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An assessment of tree biodiversity and carbon stocks in mangrove forests, Langsa City, Aceh, Indonesia

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Abstract. Mangrove forests are a unique coastal ecosystem with trees adapted to a constantly fluctuating and sometimes extreme physical environment. Mangrove forests provide important ecosystem services that benefit local people and all of us in terms of climate regulation through the storage of greenhouse gasses in biomass. This research reports carbon stock, wood volume, tree density, and biodiversity indices for two mangrove forest areas in Langsa City Regency, Aceh Province, Indonesia. The two sites represent and inland area and an ocean-exposed area within a large mangrove forest ecosystem complex. The results of the analysis show that these two tracts are quite similar in terms of carbon stock and biodiversity even though they occupy different locations within the larger tract of mangrove habitat. The study confirms these are healthy forest areas with relatively high carbon stocks.

1. Introduction

Mangrove forests are a unique coastal ecosystem. Mangroves include tree species that have adapted and evolved to thrive in a rather harsh environment. Soft, muddy soil, salty brackish water, fluctuating tide water levels, and pounding ocean waves characterize the conditions where mangrove forests grow. Few species of plants are capable of surviving in such conditions, which include extreme variations (1) in salinity where rivers carrying freshwater empty into the ocean saltwater and (2) between the outer band of vegetation facing the sometimes high-intensity ocean weather and the calmer inland mangrove areas.

These unique forest ecosystems are vegetation barriers that provide several ecosystem services. Mangroves maintain coastal stability by preventing coastal erosion from wind, waves, and storm surges, prevent inland saltwater intrusion, provide habitat for marine biota, and absorb and filter waste at the coastal edge [1,2]. The outer band of vegetation takes the brunt of wind and water storm surges protecting inland areas. Mangroves around river estuaries trap soil and nutrient runoff carried downstream preventing it from entering the ocean system [3,4]. Mangrove tight and strong rooting helps maintain the mud substrate and slows the movement of sea tides deep into the land area and introduces the subsurface layer (preventing substrate of the ground) [5].

The socio-economic benefits of these mangrove ecosystem services to local communities should not be underestimated. As a natural vegetation barrier, mangroves protect against damages and loss of life from tsunamis and tropical storms. Root structures that trap river silt and nutrient runoff protect ocean fisheries from algae blooms. The trapped particulates also provide food for species living in and around the mangrove root structures which provide safe breeding habitat for several marine species from predators [1]. Many of the mangrove marine species are caught and gathered by local people for direct dietary consumption and economic benefit. The prevention of inland saltwater intrusion protects the productivity of nearby agricultural lands upon which livelihoods are dependent.

Mangrove forests differ greatly compared to other tropical forest ecosystems. The physical structure of mangrove trees, especially their root structures are adapted for the soft soil and fluctuating levels of tidewaters. The tree species composition in mangroves is less diverse and the growth rate of mangrove trees is slower, which also means the tree wood is quite dense. Tree species diversity may be low in mangrove systems; however, the overall species biodiversity is high as the mangroves provide a coastal habitat for a rich diversity of marine life: fish, shellfish, birds, and other flora and fauna [6].

This research focuses on two tracts of mangrove forest in a 7,837-hectare mangrove ecosystem complex [7] north and west of Langsa City, Aceh Province, Indonesia. This area is the estuary of the Puah River. One 10-ha site is in the interior of the mangrove complex near the river and the site other is a 40-ha area on Telaga Tujuh Island, located on the outer west side of the mangrove complex facing the ocean (see figure 1). Both areas are dominated by *Rhizophora apiculate* known locally as "Bangka Minyak". The research aims to compare the carbon stock and species diversity in these two mangrove areas in support of local efforts at developing forest management plans that include two important forest ecosystem services, (1) carbon storage and sequestration reducing greenhouse gas (GHG) emission to the atmosphere and (2) ecosystem health in terms of mangrove tree biodiversity.

Figure 1. Location of the study site areas (A) overview map, (B) Site 2 Telaga Tujah Island, (C) Site 1 inland mangrove site near the ecotourism area

2. Methods

2.1. Description of the study site

The nearly 8000-ha mangrove forest area located in Langsa City Regency is part of the KPH Region III working area, managed by the technical implementation unit of the Forest Management Unit Service (UPTD KPH) in cooperation with community groups, NGOs, and local people. This area includes RPH Kuala Langsa, BKPH mangrove unit of KPH Region III Aceh province. Management activities consist of extraction of non-timber forest products, silvofishery, and ecotourism. Within the large mangrove area, two sites were selected. One site is on the outer edge, 40-ha Telaga Tujuh Island. The second site is in the interior and is a 10-ha tract of forest near the mangrove ecotourism site.

2.2. Data collection and analysis methods

Field inventory data were collected from sample plots dispersed through the two study site areas. Inventory plots were located on a regular grid a minimum of 50 meters apart. Tree species counts were reported in 20 x 20 m plots and seedlings in 2 x 2 m plots. Tree diameter at breast height (DBH) and total tree height were reported using a nested plot where trees > 15 cm DBH were measured in a 20 x 20 m plot, trees greater than 5 cm and less than or equal to 15 cm DBH were measured in a 10 x 10 m plot and trees greater than 2 cm and less than or equal to 5 cm DBH were measured in a 5 x 5 m plot.

Field data were input into two Excel-based tools developed by Michigan State University under the USAID LESTARI project (2015 – 2020). One tool is used to compute total tree carbon stocks (tC), wood volume (m^3 ha^{-1}), and stand density (trees ha^{-1}). The second tool is used to compute several biodiversity indices including species richness, evenness, and dominance for both trees (> 2 cm DBH) and seedlings.

Carbon calculations use an allometric equation specific to *Rhizophora apiculate* dominated mangrove forest (Eq. 1) from [8]. The allometric model uses the tree DBH to estimate total tree live biomass (kg). Carbon is computed from biomass using a factor of 0.47, the IPCC default value [9]. Carbon stock for each size class of tree in the nested plot is summed and scaled to tonnes (tC). These are summed to compute total carbon per plot and then scaled to report plot-level tC ha^{-1}. The average for all plots is computed and multiplied by the site area to estimate total carbon stock (tC).

$$B = 0.75 \times Dt^{2.23} \tag{1}$$

Where
B = total tree biomass in kg
Dt = diameter at breast height (1.3 m above ground) in cm

Wood volume (m^3) is computed using the DBH and tree height measurements in a discounted tapered cylinder equation, summed for all trees in the plot, and scaled to the hectare. The average is then computed for all plots. Using a discounted and tapered equations produced a conservative estimate for the wood volume.

$$Dw = ((^1/_4) \times ((PI) \times ((Dt/100)^2)) \times Ht) \times 0.6) \tag{2}$$

Where
Dw = wood volume in m^3
Dt = diameter at breast height (1.3 m above ground) in cm
Ht = total height of the tree in m

Stand density (tree ha^{-1}) is computed from the number of trees in the three size-class nested plots. Each size class number is scaled to the hectare level. The average density is computed for all plots in the site by tree class size.

The biodiversity tool uses species counts withing fixed area sample plots to compute several biodiversity indices for trees and seedlings. Table 1 reports the indices and the method of computation.

Table 1. Biodiversity indices and computation methods used by the tool

Indices	**Computation Method**
Species Richness	S = number of species or taxa
Menhinick's Index	D = S/(SQRT N); where S = the number of different species in the sample and N = the total number of individual organisms in the sample
Margalef's Richness Index	(S-1)/ln(N)
Shannon Index of Species Diversity	$H = -\sum_{i=1}^{s} p_i \ln p_i$; where pi = the proportion of the total number of individuals
Simpson Index of Diversity	1 - D = 1 -∑ (n / N)2; where D is the Simpson Index which measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species)
Evenness Index	Evenness = H'/lnS uses Shannon index and species richness values

3. Results

3.1. *Carbon stocks*

The carbon stocks for each plot in tC ha^{-1} are shown in Table 2. Table 3 reports the several site characteristics for the data collection and computations (number of plots, total area, plot size) and the site level carbon stocks (average tC ha^{-1} all plots, range and standard deviation of carbon all plots total tC for the site). The sample error and the range accuracy based on the number plots at 95 % confidence are also noted.

The average carbon for site 2 (269.86 tC ha^{-1}) is one and half times that of site 1 (176.22 tC ha^{-1}) and we can see from the range of carbon values in all plots that site two has a maximum carbon value (418.60 tC ha^{-1}) that is nearly two times the amount of carbon reported in the site 1 plot with the maximum amount of carbon (213.38 tC ha^{-1}). The total estimated carbon stock in site 2 is six times that of site 1 even though the area of site 2 is only four times that of site 1. The accuracy of the carbon estimate is slightly higher in site 1 than in site 2 and this is based on the number of sample plots, the size of the sample plots, and the variation of carbon across the sample plots.

Table 2. Plot level carbon stock for two sites

Plot ID	**Site 1 (tC ha^{-1})**	**Site 2 (tC ha^{-1})**
Plot 1	147.98	207.27
Plot 2	176.25	337.53
Plot 3	181.70	418.60
Plot 4	213.38	187.35
Plot 5	161.80	236.69
Plot 6	-	366.34
Plot 7	-	270.89
Plot 8	-	219.99
Plot 9	-	297.71
Plot 10	-	156.20

Table 3. Summary statistics for site-level carbon socks

	Site 1	**Site 2**
Area of the site (ha)	10	40
Number of plots (n=)	5	10
Plot size (ha)	0.04	0.04
Sampling error (95%)	5.20	4.32
Average carbon (tC ha^{-1})	176.22	269.86
Range of carbon for plots (tC ha^{-1})	147.98 – 213.38	156.20 – 418.60
Standard deviation (tC ha^{-1})	24.58	84.34
Carbon stock (tC)	1,762.22	10,794.26
At 95% confidence level of accuracy for the number of plots	Between 10 – 15 %	Between 15 – 20 %

3.2. Wood volume and stand density

The summary of trees by size class in terms of the number of trees in the sample plots, wood volume, and tree density is shown in table 4. The size-class distribution of trees for both sites is heavily skewed to the largest size class, trees greater than 15 cm DBH, compared to poles and saplings. The number of trees per plot by size class, however, is somewhat deceiving since, data are collected in nested plots of 5 x 5 m (saplings), 10 x 10 m (poles), and 20 x 20 m (large trees). The table lists in parentheses for samplings and trees and estimated number for 20 x 20 m plots based on the observed or actual number nested plot. Overall average wood density for all trees (m^3 ha^{-1}) is higher in site 2 by one and has times that of site 1. In both sites, large trees account for 90 % of the total average tree wood volume. In terms of tree density, site 1 and site 2 have nearly an equal number of trees per hectare in the pole-size class, but site 2 has more trees per hectare in the sapling and large tree class size by 66 % and 62 % respectively.

Table 4. Wood volume and tree density for two sites by tree size class

	Site 1	**Site 2**
Number of saplings (all plots) (n=)	1 (4)	2 (8)
Number of poles (all plots) (n=)	12 (24)	23 (46)
Number of trees (all plots) (n=)	86	281
Number of trees all size class (all plots) (n=)	99	307
Average wood volume (2 – 5 cm) (m^3 ha^{-1})	0.20	1.26
Average wood volume (5 – 15 cm) (m^3 ha^{-1})	30.42	39.99
Average wood volume (> 15 cm) (m^3 ha^{-1})	247.68	399.63
Average wood volume (all trees) (m^3 ha^{-1})	278.30	440.88
Average density (2 – 5 cm) (tree ha^{-1})	80	120
Average density (5 – 15 cm) (tree ha^{-1})	240	230
Average density (> 15 cm) (tree ha^{-1})	430	690

3.3. Biodiversity

The number of individual trees and seedlings observed in each sample plot are listed in Table 5. In site 1 seedlings are only observed in three of five sample plots and one plot contains more than 50% of the total observed. Trees in site 1 are observed on all five plots and are fairly evenly distributed. In site 2 seedlings are observed in 6 of the 10 plots, the same percentage of plots as in site 1. In site two one seedling plot contains 50% of all seedlings observed, similar again to site 1. Trees in site 2 range from a count of 13 to 43 individuals and trees are observed in all 10 plots.

Table 6 lists the several biodiversity indices computed for the two sites as well as the dominant species for trees greater than 2 cm DBH and seedlings. As to be expected in a healthy mangrove system the tree species richness and biodiversity indices show low values. Each site is dominated by the species *Rhizophora apiculate*.

Table 5. Number of individuals observed for each plot

	Site 1		**Site 2**	
	Trees	**Seedlings**	**Trees**	**Seedlings**
Plot 1	13	15	38	1
Plot 2	19	0	37	0
Plot 3	20	0	29	2
Plot 4	22	1	13	2
Plot 5	19	7	35	2
Plot 6	-	-	30	0
Plot 7	-	-	29	2
Plot 8	-	-	26	0
Plot 9	-	-	43	0
Plot 10	-	-	20	7

Table 6. Biodiversity indices for trees and seedlings

	Site 1		**Site 2**	
	Trees (n=93)	**Seedlings (n=23)**	**Trees (n=300)**	**Seedlings (n=16)**
Species Richness	3	3	2	2
Menhinick's Richness Index	0.31	0.63	0.12	0.50
Margalef's Richness Index	0.44	0.64	0.18	0.36
Shannon Index	0.34	0.00	0.10	0.56
Simpson Index of Diversity	0.16	0.00	0.04	0.40
Evenness	0.31	0.00	0.14	0.81
Dominant species	*R. apiculate* *R. mucronate* *A. rumphialis*	*R. apiculate*	*R. apiculate* *R. mucronate*	*R. apiculate* *R. mucronate*

4. Discussion

The two-sample study areas are only small tracts of forests totaling 50 hectares within a very large (~8,000 ha) mangrove complex at the estuary of the Puah River in Langsa City Regency, Aceh province, Indonesia. They represent two areas within the mangrove habitat here that form a barrier between the open ocean and the inlands where there are agricultural fields and populated areas. The inner area, site 1, and the outer area, site 2, geographically represent distinct spaces withing the mangrove system. We might expect to observe several extreme differences as one area is exposed directly to the ocean waves and winds and the other is not. However, while some differences exist overall these two areas are quite similar in their tree species composition and the size class distribution of mangrove trees. The dominant species in both sites is *Rhizophora apiculate* followed by *Rhizophora mucronate*. The size class distribution in both sites is dominated by the larger tree size class, greater than 15 cm DBH, contributing to around 90% of the total wood volume for each site. Also similar is the observed seedling allocation and distribution across the plots within each site. One plot in each area contains at least 50% of all observed seedlings and just over half of the plots contain seedlings. The two sites also have similar tree biodiversity index values common among healthy mangrove forest ecosystems.

Some differences do exist between the two sites. In site 1, we observe the presence of a third mangrove tree species, *Avicenia rumphialis*, that is not seen at site 2. Site 2 is denser in terms of the number of trees per hectare and wood volume and as would be expected from these two factors, has a higher average carbon stock value than site 1. Table 7 provides a comparison of the field computed carbon estimated in the two sites with the IPCC reported factors of mangrove forests in tropical wet regions of the world [10]. The estimated average carbon for both sites easily falls within the wide range of carbon stock values reported by the IPCC. Site 1 is below the IPCC average by 48.47 tC ha^{-1} while the average for site 2 is higher than the IPPC average by 45.17 tC ha^{-1}. These comparisons with the IPCC highlight again that mangrove habitat for both sites in the study area is quite healthy.

Table 7. Comparison of site carbon estimates to IPCC

			IPCC
	Site 1	**Site 2**	**Tropical Wet Region**
Aboveground biomass (t dry matter ha^{-1}). Average (Range)			192 (8.7 – 384)
Aboveground biomass (tC ha^{-1}). Average (Range)			90.24 (4.01 – 180.48)
The ratio of belowground biomass to aboveground biomass. Average			0.49
Below ground biomass (tC ha^{-1}). Average (Range)			134.46 (5.97 – 268.91)
Total live biomass (tC ha^{-1}). Average	176.22	269.86	224.69 (23.99 – 449.40)

5. Conclusion

The results of this study emphasize the value of analyzing field inventory data in mangrove forests to report ecosystem services level data and information. In this study, we report carbon stock and biodiversity. Carbon stock and biodiversity provide an important measure of the health of a forest. Tree biodiversity as reported in the two study sites while quite low is an indicator of a healthy mangrove forest ecosystem. Other studies that expand biodiversity measurements to include non-tree biota would be useful as well since these measures would likely show the rich nature of mangrove habitat in terms of the wide range of flora and fauna. The carbon stock estimates are important to show the value these forests play in storing greenhouse gasses in their biomass, avoiding emissions to the atmosphere which drive climate change. Repeat measurements to report changes in carbon stock would also be important to understand if these areas are increasing their sequestration in carbon over time or emitting carbon. The fluxes of carbon from tree growth or tree loss are important to track for developing management plans for these forest areas. Since the two sites are ecotourism areas, reporting the value of these forests in terms of carbon stocks to visitors would add to their knowledge and perhaps contribute to the conservation management of the mangrove forest.

Finally, the importance of including local communities, especially those, who benefit directly from the mangrove forests in Langsa City Regency, cannot be over-emphasized. The residence, for example, who resides on nearby Pusung Island, benefits from the shelter protection the mangroves on Telaga Tujuh Island provide. This community reveres Telaga Tujuh is a sacred island where the graves of the ancients are located. Telaga Tujuh Island is represented in several local folklore tales securing it as a sacred place in the culture of the local people.

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