dissimilarity and 1, indicating total similarity (Bray and Curtis 1957; Lee et al. 2020). Four significant clusters were generated, based on the data analysis; however, all clusters fall into agricultural and industrial plantation classifications. Most plots, especially those close to communities, had species compositions dominated by *F. falcata.* The first cluster (9 and 11) was dominated by *F. falcata* alone, the second cluster (5, 3, 4 and 2) was dominated by a combination of *F. falcata* and *G. arborea*, the third cluster (6 and 1) still dominated by *F. falcata*, but with indigenous tree species and the fourth cluster (8, 7, 10 and 12) with *F. falcata* and combinations of agricultural fruit-bearing species. With all plots containing Falcata or a combination thereof, the survey revealed that ITP has successfully encroached the riparian zones of the protected watershed.

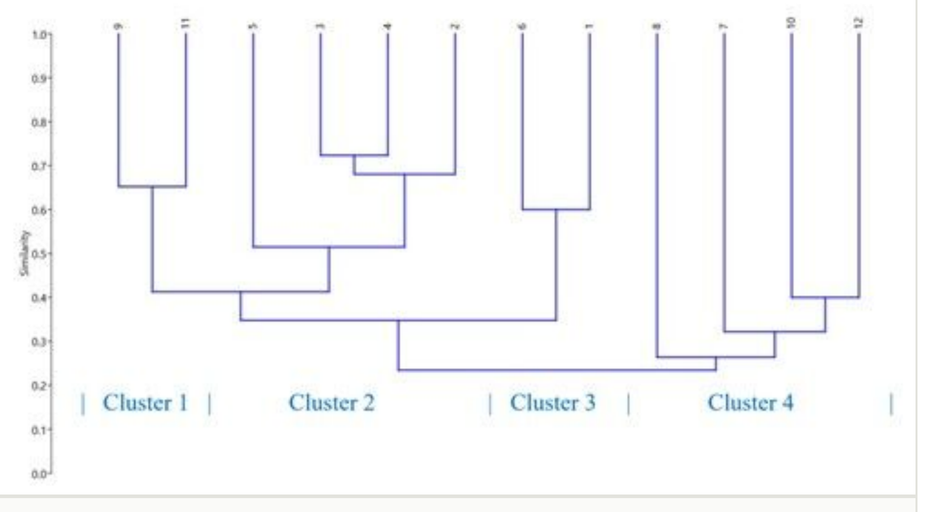

Figure 4.

Bray-Curtis Cluster Analysis per sampling plot.

These data provide valuable insights for decision-making and planning in the development of areas where plots have been established. For instance, in the case of the two most similar plots (Plots 3 and 4), the conversion of either plot to other uses would likely have a minimal impact on the overall diversity of the area, as most species found in one plot are also present in the other. However, it is crucial to consider not just the similarity of species between plots, but also the biological value of these species (Malabrigo et al. 2014). If the species in these similar plots are classified as threatened or of significant ecological importance, then conservation and protection efforts should be prioritised over conversion to alternative land uses. This approach ensures that critical species are preserved and that the ecological integrity of the site is maintained.

The Andanan River Watershed Forest Reserve (ARWFR) spans a total area of 15,097 hectares, as designated by Philippine Presidential Proclamation No. 734 on 29 May 1991. Recent GIS and Remote Sensing (RS) analysis revealed that industrial tree plantations (ITPs) now cover approximately 1,525.31 hectares, representing roughly 10.10% (Fig. 5) of the entire watershed. These ITPs are predominantly located in the mid-elevation range of 200 to 500 m above sea level, an elevation optimal for the cultivation of Falcata (*F. falcata*).

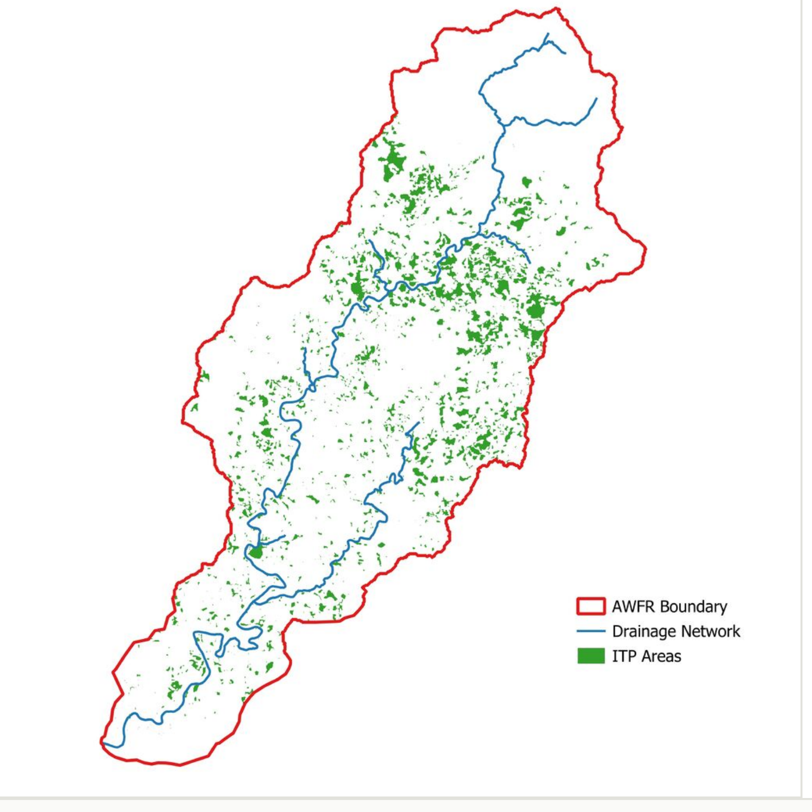

Figure 5.

Map showing the spatial extent of ITPs in ARWFR.

To assess the impact of ITPs on riparian zones, a 50-m buffer was generated along river channels using GIS geoprocessing tools. The overlay of this buffer with the ITP map revealed that approximately 36.13 hectares or 4.96% of the 729.07 hectares of riparian zones, have been converted to ITPs. While the encroachment of ITPs into riparian zones remains below 5%, making it a seemingly manageable issue, the potential ecological consequences should not be underestimated. It is, therefore, recommended to prioritise the planting of native and indigenous species to enhance biodiversity, support ecosystem resilience and improve carbon sequestration.

Given the critical ecological functions of riparian zones, it is essential to enforce strict land-use policies and implement robust monitoring and enforcement mechanisms to prevent further encroachment. Preservation and restoration efforts should prioritise the natural riparian vegetation, ensuring the long-term health and resilience of the watershed's ecosystems.

Conclusions

The tree diversity assessment of riparian zones in the barangays of Claro Cortes and Calaitan, located downstream of the Andanan River Watershed Forest Reserve (ARWFR), revealed a moderate overall species diversity despite the prevalence of monoculture industrial tree plantations (ITPs). While these riparian areas still support numerous individual trees and some notable species, the estimated carbon storage (83.15 ± 17.49 MgC ha^{-1}) is considerably lower than the global average, highlighting the potential ecological impact of land-use changes.

GIS analysis indicates that a significant portion of the protected area has been converted into industrial tree plantations, often at the expense of native vegetation. This conversion leads to biodiversity loss as native trees and plants are displaced, affecting species that rely on these riparian ecosystems for food, nesting and shelter. Furthermore, ITP areas exhibit lower carbon density compared to non-ITP areas, reinforcing concerns about their reduced capacity for carbon sequestration and long-term ecological stability.

Although the impact of industrial tree plantations on riparian biodiversity and carbon storage may be manageable, it remains a critical concern. To mitigate biodiversity loss and enhance carbon sequestration, it is essential to prioritise sustainable land-use practices that focus on preserving and restoring natural riparian vegetation. These efforts will help maintain ecosystem integrity, support wildlife habitats and strengthen climate change mitigation strategies.

Future management initiatives should explore the integration of native tree species in reforestation efforts to enhance watershed protection, safeguard freshwater resources and maintain the ecological functions of riparian zones. By recognising the importance of these ecosystems and implementing effective conservation measures, we can ensure their long-term sustainability and resilience for future generations.

Prior Informed Consent (PIC)

To comply with E.O. 247 (Bioprospecting) and R.A. 9147 (Wildlife Resources Conservation and Protection Act), the research proposal was submitted to the ARWFR

PAMB at CENRO Bayugan, Agusan del Sur, for approval and the issuance of a Gratuitous Permit. The wildlife permit was secured through PAMB Resolution No. 2022-03 at the DENR Regional Office XIII in Butuan City.

Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary material

Suppl. material 1: Excel-based SIV Calculator doi

Authors: Roger T. Sarmieinto
Data type: Excel Files
Brief description: The attached file is an Excel-based, automated SIV Calculator developed by the author to enable efficient and rapid analysis of species importance values (SIV) for floristic surveys.
Download file (513.03 kb)