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Carbon Sequestration and Storage Potential of Indigenous Tree Species in the Fresh Water Swamp Forests of Agusan Marsh Wildlife Sanctuary

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ABSTRACT

Natural wetlands such as freshwater marshlands ecosystem plays a crucial role for its ecological importance by supporting an extensive array of life forms that lives under different habitats within it, and for its carbon storage and sequestration potential. In Agusan Marsh Wildlife Sanctuary (Mindanao, Philippines), peat swamp forest habitat exists about 49% of the marshland area but information about its carbon storage and sequestration capacity is limited. In this study the tall-pole forest subtype of Agusan Marsh peat swamp was assess for its total biomass, carbon sequestration and storage potential. Furthermore, relationship between carbon stock with species richness and species density were evaluated. A field survey was conducted by establishing six circular plots to collect data on tree inventory and biomass. These were then used to compute for species richness, density, carbon stock and estimated CO2 sequestration. Recorded average total tree biomass in this study was at 514.03 tons ha-1 which is much higher than previously reported surveys of tall-pole peat swamp forest in other areas. Five tree species were identified to have contributed the greatest total carbon stock in the study area among the 67 tree species namely: Calophyllum inophyllum (11.2 %), Palaquium pinnatinervium (7.5 %), Aglaia sp (5.9 %), Vitex parviflora (4.6 %) and Lithocarpus celebicus (4.4 %). However, species richness and species density were not significantly able to predict carbon stocking of the area accounting only about 28.5% and 0.3%, respectively. Overall, the CO2 sequestered by tall-pole forest in Agusan Marsh was classified as moderately high accounting to about 942,28 tons ha-1 highlighting the relative importance of this subtype forest as storehouse of carbon in a wetland ecosystem..

Keywords:
Agusan Marsh, Carbon sequestration, Carbon storage, Swamp forest, Wetlands

1.Introduction

The Agusan Marsh Wildlife Sanctuary (hereafter referred as the Agusan Marsh) located at the very heart of the Agusan River Basin, Mindanao, Philippines is a natural wetland of utmost ecological importance supporting an extensive array of life forms. This vast complex and unique freshwater marshes and watercourse was enlisted Site No. 1009 in the Ramsar List of Wetlands of International Importance, an intergovernmental treaty of different countries committed to maintain the ecological character of wetlands. Functioning as a living sponge for storage of rain water while gradually releasing it downstream, the marshland plays a crucial role in the reduction of extreme flooding in the lower Agusan River where Butuan City and other population centres of the region were located.

The freshwater swamp forest (49% of Agusan Marsh) is one of the five main habitat types in Agusan Marsh with *Terminalia*, *Metroxylon*, and peat swamp forest as subtypes (Primavera and Tumanda, 2007; Birdlife International, 2021). It is a forest that is full (inundated) with mineral-rich water (freshwater) either as a permanent, irregular or a seasonal condition. Forest ecosystems such as peat swamps in their natural state play a role as efficient carbon storage in the terrestrial environment (FAO, 2015; Mohd Afzanizam et al., 2019). In Agusan Marsh, peat forests have been confirmed in Bunawan and San Francisco, Agusan del Sur. The peat swamp forest was further classified into five distinct vegetation zones namely: tall-pole forest, the short pole forest, the stunted forest zone, ferns and lycopods vegetation zone, and the sedge vegetation zone based on recent floristic surveys conducted in the marsh (Tandang et. al, 2014; Aribal and Fernando, 2014).

Peat swamps cover only about three percent of Earth's total land area (Parish et al. 2008), however, these ecosystems store a large fraction of the world's terrestrial carbon resources (Alibo & Lasco, 2012; Verwer et al., 2008; Parish et al., 2008). The carbon sequestration and storage potential of tree species is an interesting aspect to study (Coracero and Malabrigo, 2020) since quantifying carbon storage and sequestration capacity of trees will determine the amount of carbon stored in the ecosystem rather than allowing it accumulate into the atmosphere as greenhouse gas (Muniyappa and Nandini, 2013). To date, there are only a few online scientific publications on carbon stock assessment in Agusan Marsh, most of which in particular are centered in the peat domes of Caimpugan, San Francisco, Agusan del Sur. Therefore, the present study will serve as comparative baseline for the tall-pole forest subtype of Agusan Marsh peat swamps in Sitio Bataran, Barangay Desamparados, Talacogon, Agusan del Sur, Philippines.

2. Objectives of the Study

The objective of the study was to assess the carbon sequestration and storage potential of the tall-pole forest peat swamps of Sitio Bataran in Agusan Marsh. Specifically, it aimed to: a) conduct biomass assessment and provide baseline data for tall-pole peat swamp forest in natural/pristine condition, b) determine the carbon stock of ecologically important tree species, c) evaluate the relationship of tree carbon stock with factors like species richness and species density, and d) identify the most important species in terms of carbon sequestration and storage potential.

3. Methodology

3.1 Description of study site

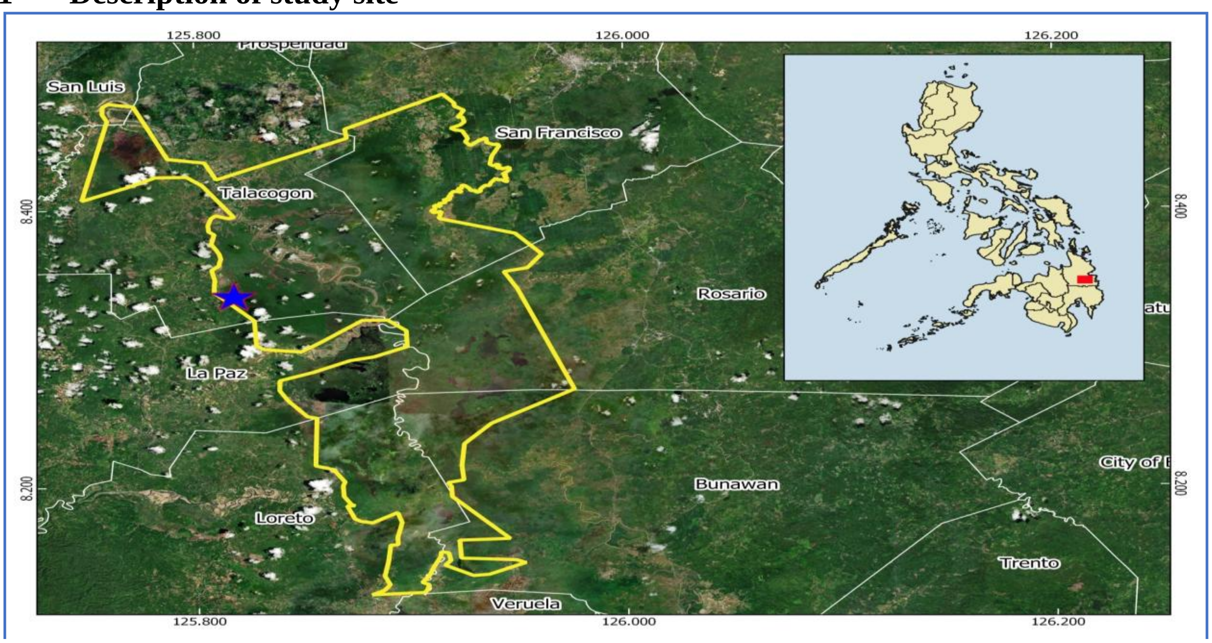

Figure 1. Location map of the study site in Sitio Bataran of Agusan Marsh Wildlife Sanctuary in the Philippines. (Source: ESRI Satellite, QGIS Online Basemap 2021)

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The site belongs to Type IV climate with evenly distributed rainfall throughout the year. Despite evenly distribution of rainfall, the area was periodically submerged for four to six month a year as rivers rise to as much as 10 meters. As the catch basin of Agusan River, Agusan Marsh has a distinct annual flooding cycle with maximum water level reached between October and February (Tomas et al., 2011) and starts to decrease through the months of August to September.
The tall-pole forest has soil characterized by a high amount of organic materials under varying stage of decomposition. Bulk density ranged from 0.22 to 0.68 g/cc while soil color ranged from brownish black to dark brown, a mixture of silty clay loam and clay. The low bulk density values of the forest type may be attributed to the moisture condition and organic matter content of the soil.

Figure 2. The vegetation in the tall-pole forest of Sitio Bataran, Agusan Marsh (upper left), organic material rich soil composition (upper right), local researchers taking tree measurements (lower left), and local researchers collecting voucher specimen (lower right).

3.2 Plot establishment and Tree inventory

Circular plots having an area of 1257 m^2 (20 m radius) at 250 m interval were laid out starting from a random location in the tall-pole forest area. Distance between plots was measured using calibrated straw tread and counter checked using GPS. About six plots for a total of 7,542 m^2 or 0.7542 ha were surveyed for the study. Locations of the plots were obtained using GPS receivers taken from the center of the plot (Table 1).

Table 1. Geographic locations of sample plots in the tall-pole forest.

Plot No.	Latitude	Longitude
1	8.339740	125.813238
2	8.337881	125.814527

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3	8.335991	125.815794
4	8.335190	125.817926
5	8.334011	125.819865
6	8.331822	125.819253

Tree inventory was carried out from May to June 2018. All trees with diameter at breast height of at least 5cm inside the plots were identified, counted and recorded. The total and merchantable heights of trees were measured using clinometers, dbh and metrics of density including basal area and density were likewise recorded. Other salient features in the field like flowering and fruiting species were noted and photo documented.

All trees were identified on field using taxonomic keys and field guides, unfamiliar trees were identified using the Manobo names of trees with the help of local researchers. Voucher specimens were also collected, photographed and placed inside herbarium bags for identification and verification purposes. After processing, all voucher specimens were stored and deposited in the herbarium of the Department of Biology, Caraga State University, Ampayon, Butuan City.

Figure 3. Some indigenous tree species encountered in the field: Albizia saponaria (Lour.) Miq. (left) and fruit of Garcinia vidalii Merr. locally known as “Libas” (right).

A total of 67 species with 298 individuals from 55 genera and 34 families was recorded. The conservation and distribution (native) status of the species were likewise assessed using online portals such as the IUCN Redlist of Threatened Species (IUCN, 2021) and DAO 2017-11 or the Updated National List of Threatened Philippine Plants and their Categories (DENR, 2017).

3.3 Data Analysis

Species richness and density was determined using PAST 2.14. It is a comprehensive, but simple-to-use software package for executing a range of standard numerical analysis and operations used in quantitative paleontology. Species richness pertains to the number of species while species density pertains to the number of individuals of the species per unit area.

Tree biomass is comprised of the total amount of living organic matter in trees and usually expressed in tonne ha^{-1} (Whitmore, 1972). For this study, non-destructive sampling was used following the allometric equations for the computation of biomass (AGB) developed by Manuri et al. (2014) for tropical peat swamp forest in Indonesia while BGB was calculated considering 15% of the aboveground biomass as followed by MacDicken [17], Alamgir [18] and Pragasan [3].:

Biomass (aboveground), AGB = $0.081*dbh^{2.049}*H^{0.672}$*, dbh in cm, H in m, R2 = 97.4*

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Biomass (belowground), BGB = 15 % of AGB
Total Plant Biomass = Biomass (aboveground) + Biomass (belowground)
The standard formula for total carbon stock in each tree was computed using the following equation,
TCS = (AGB + BGB) x 0.5
Where 0.5 is the conversion factor representing that the carbon content is assumed as 50% of the total biomass following Takimoto et al. (2008), Khan (2013) and, Sundarapandian et al. (2013). The total carbon stock is converted to a hectare basis by dividing the cumulative sum of the carbon stocks in each DBH class by the area (hectares). To determine the weight of CO_2 sequestered by each tree, the weight of carbon in the tree was multiplied by 3.6663 (Vishnu and Patil 2016). Overall computation of the CS of the study site was done to show the importance of the area in storing carbon.
Regression analysis of the data was done to know the relationship between tree carbon stock and factors such as species richness and species density. Regression analysis can help in determining the following if independent variables have significant effect or relationship with the dependent variable (Coracero and Malabrigo, 2020). Analysis of Variance (ANOVA) was also performed to check the significance of variation in total carbon stock among the two factors identified.

4. Results and Discussion

4.1 Tree biomass of tall-pole forest

The total biomass of trees in the tall-pole peat swamp forest sampled area (0.7542 ha) was 387.68 tons or an average biomass of 514.03 tons ha^{-1} (Table 2). The results are higher based on the findings of Pragasan (2014) for the four compartments of peat swamp forests in Malaysia (328.14 – 415.18 tons ha^{-1}) and Alibo & Lasco (2012) for the tall-pole forest of Caimpugan, Agusan Marsh with only 193.35 tons ha^{-1}. The dbh class with the greatest total plant biomass was the class ≥ 60 cm with 160.80 tons ha^{-1}, the smallest was 10.0-19.9 cm with 3.24 tons ha^{-1}. No trees less than 9.9 cm was recorded in the sample plots thus no biomass was computed. The contribution of total biomass was observed greatest (31.28%) for ≥ 60 cm class followed by the 40.0-49.9 cm class. The swamp forest of Sitio Bataran has a very dense ground cover composed of *Pandanus spp* and *Saccharum spp* therefore hard to access and remained pristine and old growth.

Table 2. Tree biomass of trees in the tall-pole swamp forest of Agusan Marsh.

DBH Class (cm)	AGB (t/ha)	BGB (t/ha)	TB (t/ha)	TCS (t/ha)	CO_2Seq (t/ha)
≤ 9.9	0.00	0.00	0.00	0.00	0.00
10.0-19.9	2.82	0.42	3.24	1.62	5.95
20.0-29.9	35.78	5.37	41.14	20.57	75.42
30.0-39.9	68.39	10.26	78.65	39.32	144.17
40.0-49.9	115.84	17.38	133.21	66.61	244.20
50.0-59.9	84.33	12.65	96.98	48.49	177.78
≥ 60	139.83	20.97	160.80	80.40	294.77
Total	**446.98**	**67.05**	**514.03**	**257.01**	**942.29**

4.2 Carbon storage potential of the tall-pole forest

The total carbon stock of the forest area quantified from this study was 257.01 tons C ha^{-1}. The value was relatively higher compared to the findings of peat swamp studies in Malaysia with

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236.51 tons C ha^{-1} (Mohd Afzanizam, 2019) but lower compared to the peat swamps of Indonesia (Murdiyarso et al., 2014) with mean total C-stock of 894.3 tons ha^{-1}. For studies conducted in the Philippines, Alibo & Lasco (2012) found out that the total carbon stock of tall-pole forest in Caimpugan, Agusan del Sur was 87.01 tons ha^{-1} for standing trees. Coracero and Malabrigo (2020) likewise recorded a total carbon stock of 306.48 tons C ha^{-1} but the study was conducted in an ultramafic forest in the Province of Arora.

A number of carbon storage potentials studies conducted in the Philippines are also available online. Dida et al. (2021), estimated carbon storage on the three selected watersheds in Laguna using the carbon storage and sequestration model of Integrated Valuation and Ecosystem Services and Tradeoffs (InVEST) software. With the aid of GIS technology, the study revealed that the total carbon stocks of Silang-Santa Rosa watershed have decreased from 120,113 tons in 2010 to 82,228 tons in 2018. Castillo et al. (2018) likewise quantified carbon stocks in the mangrove forest in Honda Bay and found out that mangroves can store an average of 47.9±5.1 tons C ha^{-1}.

Table 3. Overall and per plot values of species richness, species density and carbon stock.

Plot No.	Species Richness	Species Density (trees ha^{-1})	Carbon Stock
Plot 1	28	60	40.48 tons
Plot 2	27	62	40.55 tons
Plot 3	18	54	32.73 tons
Plot 4	18	66	24.01 tons
Plot 5	17	89	34.03 tons
Plot 6	23	64	22.04 tons
Overall	90	395	193.84 tons

The carbon stock value per sampling plot ranges from 22.04 to 40.55 tons with Plot 2 recording the highest (Table 3), the overall total of the area was 193.84 tons. Using JASP (Version 0.14), the relationship of total carbon stock with species richness and species density was tested in the regression analysis. A linear regression was conducted to examine how well species richness and species density could predict total carbon stocks. An analysis of standard residuals showed that the data contained no outliers (Std. Residual Min. = -1.67, Std. Residual Max. = 0.99) for species richness and (Std. Residual Min. = -1.29, Std. Residual Max. = 1.02) for species density.

Independence of residual errors was confirmed with a Durbin-Watson test (d = 2.199) for species richness and (d = 1.344) for species density. Results showed that the relationship of total carbon stocks with species richness F (1, 4) = 1.597, p = 0.275 (R^2 = 0.285) and with species density F (1, 4) = 0.012, p = 0.918 (R^2 = 0.003) (Figure 4 and 5) were both not significant to predict total carbon stock accounting to only 28.5 % and 0.3 % of the variability in carbon stocks, respectively. Pragasan (2014) however found a significant strong positive relationship between carbon stock and species density (R^2 = 0.689), while no significant relationships was observed between carbon stock and tree diversity (R^2 = 0.422) and with the altitude of the forest (R^2 = 0.399) in the Chitteri Reserve Forest, India.

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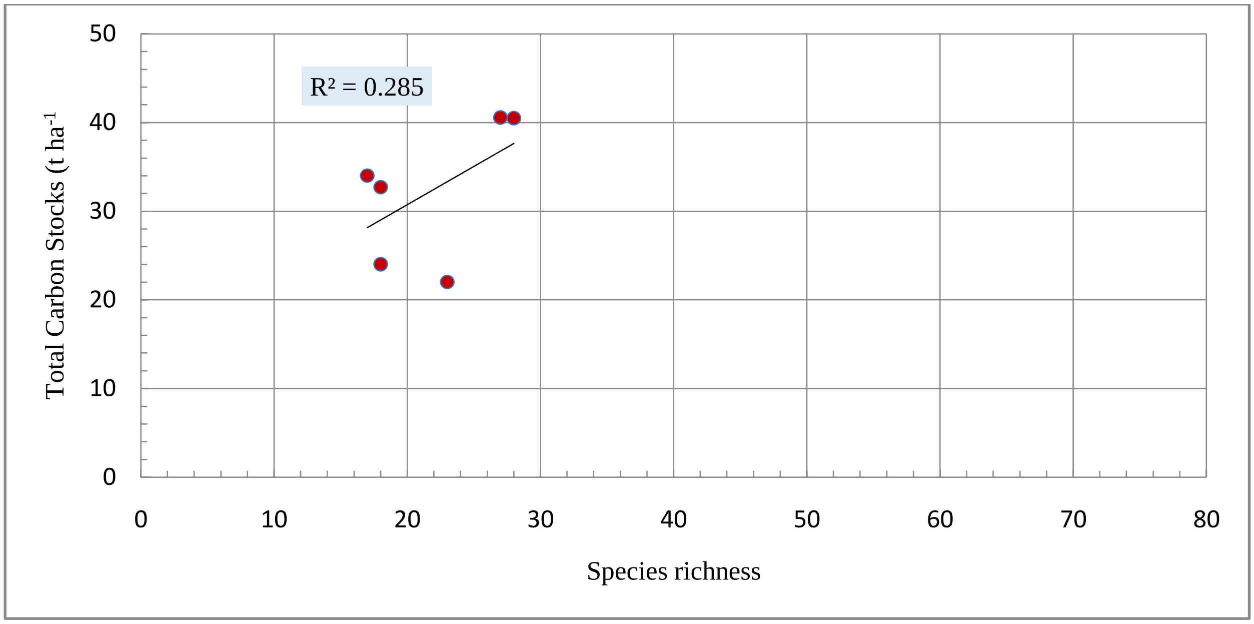

Figure 4. Regression analysis between tree carbon stock and species richness.

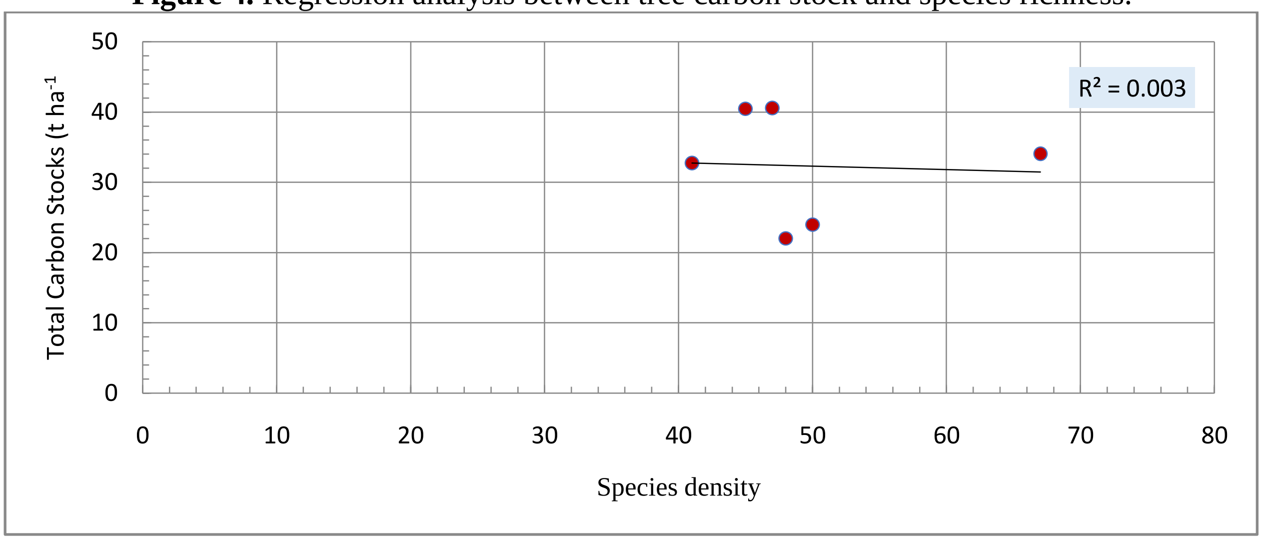

Figure 5. Regression analysis between tree carbon stock and species density.

4.3 Carbon stock and CO2 sequestered by indigenous tree species

Among the 67 different tree species identified, the contribution of *Calophyllum inophyllum*to the total carbon stock was high (11.2 %), followed by *Palaquium pinnatinervium*(7.5 %), *Aglaia sp* (5.9 %), *Vitex parviflora* (4.6 %) and *Lithocarpus celebicus*(4.4 %) (Table 4). However in terms of carbon stock per individual tree, *Dipterocarpus grandiflorus* recorded the highest carbon stock with 2.66 tons, followed by *Mangifera caesia* (1.94 tons), *Saribus rotundifolius* (1.81 tons) and *Shorea guiso* (1.78 tons). These trees were the largest and the tallest recorded in the tall-pole forest therefore have the highest biomass and carbon stored.

About four species identified were reported in the IUCN Redlist (IUCN 2021-1) as Nearly Threatened (*Garcinia rubra*), Vulnerable (*Shorea quiso*), and Endangered (*Pterocarpus indicus* and *Syzygium zeylanicum*), the rest were Least Concern and Not Assessed. Since the survey was conducted during the dry months of the year, access to the area was quite difficult and hence,

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likely there are more important threatened and endangered species present in the area may have been missed and not recorded.

The tall-pole forest covers only a small portion of the whole Agusan Marsh's fresh water swamp forest. Though small it is, the amount of CO_2 sequestered by the tree species was moderately high accounting to 710.67 tons or 942.28 tons ha^{-1}. The carbon sequestration and storage potential of the tree vegetation of this study is well within the limits of similar ecosystems reported worldwide. The study proved that trees in natural ecosystem like peat swamps acts as storehouse of carbon by storing carbon in their tissues as biomass and thereby reducing the concentration of atmospheric CO_2 a great potential of curbing the increasing concentration of greenhouse gas in the atmosphere.

Table 4. Biomass, carbon stocks and the estimated CO_2 sequestered values of the indigenous trees in the tall-pole forest of Sitio Bataran, Agusan Marsh.

Scientific Name (Family Name)	**No. of trees**	**AGB**	**BGB**	**TB**	**TCS**	**CO_2 Seq**
Calophyllum inophyllum L. (Clusiaceae)	37	37.88	5.68	43.56	21.78	79.86
Palaquium pinnatinervium Elmer ((Sapotaceae)	26	25.39	3.81	29.20	14.60	53.53
Aglaia sp.(Meliaceae)	19	19.97	2.99	22.96	11.48	42.09
Vitex parviflora Juss. (Lamiaceae)	10	15.64	2.35	17.98	8.99	32.97
Lithocarpus celebicus (Miq.) Rehder (Fagaceae)	8	14.84	2.23	17.06	8.53	31.28
Syzygium merrittianum (C.B.Rob.) Merr. (Myrtaceae)	9	13.09	1.96	15.05	7.52	27.59
Glochidion woodii Merr. (Phyllanthaceae)	11	10.85	1.63	12.48	6.24	22.87
Dillenia philippinensis Rolfe (Dilleniaceae)	7	9.65	1.45	11.10	5.55	20.34
Garcinia rubra Merr. (Clusiaceae)	6	8.65	1.30	9.95	4.98	18.24
Cananga odorata (Lam.) Hook.f. & Thomson (Annonaceae)	5	8.59	1.29	9.88	4.94	18.11
Cratoxylum sumatranum (Jack) Blume (Hyperiaceae)	7	8.47	1.27	9.75	4.87	17.86
Macaranga hispida (Blume) Müll.Arg. ((Euphorbiaceae))	7	8.04	1.21	9.25	4.62	16.95
Albizia saponaria (Lour.) Miq. (Fabaceae)	6	7.84	1.18	9.02	4.51	16.53
Tristaniopsis micrantha (Merr.) Peter G.Wilson & J.T.Waterh.	6	7.06	1.06	8.12	4.06	14.88
Leucosyke capitellata Wedd. (Urticaceae)	4	6.45	0.97	7.41	3.71	13.59
Ficus variegata Blume (Moraceae)	4	6.13	0.92	7.05	3.52	12.92
Alphitonia philippinensis Braid(Rhamnaceae)	6	5.96	0.89	6.86	3.43	12.57
Allophylus cobbe (L.) Raeusch. (Sapindaceae)	3	5.56	0.83	6.39	3.20	11.72
Elaeocarpus cumingii Turcz. (Elaeocarpaceae)	4	5.30	0.80	6.10	3.05	11.18
Commersonia bartramia (L.) Merr. (Malvaceae)	2	5.23	0.78	6.02	3.01	11.03
Archidendron clypearia (Jack) Nielsen(Fabaceae)	3	5.03	0.75	5.79	2.89	10.61
Macaranga bicolor Müll.Arg. (Euphorbiaceae)	3	4.92	0.74	5.66	2.83	10.37
Dipterocarpus grandiflorus (Blanco) Blanco (Dipterocarpaceae)	1	4.62	0.69	5.31	2.66	9.74
Pterocarpus indicus Willd. forma indicus (Fabaceae)	5	4.56	0.68	5.24	2.62	9.61
Artocarpus altilis (Parkinson) Fosberg (Moraceae)	4	4.50	0.67	5.17	2.59	9.49
Xantophyllum excelsum Miq. (Polygalaceae)	4	4.49	0.67	5.17	2.58	9.47
Areca catechu L. (Arecaceae)	4	4.35	0.65	5.00	2.50	9.17
Pterospermum sp. (Malvaceae)	2	4.10	0.61	4.71	2.36	8.64
Kleinhovia hospita L. (Malvaceae)	3	3.40	0.51	3.91	1.96	7.17
Mangifera caesia Jack (Anacardiaceae)	1	3.37	0.51	3.88	1.94	7.11
Artocarpus blancoi (Elmer) Merr. (Moracea)	2	3.35	0.50	3.85	1.93	7.06
Milletia elliptica (Roxb.) Steud. (Fabaceae)	2	3.35	0.50	3.85	1.93	7.07
Nephelium lappaceum L. (Sapindaceae)	2	3.34	0.50	3.84	1.92	7.04
Saribus rotundifolius (Lam.) Blume (Arecaceae)	1	3.15	0.47	3.62	1.81	6.64

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Shorea guiso Blume (Dipterocarpaceae)	1	3.10	0.46	3.56	1.78	6.53
Ficus balete Merr. (Moraceae)	1	3.02	0.45	3.47	1.73	6.36
Barringtonia racemosa (L.) Spreng. (Lecythidaceae)	4	2.99	0.45	3.43	1.72	6.30
Mitragyna rotundifolia (Roxb.) Kuntze (Rubiaceae)	5	2.95	0.44	3.39	1.70	6.22
Tristaniopsis decorticata (Merr.) Peter G.Wilson & J.T.Waterh.	3	2.88	0.43	3.31	1.66	6.07
Alangium javanicum (Cornaceae)	2	2.75	0.41	3.16	1.58	5.80
Ormosia calavensis Blanco (Fabaceae)	3	2.72	0.41	3.12	1.56	5.73
Octomeles sumatrana Miq. (Tetrameliaceae)	1	2.67	0.40	3.07	1.53	5.62
Premna odorata Blanco (Lamiaceae)	2	2.35	0.35	2.71	1.35	4.96
Garcinia vidalii Merr. (Clusiaceae)	2	1.97	0.30	2.27	1.13	4.16
Litsea perrottetii (Blume) Fern.-Vill. *(Lauraceae)*	3	1.84	0.28	2.12	1.06	3.88
Nauclea orientalis (L.) L. (Rubiaceae)	3	1.72	0.26	1.98	0.99	3.63
Myrica javanica Blume (Lauraceae)	2	1.48	0.22	1.71	0.85	3.13
Ficus benguetensis Merr. (Moraceae)	2	1.42	0.21	1.64	0.82	3.00
Canarium ovatum Engl.(Burceraceae)	3	1.38	0.21	1.59	0.79	2.91
Lagerstroemia speciosa (L.) Pers. (Lythraceae)	2	1.36	0.20	1.56	0.78	2.87
Parashorea malaanonan (Blanco) Merr. (Dipterocarpaceae)	1	1.35	0.20	1.55	0.78	2.85
Xylopia ferruginea (Hook.f. & Thomson) Baill. (Annonaceae)	3	1.17	0.18	1.35	0.67	2.47
Canarium hirsutum Willd (Burceraceae)	1	1.16	0.17	1.34	0.67	2.45
Barringtonia acutangula (L.) Gaertn. (Lecythidaceae)	1	1.06	0.16	1.22	0.61	2.23
Colona serratefolia Cav. (Malvaceae)	3	1.06	0.16	1.22	0.61	2.24
Ficus nota(Blanco) Merr. (Moraceae)	3	1.05	0.16	1.21	0.60	2.21
Syzygium zeylanicum (L.) DC (Myrtaceae)	1	1.04	0.16	1.20	0.60	2.20
Pandanus copelandii Merr. (Pandanaceae)	8	0.89	0.13	1.02	0.51	1.87
Cinnamomum mercadoi Vidal (Lauraceae)	2	0.77	0.12	0.89	0.44	1.63
Shorea negrosensis Foxw. (Dipterocarpaceae)	1	0.68	0.10	0.78	0.39	1.44
Teijsmanniodendron ahernianum (Merr.) Bakh. (Lamiaceae)	3	0.68	0.10	0.78	0.39	1.43
Ziziphus talanai (Blanco) Merr.(Rhamnaceae)	2	0.57	0.09	0.66	0.33	1.20
Cerbera manghas L. (Apocynaceae)	1	0.48	0.07	0.56	0.28	1.02
Symplocos cochinchinensis (Lour.) S. Moore (Symplocaceae)	1	0.48	0.07	0.56	0.28	1.02
Homolanthus populneus (Geiseler) Pax (Euphorbiaceae)	2	0.46	0.07	0.53	0.26	0.97
Myristica philippensis Lamk (Myristicaceae)	1	0.25	0.04	0.29	0.14	0.52
Mangifera indica L. ((Anacardiaceae))	2	0.22	0.03	0.26	0.13	0.47
Totals	**298**	**337.11**	**50.57**	**387.68**	**193.84**	**710.67**

**Legend: AGB-above ground biomass, BGB-below ground biomass, TB-total biomass, TCS-total carbon stored*

5. Conclusions

The average total tree biomass in this study was found to be much higher than what were previously reported for tall-pole peat swamp forest in other areas. Among the inventoried tree species, five tree species were identified to have contributed the greatest total carbon stock in the study area namely: *Calophyllum inophyllum* (11.2%), *Palaquium pinnatinervium*(7.5 %), *Aglaia sp* (5.9 %), *Vitex parviflora* (4.6 %) and *Lithocarpus celebicus*(4.4 %). But in terms of carbon stock per tree, *Dipterocarpus grandifloras* (2.66 tons), *Mangifera caesia* (1.94 tons), *Saribus rotundifolius* (1.81 tons) and *Shorea guiso* (1.78 tons) were the highest which also corresponds to the largest size among observed trees in the surveyed plots. Four important tree species were also found to have been reported either as nearly threatened, vulnerable and endangered tree species. Linear regression analysis for the relationship of species richness and species density with carbon stocking were found to be not significant. Overall, the CO_2 sequestered by tall-pole forest in Agusan Marsh was classified as moderately high accounting to about 942,28 tons ha^{-1} highlighting the relative importance of this subtype forest as storehouse of carbon in this wetland ecosystem.

The Agusan Marsh Wildlife Sanctuary has been declared a protected landscape; however, the local people have used the area as unlimited access to firewood collection and land conversion for agriculture, apart from unreported illegal extraction of timber and non-timber resources. Hence, restoration of the already slowly degrading fresh water swamp forest through assisted regeneration may be a necessary option in the future to enhance the total carbon sequestration and storage potential of the forest vegetation. Furthermore, it might also be necessary to conduct awareness programs for the local people in this regard.

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Conflict of interest

The authors declare no conflict of interest in this paper

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