Species Diversity, Biomass and Carbon Stock Assessment of Kanhlyashay Natural Mangrove Forest

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Abstract: Mangrove ecosystems sequester and store large amounts of carbon in both biomass and soil. In this study, species diversity, the above- and below-ground biomass as well as carbon stock by the mangroves in Kanhlyashay natural mangrove forest were estimated. Six true mangrove species from four families were recorded in the sample plots of the study area. Amon them, *Avicennia officinalis* L. from the Acanthaceae family was the abundant of species with an importance value of 218.69%. Shannon-Wiener's diversity index value (H'=0.71) of the mangrove community was very low compared to other natural mangrove forests since the mangrove stands in the study site possessed a low number of mangrove species and were dominated by a few species. Estimated mean biomass was 333.55 ± 181.41 Mgha^{-1} (AGB = 241.37 ± 132.73 Mg ha^{-1}, BGB = 94.17 ± 48.73 Mgha^{-1}). The mean overall C-stock of the mangrove stand was 150.25 ± 81.35 Mg C ha^{-1} and is equivalent to 551.10 ± 298.64 Mg CO_2-eq. The role of forests in climate change is two-fold as a cause and a solution for greenhouse gas emissions. The result of the study demonstrated that the mangroves in LetKhutKon village have high carbon storage potential, therefore it is necessary to be sustainably managed to maintain and increase carbon storage. Climate change mitigation may be achieved not only by reducing the carbon emission levels but also by maintaining the mangrove ecosystem services as carbon sinks and sequestration.

Keywords: biomass; carbon stock; allometric models; natural mangrove forest; Myanmar

1. Introduction

Mangrove forests are one of the most productive and diverse ecosystems in the world and provide significant ecological, economic, and social benefits (Myint et al., 2008). The ecological benefits supported by the mangrove forests are bio-protection from littoral erosion (Abino, Castillo, et al., 2014; Naylor et al., 2002), shoreline stabilizations, reducing the devastating impact of hurricanes, waves, and tsunamis, and protection from cyclones (Abino, Castillo, et al., 2014; Alongi, 2002). Additionally, mangrove ecosystems have a high carbon sequestration capacity, which is reflected in high aboveground biomass, high net primary production (NPP), the low decomposition rate of mangroves sediments, and belowground to aboveground biomass ratio (Alongi, 2008; Donato et al., 2011; Lovelock, 2008; Rasquinha & Mishra, 2021). Mangrove forests have a critical role in climate change mitigation because they are able to absorb and store 3-5 times more carbon than other upland forests, mainly in soil (Donato et al., 2011). Despite accounting <1% of the world's tropical forest area (Alongi, 2014), mangroves account for 3-4% of global carbon sequestration by the total tropical forest area (Alongi, 2014), mangroves account for 3-4% of global carbon sequestration by the total tropical forest area (Alongi, 2020; Bhomia et al., 2016) and contribute 10-15% to the carbon sequestered by the world's ocean (Alongi, 2014). Globally, the average carbon stock of the mangrove ecosystem is 1023 Mg ha^{-1} (Donato et al., 2011); consequently, mangrove ecosystems are now being recognized for their pivotal role in global climate change mitigation. Concerning the characteristics of high carbon reservation and huge ecological benefits, mangrove ecosystems are eligible for inclusion in the United Nation's Reduce Emissions from Deforestation and Forest Degradation and to Enhance Carbon Stocks (REDD+) strategies (Kankare et al., 2013) as well as the payments for ecosystem services (PES) (Kosoy & Corbera, 2010) initiatives that are emerging in many countries. On the other side, the deforestation rate of mangrove forests is still higher than inland terrestrial forests. Globally, it is estimated that mangrove forests have been lost with an annual average rate of 0.16% to 0.39% (Friess et al., 2019) and pose a significant risk to carbon emissions as a consequence of mangrove deforestation.

Mangrove forests in Myanmar grow along the 2832 km-long coastlines, oriented along the Bay of Bangal and the Andaman Sea (Veettil et al., 2018). The total area of mangroves in Myanmar reaches 3.3% of the total area of mangroves of the world (Spalding, 2010; Veettil et al., 2018), and mangrove forest types can be divided into the Delta Mangrove and Coastal Mangrove (Oo, 2002). Mangrove ecosystems provide important services such as ecological, economic, and environmental benefits to local people; however, mangrove coverage in Myanmar has decreased by more than half of the total mangrove area over the past three decades. Myanmar is regarded as the current mangrove deforestation hotspot globally (De Alban et al., 2020) with the highest annual rates (~1%) of mangrove e deforestation and third-highest potential annual CO_2 emissions (784 kg CO_2-eq yr^{-1} (GGGI, 2019). The biggest drivers of mangrove deforestation in Myanmar are over-exploitation, illegal felling, agricultural expansion, and conversion to fish and shrimp ponds (Aye et al., 2019). The inventory of carbon stocks in mangrove ecosystems is limited, and only a few studies have quantified the carbon stocks in mangrove ecosystems is limited, and only a few studies have quantified the carbon stocks of these ecosystems in Myanmar.

Forest biomass is regarded as an important variable in quantifying the role of forests in the carbon cycle (Galidaki et al., 2017); thus, the estimation of biomass is crucial for studying the carbon cycle of the forest ecosystem. Allometric models are widely applied for biomass estimation of mangrove forests (Hashim & Suratman, 2020) and allometric equations for biomass estimation are developed by applying physical parameters of the tree, such as height, diameter at breast height, basal area, density, and their combination. The objectives of the present study were to (1) estimate the species diversity of mangrove stands, (ii) evaluate the potential of biomass and carbon stock, and (iii) explore the relationships of stand-level carbon stock to stand structural variables such as mean diameter, mean height, basal area, and their combination.

2. Materials and Methods

2.1. Description of study Site

The research was carried out in the Kanhlyashay natural mangrove forests located at the estimated coordinates 16° 21′ 26.93″ N and 96° 13′ 02.37″ E. The mangrove stands naturally reappeared on the mudflats after the Cyclone Nargis wreaked havoc in 2008. The abundant growth of mangroves lies around 1-8 m above the current level of the sea and covers approximately 197 ha (487 acres) along the banks of the sea; then, the mangroves serve as a natural barrier against natural disasters such as sea-level rise, storm surges, and floods and help minimize the damage done to property and life in the LetKhutKon village located in the Kungyanggon township of Yangon Division. The Kungyanggon natural mangrove forest has planned to designate as a protected public forest by the Forest Department, Ministry of Natural Resources and Environmental Conservation, Myanmar. The soil formation in the study site has been underlain by the intertidal mudflats that are essential habitats for many fishes as nurseries and feeding grounds. Most of the local communities in the LetKhutKon village depend on small-scale marine fisheries for their livelihood; those area has an average precipitation of 2375 mm, with an average temperature of 26.8 °C and a tropical monsoon climate (DMH, 2011). The study site was selected based on accessibility and safety in going to and from the natural mangrove stands. Additionally, this study is the first comprehensive forest inventory in the Kanhlyashay natural mangrove forests. The natural mangrove formation has been dominated by *Avicennia* *officinalis* L. in association with *Sonneratia apetala* Buch. Ham., *S. caseolaris* (L.) Engl., and *Aegiceras corniculatum* (L.) Blanco; then, *Avicennia alba* Blume and *Bruguiera sexangula* (Lour.) Poir. are rarely observed in the mangrove stand.

The fieldwork was performed from June to July 2021 during the rainy season. LetKhutKon village near the Andaman Sea has equal lengths of dry and rainy seasons. The wet season is oppressive and overcast, the dry season is muggy and partly cloudy, and it is hot year-round. Throughout the year, the temperature typically varies from 19°C to 36°C and is rarely below 17°C or above 39°C. The hottest month of the year is April with an average maximum temperature of 37°C and the coldest month is January with an average low of 19°C and a high of 32 °C. A map of the research stations was presented in Figure.1.

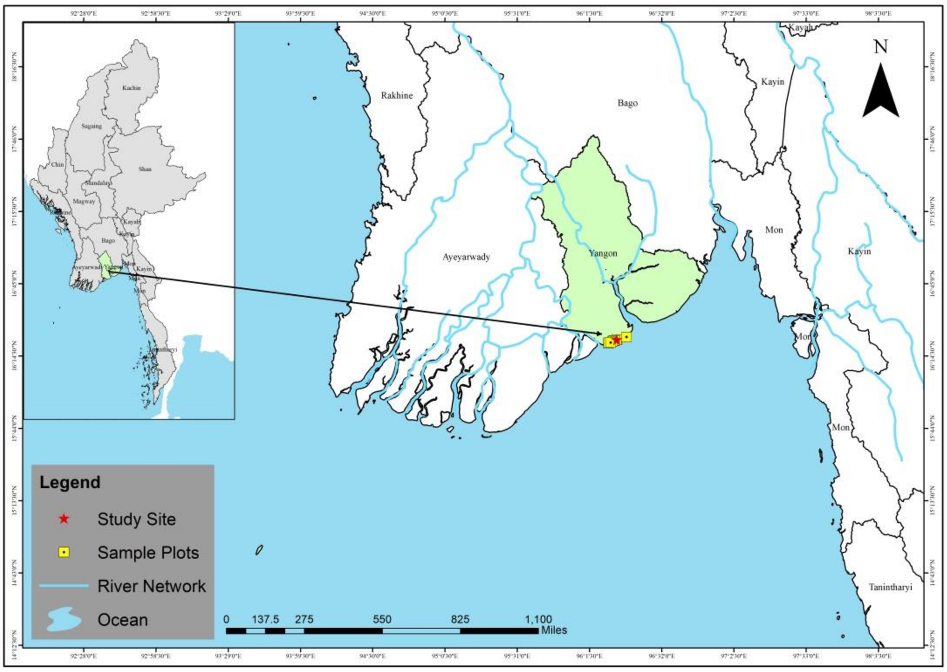

Figure 1. Location of the study site, and sampling points in the mangrove stand of Kanhlyashay natural mangrove forest

2.2. Data Collection

A total of 25 sampling plots of 400 m^2 were established through a non-destructive quadrat sampling techniques to determine the species composition, biomass, and carbon stock in the study area. The total sampling area covered was 0.5% (1 ha) of the total area. A global positioning system (GPS) was used to mark the spatial location of each sampling plot. Within each sampling plot, all trees with a diameter at breast heigh (dbh) of ≥5 cm were measured, identified, and counted. A diameter tape was used to measure the dbh; total tree heights were estimated using Suunto Clinometer. The dbh of Bruguiera and Rhizophora species were determined by measuring the trunk dimeter at 30 cm above the buttress and above the highest prop root, respectively, whereas the dbh of the rest was measured at 130 cm aboveground (Asadi et al., 2018). The distribution of stand density, species composition, biomass, and carbon stock per plot of the natural mangrove stand in the Letkhutkon village was described in Table.1.

Table 1. Distribution of stand density, biomass, carbon stock, and CO_2 equivalent in the natural mangrove stand, LetKhutKon Village

Plot	Stand Density (Stems ha^{-1})	Species	DBH range (cm)	Height Range (m)	Basal Area (m^2 ha^{-1})	Biomass (Mg ha^{-1})			C-stock (Mg C ha^{-1})	CO_2-equivalnet (Mg CO_2 eq)
						AGB	BGB	TB		
1	1250	Ao, Sa	5.00-29.00	3.05-9.75	19.950	131.077	55.307	186.38	83.18	305.26
2	1125	Ao,Sa	8.00-34.00	3.05-8.23	21.725	145.769	61.048	206.82	92.32	338.82
3	875	Ao,Sa	5.50-34.00	2.44-7.93	26.000	214.807	83.486	298.29	135.52	490.01
4	875	Ao	5.00-35.30	2.13-8.53	19.375	159.381	62.136	221.52	99.14	363.14
5	875	Ao	5.20-31.80	2.74-8.23	25.725	211.055	82.610	293.67	131.41	482.29
6	875	Ao	5.30-37.00	2.74-8.23	33.900	294.506	111.881	406.39	182.05	668.13
7	625	Ao	16.40-40.00	5.18-9.45	42.950	405.162	147.636	552.80	248.00	910.18
8	1000	Ao	5.50-40.70	2.74-9.14	47.750	425.534	159.583	585.12	262.24	962.42
9	1625	Ao	7.60-41.20	3.05-9.14	69.125	603.928	228.753	832.68	373.06	1369.13
10	1000	Ao	6.60-37.20	4.27-9.50	30.025	248.525	96.739	345.26	154.54	567.14
11	1125	Ao	6.00-40.10	3.66-9.45	41.025	352.219	134.529	486.75	218.01	800.09
12	750	Ao	6.10-39.50	3.35-9.14	29.575	259.835	98.089	357.92	160.38	588.58
13	1375	Ao	5.00-41.30	3.05-9.14	51.650	446.873	170.086	616.96	276.36	1014.26
14	1525	Ac,Ao,Sa	5.00-26.60	2.13-8.23	17.075	113.658	49.255	162.91	72.63	266.55
15	1075	Ao,Sa	5.90-28.80	2.13-9.14	24.325	187.260	75.120	262.38	117.31	430.52
16	1875	Ao,Sa,Sc	5.10-35.60	2.13-9.50	41.225	302.509	121.188	423.70	189.44	695.26
17	975	Ao	5.50-38.80	2.13-8.84	30.275	258.542	99.003	357.55	160.13	587.66

18	2025	Ao	5.40-37.60	2.13-9.14	43.800	346.801	138.028	484.83	216.83	795.76
19	1075	Ao	6.10-29.00	3.66-8.84	22.900	171.747	70.439	242.19	108.19	397.07
20	925	Ao	8.30-23.50	3.35-8.23	17.750	126.148	53.263	179.41	80.06	293.83
21	1175	Ao,Sa,Sc	6.50-37.00	2.13-7.62	30.025	229.082	91.594	320.68	143.39	526.24
22	1075	Ac,Aa,A0,Bs,Sc	5.10-36.70	1.70-7.93	22.875	166.665	66.580	233.25	104.30	382.78
23	950	Ac,Ao,Sa	5.00-31.00	1.50-6.86	17.200	122.801	49.746	172.55	77.12	283.02
25	550	Ac,Sa	5.00-17.00	2.13-5.49	4.925	26.691	12.363	39.05	17.37	63.73
25	950	Ac,Sa,Sc	5.50-25.90	2.44-7.62	14.800	83.713	35.868	119.58	53.33	195.73
Mean			6-33-33.94	2.76-8.53	29.838	241.372	94.173	335.55	150.25	551.10
Standard deviation			2.32-6.26	0.84-0.96	14.032	132.731	48.728	181.41	81.35	298.64

Note: Ao-*Avicennia offcinalis*; So-*Sonneratia caseolaris*; Sa-*Sonneratia apetala*; Ac-*Aegiceras corniculatum*; Bs-*Bruguiera sexangular*; Aa-*Avicennia alba*

2.3. Species Composition and Diversity

Species composition and diversity were calculated based on the forest inventory data. Species composition is the number of different species in the study area; it can be described in terms of relative density (RD), relative frequency (RF), and relative basal area (RBA). The importance value index (IVI) provides an overview of the influence or role of at type of mangrove species in the community. Importance values of a species range from 0-300%, and tree species having an IVI of more than 10% were considered dominant tree species in this study. The formula used to calculate RD, RBA, RF, and IVI were listed below.

RD = (Number of individuals of a species/ Total number of individuals of all species) ×100 (1)

RBA = (combined BA of a species/ total BA of all species) × 100 (2)

RF = (frequency of a species/ sum of all frequencies) × 100 (3)

IVI = RD + RBA + RF (4)

The basal area was calculated as

$$\text{BA/ Tree (m}^2\text{)} = \frac{\pi \times DBH^2 \times 0.0001}{4} \quad (5)$$

where, π = a constant (3.146); DBH -diameter at breast height (cm), 0.0001 is a constant used to convert the measured centimeter square into meter square.

$$\text{Total Stand Basal Area (m}^2\text{/ha)} = \frac{\text{Sum of basal area for each tree}}{0.04} \quad (6)$$

$$= \text{Sum of basal area} \times 25$$

where, 0.04 is plot size in hectare and 25 is a constant used to extrapolate the measurement of the basal area from per plot (m2/plot) to per hectare (m^2/ha).

The species diversity index, determined in this study using the Shannon-Wiener's Index (Tufillaro et al., 1995), indicate a qualitative description of mangrove habitant in terms of species distribution and evenness; this species diversity index was used in several studies (Juan et al., 2009; Lumbres et al., 2014; Sharma et al., 2010) and was calculated using the following form:

$$H' = \sum P_i ln P_i \quad (7)$$

where,

H'=the value of the Shannon-Wiener diversity index

Pi = the proportion of its species individuals to total species individuals

ln = the natural logarithm of P_i

Evenness Index, E = H'/ln(S) (8)

where, S= Number of species in the study area

2.3.1. Aboveground and belowground biomass estimation and carbon stocks

Inside of each plot, all mangrove tree ≥5 cm in diameter were identified according to (Tucker, 2003) and measured the trunk diameters (cm) and total height (m) for estimating above and below-ground biomass. Tree measurements, including diameter at breast height (dbh) and height (H) in sample plots, were converted into tree biomass by using an allometric equation (tree biomass equation) and then into carbon storage. Here, allometric equations adapted from (Komiyama et al., 2005) were used to estimate AGB and BGB as shown in equation (9) and (10). The reason for choosing these allometric equations was they utilized mangroves of Southeast Asia as samples when developing the equations and were favored by many researchers as they didn’t require tree height data.

The mean value of wood density (□) of each species was obtained from the Global Wood Density Database (Chave et al., 2009) by using the *getWoodDensity* function from the “BIOMASS” package in R program. Then, the total aboveground and belowground biomass production in the plots were obtained by summing the biomass of all the standing trees and the biomass of each sample plot had been converted to stand-level biomass (Mg ha^{-1}). Then, carbon storage of aboveground and belowground biomass showed in mega-grams per hectare (Mg C ha^{-1}).

$$AGB = 0.251 \times \square \times D^{2.46} \qquad (9)$$

$$BGB = 0.199 \times \square^{0.899} \times D^{2.22} \qquad (10)$$

where,

AGB (kg) = aboveground biomass estimates in kg per tree
BGB (kg) = belowground biomass estimates in kg per tree
D = Diameter at breast height (DBH) in cm
□ = wood density in g cm^{-3}

The AGB and BGB were converted to above and below-ground carbon stock by multiplying 0.47 and 0.39 as a conversion factor (FAO, 2011; Feldpausch et al., 2004; IPCC, 2006; J.B. et al., 2016; Kauffman et al., 2011) using the equations below:

$$\text{Aboveground carbon stock} = AGB \times 0.47 \qquad (11)$$

$$\text{Belowground carbon stock} = BGB \times 0.39 \qquad (12)$$

2.4. Statistical Analyses and Modelling Work

Regression analysis was used to establish allometric relationships of stand-level aboveground biomass carbon stock (Mg C ha^{-1}) with mean DBH (cm), mean height (m), and stand basal area (m^2 ha^{-1}). In forest biomass studies, the error variances for the allometric non-linear equations based on arithmetical units of measurement were not constant over all observations (heteroscedasticity) in most cases (Altanzagas et al., 2019; Baskerville, 1972). Using log-transformed data for linear regressions was the most commonly used method for estimation of parameters in non-linear models to eliminate the effects of heteroscedasticity (Altanzagas et al., 2019). To minimize the systematic bias, a correction factor (CF) was calculated for each model (Sprugel, 1983). The stand-level aboveground carbon stock models based on structural variables such as mean DBH, mean H, and BA can be expressed as follows:

$$\text{Model 1: } \ln(C) = \ln a + b \ln(\bar{D}) + \varepsilon \qquad (13)$$

$$\text{Model 2: } \ln(C) = \ln a + b \ln(\bar{H}) + \varepsilon \qquad (14)$$

$$\text{Model 3: } \ln(C) = \ln a + b \ln(BA) + \varepsilon \qquad (15)$$

$$\text{Model 4: } \ln(C) = \ln a + b \ln(BA) + c \ln(\bar{H}) + \varepsilon \qquad (16)$$

where, C = aboveground carbon stock (Mgha^{-1}), BA = basal area (m^{2}ha^{-1}), $\bar{D}$ = mean DBH, $\bar{H}$ = mean height (m), a,b, and c = regression coefficients.

All the statistical analyses were performed using R programming software version-R 4.1.1. Before statistical analyses, data were checked to meet the requirements of normal distribution and variance homogeneity. All variables were tested for normality using a Shapiro-Wilk test. Logarithmic transformation was applied to both dependent and independent variables when the statistical requirements were violated. Data were analyzed through linear regression models. Pearson correlation test was used to analyze the relationship among structural characteristics. Finally, equation performance was carried out using various goodness-of-fit statistics, namely the adjusted coefficient of determination (R^2-adj), root mean squared error (RMSE) value, Akaike information criterion (AIC), Bayesian Information Criteria (BIC), Breusch-Pagan Test (bptest), Durbin-Watson test and *p*-value.

$$R^2\text{-adj} = 1 - \frac{(n-1)\sum_{i=1}^{n}(yi-\widehat{y}\,i)^2}{(n-p)\sum_{i=1}^{n}(yi-\bar{y}i)^2} \quad (17)$$

$$\text{AIC} = -2\text{logLik} + 2(p+1) \quad (18)$$

$$\text{BIC} - -2\text{logLik} + (p+1)\log(n) \quad (19)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(yi-\ \hat{y}i)^2}{n-p}} \quad (20)$$

where , yi =observed value, $\hat{y}$i = the estimated value, $\bar{y}i$ = the mean value of the observed carbon stock; n = the number of samples; p = the number of parameters, and logLik = the log-likelihood values of the non-linear regression model.

3. Results and Discussion

3.1 Species Composition

The mangrove stand in the study area comprised six true mangrove species, namely: *Avicennia officinalis* L., *A. alba* Blume, *Sonneratia apetala* Buch.-Ham., *S. caseolaris* (L.) Engl., *Aegiceras corniculutum* (L.) Blanco and *Bruguiera sexangula* (Lour.) Poir., belonging to four families. Mangrove species are classified as true mangrove or associated mangrove based on the criteria of Tomlinson. True mangrove species of *Nypa fruticans* Wurmb, and a few associated mangrove species such as *Derris trifoliate*, *Imperata cylindrica* (L.) P.Beauv., were also found, but were not considered in biomass calculations. Mangrove species recorded at the study site were among the 44 true mangrove species thriving in Myanmar (Zöckler & Aung, 2019). A total of 1102 individuals were enumerated from the 25 (20 × 20) plots. Among them, 78.77% were found to be of a single species, *A. officinalis* belonging to Acanthaceae family. *S. apetala* and *S. caseolaris* from the Lythraceae family and *Aegiceras corniculutum* from the Myrsinaceae family were the other major species occupying 13.97%, 4.17%, and 2.90% of the total species recorded from the study site. The remaining 0.09% was collectively represented by *A. alba* from the Acanthaceae family and *B. sexangular* from the Rhizophoraceae family. Most of these two species have dbh <5 cm, which was below the threshold for biomass determination using the allometric equations. Figure 2 explained the species distribution of mangroves in Letkhutkon Village.

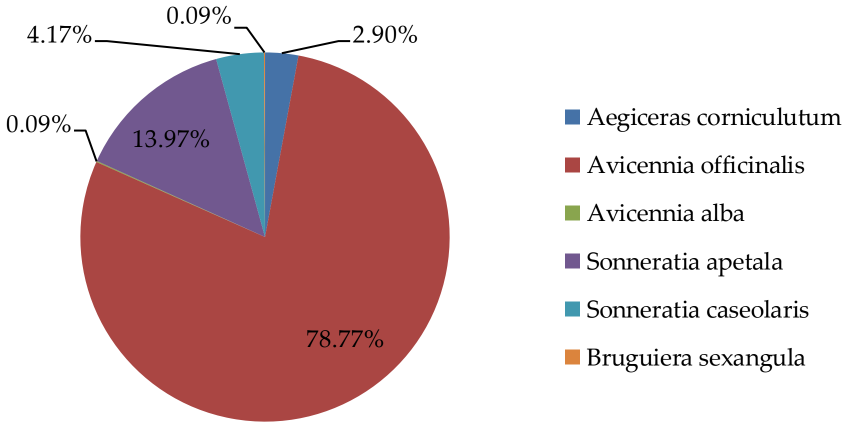

Figure 1. Species distribution of mangrove forests in Letkhutkon Village

Densities of mangroves in the 1-ha sample area ranged from 550 to 2025 trees per ha (mean 1102 ± 353 stems ha^{-1}); a total basal area of the stand was 745.92 m^2 ha^{-1} (29.84 ± 14.03 m^{2}ha^{-1}) and varied from 4.94 m^2 ha^{-1} to 69.11 m^2 ha^{-1}. The highest number of trees was found in plot 18 (81 individuals) followed by plot 16 (75 individuals), plot 9 (65 individuals), plot 14 (61 individuals). The lowest number of trees was found in plot 24 (22 individuals) and plot 22 had the most abundant species (five species) as shown in Figure.3. The DBH of individual trees varied between 5 cm and 41.3 cm, with total height ranging from 1.5 m to 9.75 m, with an average of 16.64 ± 8.23 cm and 5.71 ± 1.90 m. About 50% of the tree diameters and heights were between 10-21.98 cm and 4.27-7.32 m, respectively. Among the six mangrove species generally found at the study site, *A. officinalis* was found to have the maximum DBH (15.80 ± 3.47 cm) and height (5.70 ± 0.85 m). The lowest height and DBH were recorded in *Aegiceras corniculutum* with 12.19 ± 1.83 cm and 3.52 ± 0.61 m respectively. Additionally, Figure. 4 described Height-Diameter scatter plot of mangroves at the study site. The functional relationship between height and diameter of a tree was effectively described by a log function. Tree height was positively correlated with the diameter of the mangrove stand and the coefficient of determination (R^2) was 0.61.

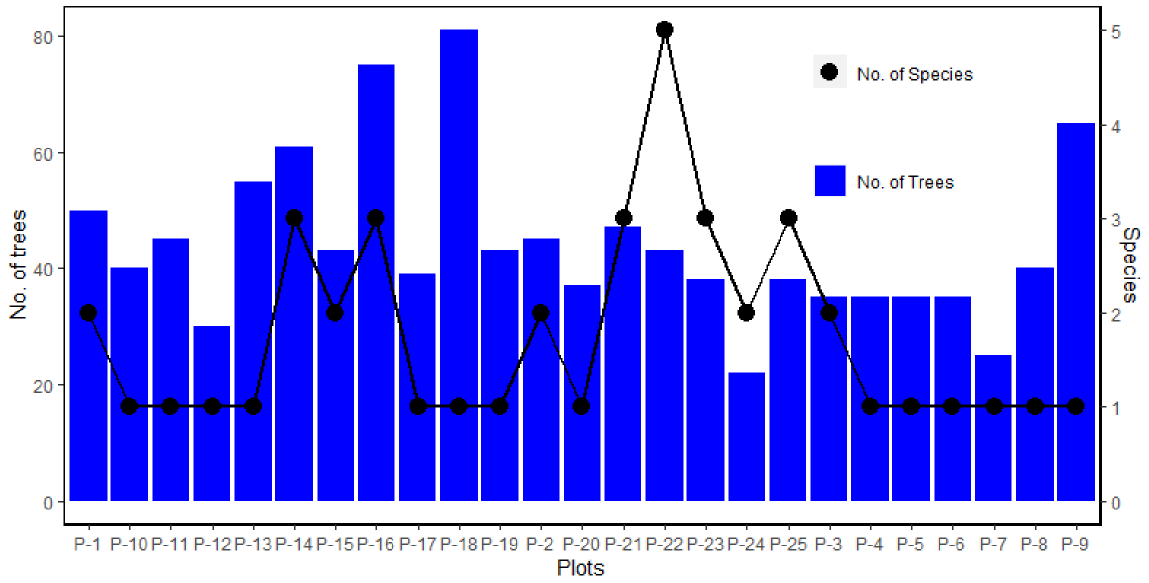

Figure 2. Tree abundance and number of species found in different plots in the mangrove stand of Letkhutkon Village

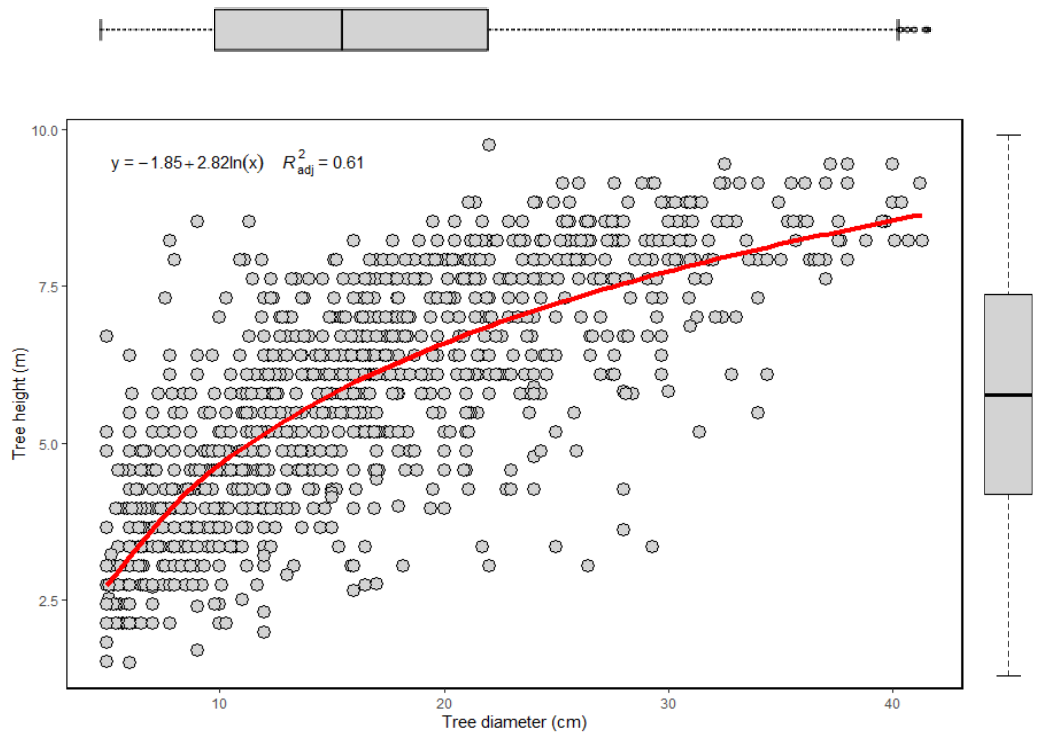

Figure 3. Scatter plot of tree height vs diameter in the mangrove stands of Letkhutkon Village

3.2. Structural Analysis

Important value index (IVI) was used to express the dominance and ecological success of any species with a single value; it was determined based on the total contribution of a species to the community by employing its relative density, relative basal area, and relative frequency in a study plot or area (Faridah-Hanum et al., 2012). The more the number of individuals found, the higher density values. In the study site, the mangrove species of *A. officinalis* was found to have the highest average stem density (868 ± 463 ha^{-1}) and the highest relative density of 78.77%, followed by *S.apetala* (13.9%), *S. caseolaris* (4.17%) and *Aegiceras corniculutum* (2.90%). The least mean stem density was recorded by *A. alba* and *Bruguiera sexangular* (25 ± 0.00 ha^{-1}). Frequency value of mangrove species is related to the number of plots where mangrove species are found. Here, *A. officinalis* has generally the highest frequency of presence in the study because this species has evenly distributed in each plot. The relative frequency of *Aegiceras corniculutum* (11.36%) was higher than that of S. caseolaris (9.09) % because Aegiceras corniculutum was more evenly distributed than S. caseolaris. High importance values were owned by the dominant species in a community. Here, A. officinalis showed the highest mean basal area (26.55 ± 16.940 m^2 ha^{-1}), contributing up to 87.66% of the total basal area, had the highest important value index (IVI) of 218.69%, then followed by 45.53% for S. apetala, 15.97% for S. caseolaris, 15.06% for *Aegiceras corniculutum*, and 2.37% for *A. alba* and *Bruguiera sexangular* (Table 2). The highest value of importance index of A. officinalis explained that *A. officinalis* plays a relatively significant role in maintaining the sustainability of the mangrove ecosystem in the study area.

The genus Avicennia is a pioneer group of dominant plant species and mangrove plants in the genus Avicennia have both economic and ecological values (Thatoi et al., 2016). A. officinalis is widely distributed in Bangladesh, Cambodia, India, Indonesia, Malaysia, Myanmar, New Guinea, the Philippines, Sri Lanka, Thailand, Vietnam, and north-eastern Australia (Tomlinson, 1986). Avicennia species develop pencil-like pneumatophores, while Sonneratia species have thick cone-shaped pheumatophores. *S. apetala* species is also the pioneer species and mainly associated with A. officinalis species (Duke, 1988; Nasrin et al., 2017; Tomlinson, 1986); they are growing on newly formed mudflats near the river mouth and found close to the sea. Therefore, mangrove species of *A. officinalis* and *S. apetala* play a vital role in reducing wave and tidal energy and retaining sediments. In Bangladesh, *Avicennia officinalis* is planted with *Sonneratia apetala* for the coastal afforestation programme to protect the coastal community against tropical cyclones, storm surges, waves, tides, and saltwater intrusion. In the present study, *A. officinalis* and *S. apetala* have higher density, frequency, stand basal area, and importance values than other species of the mangrove stand; this condition showed that *A. officinalis* and *S. apetala* have high adaptive abilities in the mangrove stand of Letkhutkon Village.

Table 2. Tree species found in the mangrove stand of Letkhutkon Village (mean ± sd)

Species	Mean Stem Density (No. of Trees ha^{-1})	Mean BA (m^2 ha^{-1})	RD (%)	RF (%)	RBA (%)	IVI (%)
Avicennia officinalis	868 ± 463	26.16 ± 16.94	78.77	52.27	87.66	218.70
Sonneratia apetala	154 ± 162	2.63 ± 4.50	13.97	22.73	8.83	45.53
Sonneratia caseolaris	46 ± 116	0.807 ± 1.99	4.17	9.09	2.71	15.97
Aegiceras corniculutum	32 ± 84	0.24 ± 0.65	2.90	11.36	0.80	15.06
Avicennia alba	25 ± 0.0	0.053 ± 0.00	0.09	2.27	0.01	2.37
Bruguiera sexangula	25 ± 0.0	0.05 ± 0.00	0.09	2.27	0.01	2.37

RD is relative density; RF is relative frequency; RBA is relative basal area. The important value is calculated as IVI = RD + RF + RBA and IVI value can add up to a maximum value of 300 (Curtis & McIntosh, 1950; Schaefer-Novelli, 1984).

Shannon-Wiener index was used to estimate the diversity of species in the study area. The Shannon-Wiener's diversity index (H) was categorized as low with a value of 0.71 and the Shannon evenness index (SEI) was 0.40. Supporting the results of other studies were the Shannon-Wiener's diversity index value of natural mangrove forest in the Mahanadi Mangrove Wetland (MMW), East Coast of India was 0.79 ± 0.38 (Sahu et al., 2016), the mangrove of Lauhan village in East Java, Indonesia was 1.51 (Asadi et al., 2018), and mangrove forest in Palawan, the Philippines was 0.99 (Abino, Castillo, et al., 2014). Therefore, Shannon-Wiener's diversity index (H) value of the mangrove community of Letkhutkon Village was very low compared to other natural mangrove forests since the mangrove stands in the study site possessed a low number of mangrove species and was dominated by the few species. In contrast to tropical lowland rainforest, the mangroves have very low diversity by the few species as few plants have their special adaptations, which are attributed to their unique stand's formation and harsh coastal habitat (Rasquinha & Mishra, 2021).

3.3. Biomass and Carbon Stock of Natural Mangrove

Allometric method is the most widely used method for biomass estimation of the forest because this method provides non-destructive and less time-consuming than other methods (Kridiborworn et al., 2012). In this study, the parameters of diameter at breast height (DBH) and wood density (□) were applied to compute mangrove biomass by using allometric equations of Komiyama et al.(Komiyama et al., 2005). As shown in Table 1, the overall mean biomass of the mangrove stand in LetKkhutkon Village was found to be 335.55±181.41 Mg ha^{-1} (the average aboveground biomass = 241.37±132.73 Mg ha^{-1} and the average belowground biomass=94.17±48.73 Mg ha^{-1}) wherein the total biomass produced was 8388.62 Mg ha^{-1}.The reported AGB of mangroves in Letkhutkon Village

(241.37±132.73 Mg ha^{-1}) was comparable to other mangroves, with the values of 255.7 Mg ha^{-1}reported in Lamu, Kenya (Kairo et al., 2021), 246.90 Mg ha^{-1} at Guarás Island located in the state of Para (Salum et al., 2020) and 80.23 ± 15.95 t ha^{-1} at the Kerala state, the southwest corner of India (Harishma et al., 2020). There were considerable variations in the biomass between different species as shown in Tables 3 and 4. Among the different species, the highest biomass of 7604.607 Mg ha^{-1} was recorded in *A. officinalis* (above and below-ground biomass were 5484.659 Mg ha^{-1} and 2119.947 Mg ha^{-1}) and the lowest biomass was in *A. alba*, having 0.333 Mg ha^{-1}. The biomasses of remaining species such as *S. apetala*, *S. caseolaris*, *Aegiceras cornoculutum*, and *Bruguiera sexangula* were 597.564 Mg ha^{-1}, 135.820 Mg ha^{-1}, 49.898 Mg ha^{-1}, and 0.397 Mg ha^{-1}, respectively.

Table 3. Biomass and carbon stock differences among the species in the mangrove stand

Species	Biomass (Mg ha^{-1})		C-stock (Mg C ha^{-1})	
	AGB	BGB	AGC	BGC
Avicennia officinalis	5484.66	2119.95	2577.79	826.78
Sonneratia apetala	420.54	177.03	197.65	69.04
Sonneratia caseolaris	94.67	41.15	44.50	16.05
Aegiceras corniculutum	33.95	15.95	15.96	6.22
Avicennia alba	0.21	0.12	0.10	0.05
Bruguiera sexangula	0.26	0.14	0.12	0.05

Table 4. Mean diameter breast height, biomass, and carbon stock of recorded mangrove species in the mangrove stands of Letkhutkon Village (mean ± sd)

Species	Mean DBH	Biomass (Mg ha-1)			Vegetation Carbon Stock (Mg C ha-1)		
		AGB	BGB	TB	AGC	BGC	TVC
Avicennia officinalis	17.66 ± 8.47	6.32 ± 6.89	2.44 ± 2.43	8.76 ± 9.31	2.97 ± 3.24	0.95 ± 0.94	3.92 ± 4.18
Sonneratia apetala	13.43 ± 6.13	2.73 ± 2.89	1.15 ± 1.11	3.88 ± 3.99	1.28 ± 1.36	0.45 ± 0.43	1.73 ± 1.79
Sonneratia caseolaris	13.81 ± 5.79	2.06 ± 2.18	0.90 ± 0.85	2.95 ± 3.03	0.97 ± 1.03	0.35 ± 0.33	1.32 ± 1.36
Aegiceras corniculutum	9.24 ± 3.08	1.06 ± 0.84	0.50 ± 0.36	1.56 ± 1.19	0.50 ± 0.40	0.19 ± 0.14	0.69 ± 0.53
Avicennia alba	5.20	0.21	0.12	0.33	0.10	0.05	0.15
Bruguiera sexangula	5.10	0.25	0.14	0.40	0.12	0.06	0.18
Total	16.64 ± 8.23	5.48 ± 6.44	2.14 ± 2.28	7.61 ± 8.72	2.57 ± 3.03	0.83 ± 0.89	3.41 ± 3.91

The aboveground biomass (AGB) and belowground biomass (BGB) contributed 71.93% and 28.07%, respectively, to the total mangrove biomass. The ratio of BGB to AGB (R:S ratio) ranged from 0.34 to 0.58 and the average ratio of BGB to AGB was 0.44 or 1:2.29. For comparison, the belowground biomass to aboveground biomass (R:S) ratio of mangroves was 0.46 or 1:2.17 in Kerala State, India (Harishma et al., 2020) and 0.38 or 1:2.60 in Samar, the Philippines (Abino, Castillo, et al., 2014). Mangrove forests have a higher root: shoot ratio (R:

S) (generally R:S ratios between 0.33 or 1:3 and 0.50 or 1:2 (Komiyama et al., 2008)) when compared to the upland forests (R:S ratios between 0.22 or 1:4.52 and 0.25 or 1:3.96 (Cairns et al., 1997)). Mangrove species are capable of allocating a high proportion of their total biomass to the belowground components which could be adapted to living in the soft sediments (Komiyama et al., 2008). Figure.5 described the root: shoot (R:S) ratio against tree diameter at breast height (DBH in cm). Trees with DBH 10–21.98 cm had a mean R:S ratio of 0.44 while trees < 10 cm DBH had a mean R:S ratio of 0.52 and trees > 21.98 cm DBH had a value of 0.38. Our findings showed R:S ratio decreased significantly with increasing tree DBH.

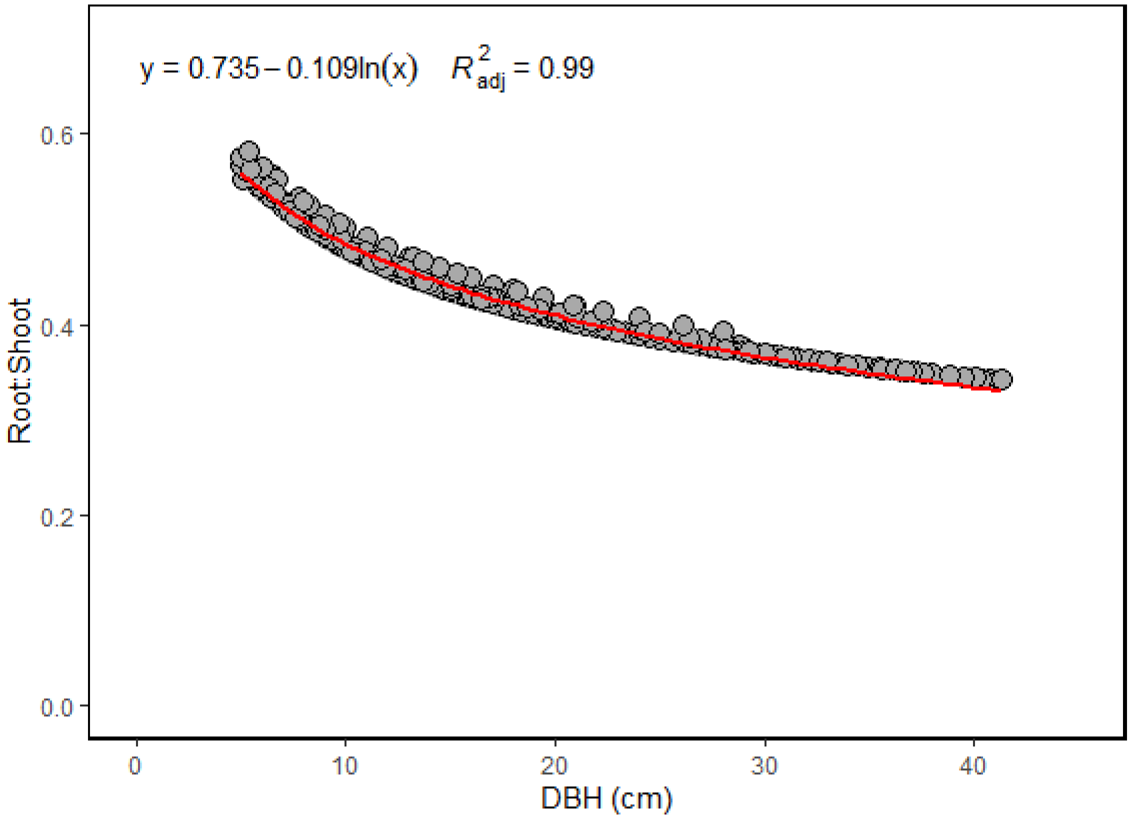

Figure 4. Root: Shoot (R:S) rations against tree diameter at breast height (DBH in cm)

The biomass of the plant is associated with the carbon storing capacity of the plant (O'Connor, 2003), so estimating the biomass potential of mangrove vegetation can be used to calculate the carbon stock. The total carbon stock (C-stock) of the mangrove stand in Letkhutkon Village was 3754.304 Mg C ha^{-1} and varied from 17.37 Mg C ha^{-1} to as high as 373.06 Mg C ha^{-1} with a mean value of 150.25 ± 81.35 Mg C ha^{-1}. The average C-stock of the mangrove stand was equivalent to the carbon dioxide sequestration of 551.10 ± 298.64 Mg CO_2-eq (1 ton of carbon=3.67 tons of carbon dioxide) stored in the biomass. The total aboveground C-stock was 2836.12 Mgha^{-1} and varied from 12.54 Mg C ha^{-1} to as high as 283.85 Mg C ha^{-1} with a mean value of 113.44 ± 62.38 Mg C ha^{-1}. The belowground biomass was 2354.33 Mg ha^{-1} with an overall average of 94.17 ± 48.73 Mg ha^{-1} and the mean belowground C-stock was 36.73 ± 19.00 Mg C ha^{-1} (Table 1). The estimated biomass (335.54 ± 181.41 Mg ha^{-1}) and stored carbon (150.17 ± 81.37 Mg C ha^{-1}) of mangrove stand in the present study was higher than that of Labuan, Indonesia (168.05 Mg ha^{-1} and 74.7 Mg ha^{-1}) (Asadi et al., 2018), Kerala mangrove in Southwest Coast of India (117.1 t ha^{-1} and 139.82 t ha^{-1}) (Harishma et al., 2020), mangrove stand in the east coast of India (178.3 t ha^{-1} and 89.1 t ha^{-1}) (Sahu et al., 2016), and natural mangrove stands in Bohol Province, Philippines (323.6 t ha^{-1} and 145.6

t ha^{-1}) (Camacho et al., 2011); however, the C-stock estimated in this study was lower than the C-stock obtained in the natural mangrove forest of Bahile, Puerto Princesa City, Palawan (757.7 t ha^{-1} and 356.1 t C ha^{-1}) (Abino, Lee, et al., 2014), and Thailand (345 t ha^{-1} and 155 t ha^{-1}) (Jachowski et al., 2013). The contribution of mangrove species to mean C-stock was in the following order: *A. officinalis* > *S. apetala* > *S. caseolaris* > *Aegiceras corniculutum* > *Bruguiera sexangula* > *A. alba* as shown in Tables 3 and 4. Among the established sample plots, the highest biomass and C-stock were attributed in plot-9 with its corresponding maximum stand basal area of 69.125 m^2 ha^{-1}, whereas the lowest biomass and C-stock occurred in plot-24 with its corresponding minimum stand basal area of 26.692 m^2 ha^{-1}. Because plot 9 has the highest total DBH among the recorded sample plots; however, the DBH of trees measured in plot 24 was very low, since the trees were newly growing.

3.4. The Relationships between Carbon Density and Structural Variables

Pearson's correlation coefficient was used to see the relationship between the variables at a 95% confidence interval. The correlations between the predictor variables and the dependent variable were shown in Table 5. Aboveground carbon stock (AGC) was positively correlated with all structural variables such as mean DBH (D), mean height and stand basal area (BA). AGC was positively associated with BA ($R=0.9921$, $p<2.2 \times 10^{-16}$), mean DBH ($R=0.8033$, $p=3.94 \times 10^{-06}$) and mean height ($R=0.6838$, $p=3.21 \times 10^{-04}$); this finding indicated that basal area was a significant predictor of the aboveground carbon stock of trees in the mangrove stand.

Table 5. Pearson's correlation coefficients between aboveground carbon (AGC) density and structural parameters of the stand

Structural Variables	Pearson Correlation Coefficient with AGC (Mg C ha^{-1})	p-value
Mean DBH (cm)	0.8033	3.94×10^{-06}
Mean H (m)	0.6838	3.21×10^{-04}
BA (m^2/ha)	0.9921	$<2.2 \times 10^{-16}$

3.5. Influence of Structural Variables on Aboveground Carbon Storage

Linear regression analysis was performed to describe the relationship between stand level carbon storage (Mg C ha^{-1}) as the dependent variable and stand structural parameters such as mean DBH, mean H and basal area as independent variables. All models were named and described in Table 6. As specified in the Table, carbon stock was significantly correlated with structural variables. Through the linear regression analysis, we found that carbon stored in the tree biomass was influenced by forest structural characteristics.

Table 6. Linear regression analysis result of stand structural variables and aboveground carbon storage (AGC)

Model	Adj. R^2 (%)	RMSE	AIC	BIC	bptest	CF	p-Value
Model 1	67.92	0.267	10.570	13.977	0.251	1.0398	8.14×10^{-07}
Model 2	46.25	0.346	22.440	25.847	0.382	1.0877	0.000214
Model 3	97.21	0.079	-45.586	-42.180	0.230	1.0034	$<2.2 \times 10^{-16}$
Model 4	97.28	0.076	-45.350	-40.808	0.187	1.0033	$<2.2 \times 10^{-16}$

Note: Model 1: one-variable (mean DBH (cm)), Model 2: one-variable (mean Height, (m)), Model 3: one-variable (basal area, (m^2)), Model 4: two-variable (BA, H (m^2, m)). The statistics represent the coefficient of determination (R^2-adj), Root Mean Square Error (RMSE), Akaike information criterion (AIC), Bayesian Information Criterion (BIC), bptest, Correction factor (CF) and p-value.

Model (1) analyzed the relationship between aboveground carbon stock-AGC (Mg C ha^{-1}) and mean diameter at breast height. The model had R^2-adj = 0.6792, AIC = 10.570, BIC = 13.977, RMSE = 0.267 and $p = 8.14 \times 10^{-07}$. As mean DBH increased by 1 cm, on an average aboveground carbon stock increased by 2.1231 Mg ha^{-1} keeping all things constant; it showed AGC had a direct correlation with DBH, therefore it could be assumed that DBH was a reliable dendrometric variable for aboveground carbon stock estimation (Brahma et al., 2021; Ghasemi et al., 2016; Kebede & Soromessa, 2018). The mangrove tree biomass model, which was determined from DBH, only had a practical advantage because most of the inventories included DBH measurements. Furthermore, it was easy to measure accurately in the field.

$\ln(AGC) = -1.3088 + 2.1231 \ln(D)$

The relationship between aboveground carbon stock-AGC (Mg ha^{-1}) and mean height (m) was assessed in model 2; this model had a coefficient of determination of 0.4625 and the parameters were statistically significant ($p = 0.0002142$). Although AGC had a significant positive relationship with Mean H, it showed a lower R^2-adj (46.25%), higher AIC (22.440), and higher BIC (25.847) when compared with the relationship between AGC and mean DBH; thus, mean height (m) as an individual independent variable was deniable as one of the important predictors for the estimation of AGC.

$\ln(AGC) = 1.3728 + 1.8867 \ln(H)$

The result of the linear regression analysis of the model (3) revealed that aboveground carbon stock density (Mg ha^{-1}) had a significant, positive relationship with stand basal area (m^2 ha^{-1}) with a coefficient of determination of 0.9834; parameters were statistically significant ($p < 2.2 \times 10^{-16}$). The result was statistically interpreted, as the stand basal area increased by 1 m^2 ha^{-1}, and on an average above-ground carbon stock increased by 1.21227 Mg ha^{-1} keeping all things constant. The strong relationship between stand basal area and aboveground carbon stock is because both variables have been associated with the diameter of a tree trunk; it means if the size of the tree trunk increases, the stand basal area increases because tree basal area is the cross-sectional area of a tree trunk measured at the breast height over bark, and as a consequence, the aboveground biomass and carbon stock also increase.

$\ln(AGC)= 0.58368 + 1.21227 \ln(BA)$

Across all structural variables, stand-level carbon stock showed the highest relationship (R^2-adj = 97.21, $p < 2.2 \times 10^{-16}$) with the stand basal area. When the stand basal area and tree height were used as compound variables in the model, it explained 97.28% of carbon variation. Model (4) has appeared the best fit model showing fitting statistics (R^2-adj= 97.28, AIC = -5.350, BIC = -40.808, RMSE = 0.076, p-value $< 2.2 \times 10^{-16}$) and very close to model 3. Despite that fact, both models (3 and 4) were still able to explain carbon storage very well (Adj. $R^2 > 90\%$).

$\ln (AGC) = 0.46971 + 1.16254 \ln(BA) + 0.16235 \ln (H)$

For a better analysis of residual distribution, we used the respective statistical test for checking the models. We ran the Durbin–Watson test to detect the autocorrelation in the residuals. The test statistics were for model 3: DW = 1.7032, p-value = 0.2052 and for model 4: DW = 1.5571, p-value = 0.1014. For both models, the presence of autocorrelation was not significant as the p-value > 0.05 and the value of DW ~ 2. We further ran the Shapiro–Wilk test for normality and both models were normality distributed (p-value = 0.8458 and 0.7164 for model 3 and model 4 respectively). Additionally, we performed Breusch–Pagan test (bptest) to determine whether heteroscedasticity was present in the regression model. The test statistics concluded there may not be heteroscedasticity as the p-value > 0.05; thus, the best fit equations for estimating stand-level carbon stock were Model 3: $\ln(AGC) = 0.58368 + 1.21227 \ln(BA)$, one-variable model using stand basal area (m2 ha^{-1}) as predicted variable, and Model 4: $In(AGC) = 0.46971 + 1.16254 \ln(BA) + 0.16235 \ln (H)$, two-variable model using stand basal area and mean height (m^2, m).

4. Conclusions

By applying the non-destructive methodology, biomass and caron stock of the mangrove stand of Kanhlyashay natural mangrove forest were estimated. A lover diversity index value (H'=0.71) was observed in the natural mangrove stand that was dominated by the species of *Avicennia officinalis* (IVI=218.69%) from Acanthaceae family comprised 78.77% of the total tree count. Therefore, *A. officinalis* has high adaptive abilities in the mangrove stand of Letkhutkon Village. Pioneer mangrove species such as *A. officinalis* and *Sonneratia caseolaris* have a good survival rate on the mudflats, and they are suitable mangrove species for mangrove afforestation on unoccupied mudflats because of their tolerance to increase d salinity. The total biomass and carbon stock in the natural mangrove forest were 335.55 ± 181.41 Mg ha^{-1} and 150.25 ± 81.37 Mg C ha^{-1}, where the above and below-ground carbons tock contributed 71.93% and 28.07%, respectively. Stand-level allometric equations in the estimation of aboveground carbon stock were implicated. The finding revealed that the one-variable model of the stand basal area and the two-variables model (basal area + mean height) were suitable based on fitting statistics and certain statistical tests for high-precision estimates of stand-level carbons stock of mangrove stand in the study site. Our observation highlighted that the natural mangrove forests in the study site has the potential to store and sequester a significant amount of carbon. Because natural mangrove forest in the study site us a young age stand and is dominated by the fast-growing pioneer species. At a young age stand, the rate of carbon sequestration is high. In addition to the stand age, the rate of carbon uptake of the forest ecosystem, depends on forest management. Therefore, forest management activities are necessary to maintain forest carbon sequestration capacity.

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