Chapter

Ground Forest Inventory and Assessment of Carbon Stocks in Sierra Leone, West Africa

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Abstract

Forest and woodland are renewable natural resources providing basic human necessities. They have the ability to sequester carbon and mitigate climate change. Sustainable forest management is guided by forest mensuration and inventory which include measuring and calculating growth and changes in trees and forests. The objective of the study was to estimate timber resources and carbon stock using simple hand tools in Kasewe and Singamba forests in the southern part of Sierra Leone. All trees with diameter at breast height (DBH) $\geq$ 10 cm were measured in every plot for DBH, and three trees were measured for height. The correlation between mean wood volume and carbon stock was highly significant. For Kasewe plantation forest, mean wood volume and carbon stock were 151 m^3 ha^{-1} and 44 t C ha^{-1}, respectively, and for the Singamba natural forest, they were 181 m^3 ha^{-1} and 82 t C ha^{-1}, respectively. The linear correlation between basal area and volume, DBH and volume and basal area and total biomass was significant for the plantation species tested. Realistic national forest inventory and community forestry are inevitable for sustainable forest management in Sierra Leone.

Keywords: biomass, community forestry, carbon stock, forest mensuration and inventory, sustainable forest management

1. Introduction

Forest and woodland (tree and shrub savannah, parklands and bush fallows [1]) are renewable natural resources providing basic human necessities [2, 3]. Although both ecosystems are wooded habitats where trees predominate [3], the former consists of closed canopy [4, 5] which permits very little sunlight to penetrate to the ground below, while the later has a more open canopy [5] and its sparse woody mid-storey allows more sunlight to reach the ground [4]. They have the ability to sequester carbon and mitigate climate change [6]. Forest ecosystems are mostly viable carbon sinks [6, 7] globally due to net growth in planted trees [7] with the majority of sequestered carbon held in woody biomass [8] but can also be a carbon source when degraded [7]. The rainforest of West Africa, a hotspot of biodiversity, has approximately 9000 species of vascular plant, including 1800 endemic species [8, 9] and an estimated area of 621,705 km^2. This forest area declines every year through anthropogenic activities [1] and natural disasters such as landslides, earthquakes and flooding [10].

Forest resource assessment in relation to timber volume [11–13] and carbon stocks [14, 15] provides information about the status of the productivity of the forest. This assessment is traditionally done through ground forest inventory. Forest assessment is very important for decision-making and policy formulation [11] and establishment of sustainable management plans at both national and international levels.

The objective of the study was to estimate timber resources and carbon stock using simple hand tools in Kasewe and Singamba forests in the southern part of Sierra Leone.

2. Materials and methods

2.1 Sampling design

2.1.1 Method of sampling in Kasewe plantation forest

A systematic sampling design was established for conducting timber inventory in this plantation forest at the age of 14 years. A trunk road (Bo-Freetown highway at Moyamba Junction) passing through the forest served as the baseline.

In the *Gmelina arborea* stand, three transects, 40 m apart and at right angle to the baseline—the Bo-Freetown Highway—were established; and every transect was 75 m long. Two square plots, 30 × 30 m, were demarcated along each transect at an interval of 5 m, making sure that each plot was bisected by its corresponding transect and the first plot was located 5 m away from the baseline. The plots were considered to be representative of the stand [15]. For the purpose of this research, a total of six plots were laid out covering a sampling area of 0.54 ha (**Figure 1**) in the *Gmelina* stand.

This method was replicated in the adjacent *Tectona grandis* stand about 100 m away from the *Gmelina* stand, giving a total of 12 plots. The above sampling design is demonstrated in the forest as shown in **Figure 2**.

2.1.2 Sampling design in Singamba natural forest

Within the Singamba mixed forest, two vegetation communities or ecology types, namely, secondary forest (aged over 5 years after its last farming disturbance) and forest regrowth (resulting from shifting cultivation farming about 2-–5 years ago), adjacent to each other, were identified for data collection. Systematic sampling was employed for this study area. Circular plots of radius of 10 m were adopted for data collection. These have the advantage of reducing the edge effect in the sample. Using an existing footpath as a baseline, two quadrants, 100 m by 80 m and 100 m by 60 m, respectively, were demarcated; a total of 20 plots, 12 and 8 plots in the respective quadrants, was laid out systematically on transects that were 25 m apart (**Figure 3**) in each ecology type.

2.2 Data collection

2.2.1 Data collection in Kasewe plantation forest

All trees within each plot were measured for diameter at breast height (DBH) at 1.3 m above the ground, and three dominant trees were measured for total height. A minimum of 10 cm DBH [16, 17] was considered for a tree to be enumerated, targeting commercial stems. Tree height was measured using a Suunto hypsometer,

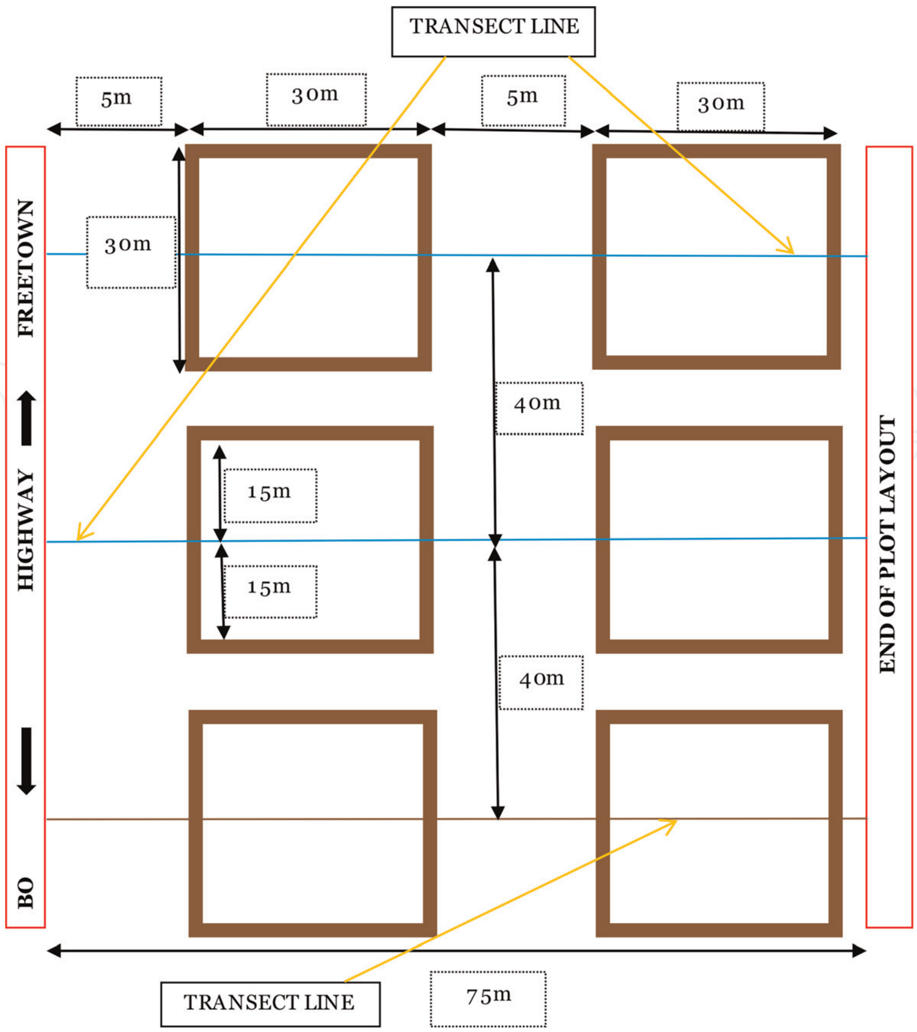

Figure 1.
Plot layout and dimensions in systematic sampling design.

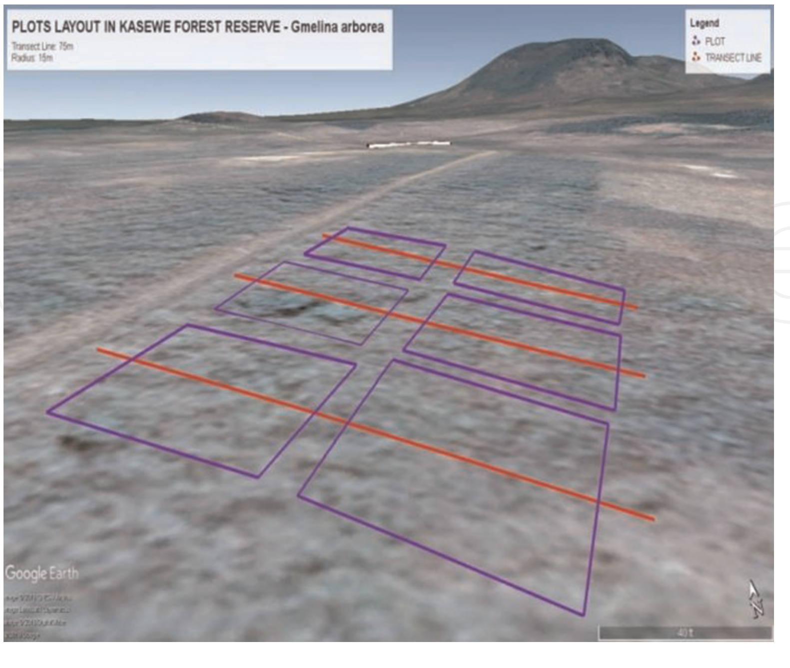

Figure 2.
Photograph of plot layout in Kasewe plantation forest.

and DBH was measured using a diameter tape. A linear function of DBH and height (**Figure 4**) was developed from the data for dominant trees for estimating the height of the remaining trees not measured in the field.

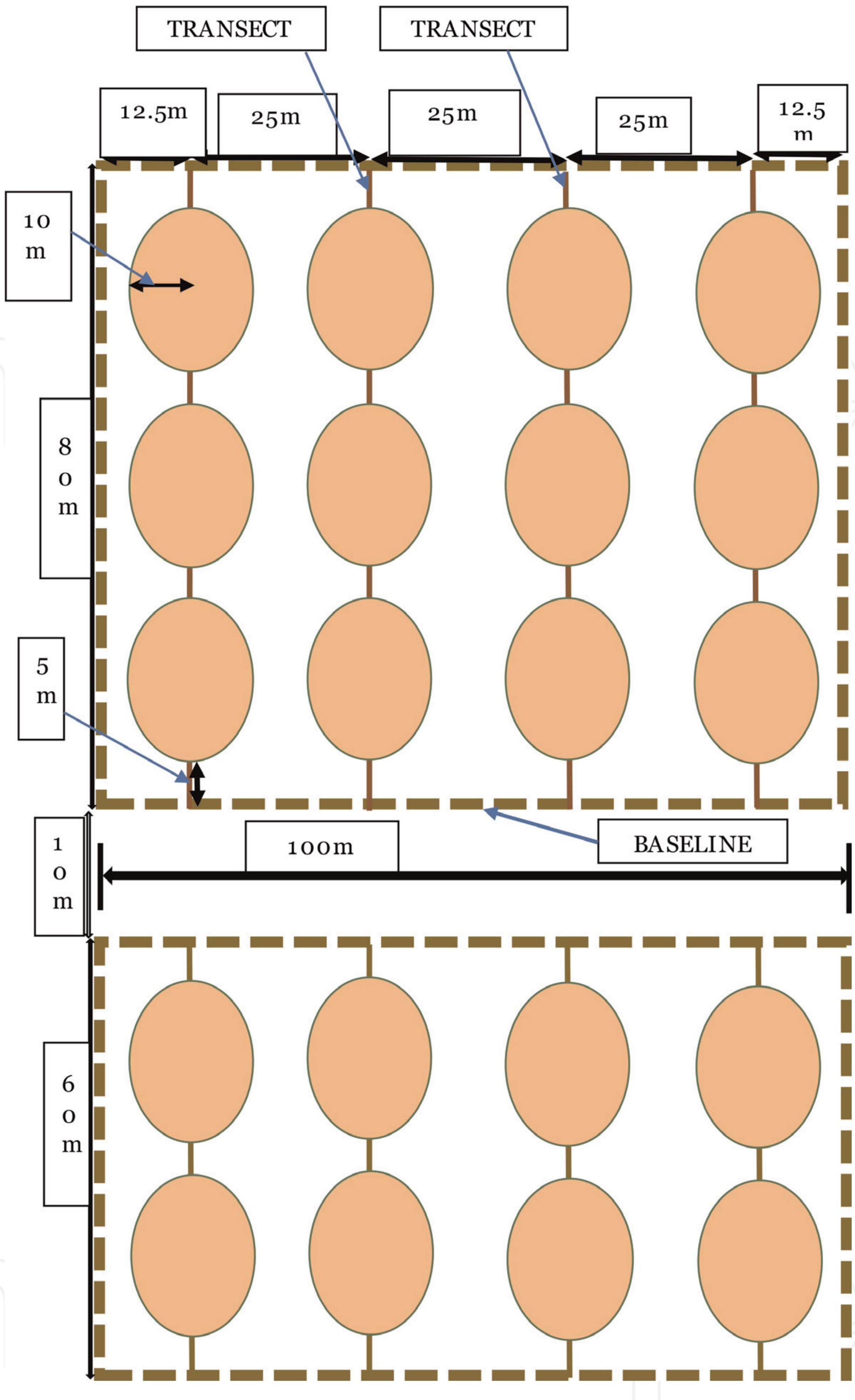

Figure 3.
Plot layout in Singamba natural forest.

Bark thickness of all sample trees in every plot was measured in both the *Gmelina* and *Tectona* stands. In the absence of a Swedish bark gauge, a knife and a ruler were used to measure the bark thickness of the trees in the sample plots. The knife was used to cut a small square portion of the bark at the point of measurement for DBH. This was done carefully, and the bark removed was measured in millimetres using a ruler.

2.2.2 Data collection in Singamba natural forest

In each circular plot located in both secondary forest and forest regrowth (within the natural forest), tree or shrub species of a minimum DBH of 10 cm was

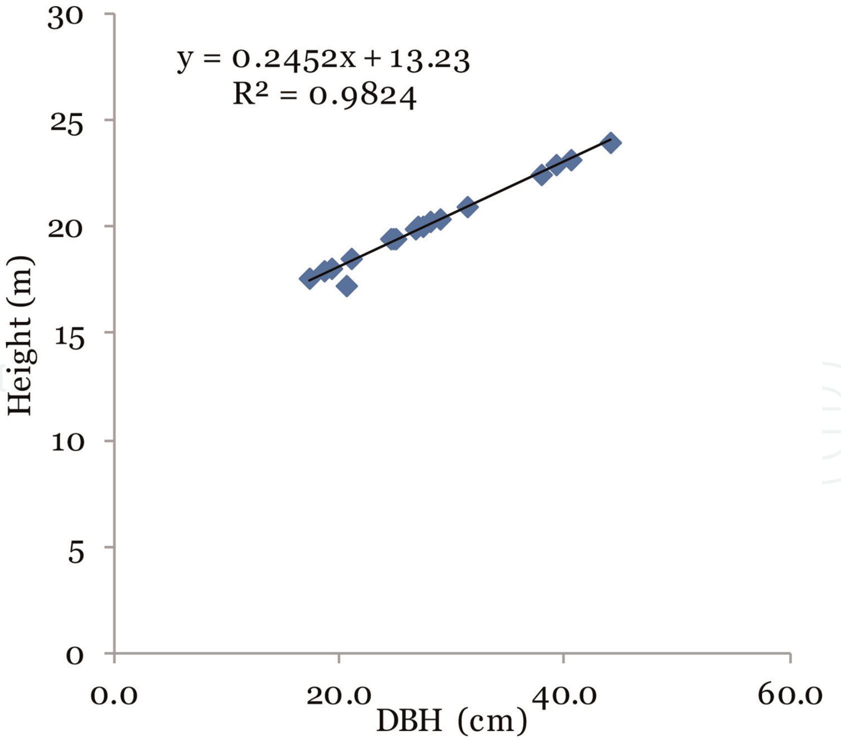

Figure 4.
Linear function for estimating tree height of Gmelina at Kesewe plantation forest. Note: y → tree height (m), x → DBH (cm).

identified by a local tree spotter in the Mende language; this was recorded and later translated to botanical name using Trees of Sierra Leone [18] and further verified from [19]. Diameter measurement was taken for all trees 10 cm and above at 1.3 m above ground level in each plot. The total height of three dominant trees was also measured in every plot.

2.3 Data analysis

2.3.1 Kasewe plantation forest

For the estimation of tree yield (stem count, basal area and volume), biomass and carbon non-harvest techniques [4] were adopted for the following parameters:

- Basal area
- Volume over bark
- Standing biomass
- Carbon stock in standing trees

2.3.1.1 Yield parameters

A linear function was first developed (from the dominant trees) for estimating the height of all the trees not measured for height in the field.

2.3.1.1.1 Stem count

The DBH tally was used to determine stand density for the standing trees [20–22]:

$$N = (1/n)\sum (x_i/a_i) \tag{1}$$

where N is number of stems per ha, n is number of plots, x_i is number of stems in plot and a_i is area of plot i in ha.

2.3.1.1.2 Basal area calculation

The basal area (m^2) of all trees in the sample plots in both the *G. arborea* and *T. grandis* stands were calculated using the formula [23, 24]:

$$G = \sum \left(\sum \pi d_i^{\,2}/40{,}000\right)/A \tag{2}$$

where G is basal area per hectare and A and d_i are the total sampling area (ha) and DBH (cm) of stem i, respectively.

2.3.1.1.3 Volume estimation of trees per hectare

The volume (m^3) of all trees in the sample plots in both the *T. grandis* and *G. arborea* stands was estimated using separate predetermined allometric equations, initially in m^3 per tree and then converted to $m^3\ ha^{-1}$. For *G. arborea*, the volume over bark (ob) was estimated by the following volume equation according to Mattia and Dugba [25]:

$$\text{Volume (ob)} : V = 0.24950005 + 0.000018027\left(DBH^2 ht\right) \tag{3}$$

(Note: Eq. (1) is applied best to trees with DBH ≥ 10 cm)
Volume under bark (ob) was estimated from DBH under bark.
For *T. grandis* the volume (ob) was estimated according to [26]:

$$V = 0.0012 DBH^{1.9912} \tag{4}$$

where V = total volume over bark in m^3, DBH = tree diameter at breast height, 1.3 m aboveground level in cm and ht = total height in m.

2.3.1.2 Estimation of live tree biomass and carbon stock for Gmelina arborea *stand*

For the purpose of this study, biomass carbon has been considered and studied for only trees of minimum DBH of 10 cm in both natural and plantation forests. The accumulated biomass and carbon contained in the standing trees of *G. arborea* were estimated by individual trees and by plots.

2.3.1.2.1 Aboveground biomass

To estimate the aboveground biomass (AGB), the equation according to Arias [27] was adopted for *Gmelina*, initially in kg per tree:

$$AGB = 0.075 * DBH^{2.4167} \tag{5}$$

Then, it was converted to tonne ha^{-1} ($t\ ha^{-1}$) after multiplying by a scaling up factor (SF) [28]: SF = 10,000/NA; NA is the area of single plot in m^2.

$$SF = 10,000/NA = 10,000/900$$

2.3.1.2.2 Belowground biomass

The belowground biomass (BGB) was estimated according to the recommendation of the Intergovernmental Panel for Climate Change (IPCC) [28]:

$$\text{BGB} = \text{AGB} * 0.235, \text{ i.e.}23.5\% \text{ of AGB.} \tag{6}$$

$$\text{Total biomass} = \text{AGB} + \text{BGB in t ha}^{-1} \tag{7}$$

2.3.1.2.3 Carbon stock for Gmelina arborea

Carbon (C) stock was derived from aboveground biomass by assuming that nearly 50% of the biomass is made up by carbon [28–30].

$$\text{C} = \text{Biomass}\left(\text{t ha}^{-1}\right) * 0.47. \tag{8}$$

CO_2 was calculated as follows:

$$\text{CO}_2 = \text{Carbon}\left(\text{t Cha}^{-1}\right) * 44/12. \tag{9}$$

2.3.1.3 Estimation of live tree biomass and carbon for Tectona grandis

The AGB for teak was estimated using a method similar to that for *Gmelina* but adopting the following equation for initial estimate [26]:

$$\text{AGB} = 0.5043 * \text{DBH}^{2.0636} \tag{10}$$

The BGB, total biomass, carbon stock and CO_2 for teak were calculated according to Eqs. (6)–(9), respectively.

2.3.2 Data analysis for Singamba forest

2.3.2.1 Wood production parameters

The quantitative metric data was used to estimate three parameters for wood production: the number of stems ha^{-1} (N), basal area ha^{-1} (G) and wood volume ha^{-1} (V).

2.3.2.1.1 Number of stems ha^{-1}

This was estimated using Eq. (1) (Section 2.3.1.1)

2.3.2.1.2 Basal area ha^{-1}

The formula used was Eq. (2) (Section 2.3.1.1).

2.3.2.1.3 Wood volume ha^{-1}

This was estimated using the formulae according to Eqs. (12) and (13) [23]; a form factor of 0.562 from Mattia and Dugba [25] for natural mangrove forest (comprised of seven mangrove species) in Tanzania was employed:

$$\text{V} = \left\{\sum\left(\sum \text{v}_{\text{ij}}\right)\right\}/\text{na} \tag{11}$$

$$\text{v}_{\text{ij}} = \text{g}_{\text{i}}\ \text{h}_{\text{i}}\ \text{f} \tag{12}$$

where V = average volume ha^{-1} in m^3 estimated from n sample plots, v_{ij} = volume (m^3) of individual standing tree measured on the i^{th} plot, g_i = basal area (m^2) of j^{th} stem in the i^{th} plot, n = number of sample plots, a = area of a single plot in ha, h_i = total height (m) of j^{th} stem and f is form factor, i.e. the coefficient employed to reduce the volume of a cylinder.

2.3.2.2 Estimation of live tree biomass and carbon stock for Singamba rainforest

The following equation was adopted for estimating biomass of the natural forest [31]:

$$AGB = 0.0547 * DBH^{2.2148} * Ht^{0.6131} \quad (13)$$

And the scaling factor applied was 10,000/(314.16).

The calculation of BGB, AGC, BGC, total biomass and total carbon followed the same method as that for Kasewe plantation forest (Section 2.3.1.2; definitions of all terms remain the same as before).

2.3.3 Statistical analysis

The above tree parameters were calculated using Excel software. Means, standard deviations, variances, standard errors and confidence intervals [32, 33] for various wood production parameters were computed. Relationships between basal area and wood volume, between basal area and total biomass and between total biomass and carbon stock, were determined using regression analysis.

3. Results

3.1 Kasewe plantation forest

3.1.1 Wood volume

The mean DBH and height are shown in **Table 1**. The overall mean wood volume of Kasewe plantation forest was 151.06 m^3 ha^{-1}; the mean volumes over bark for *G. arborea* and *T. grandis* were 157.88 and 144.23 m^3 ha^{-1}, respectively (**Table 1**).

The volume of wood for *Gmelina* was recorded by plots (**Figure 5**).

The percentage of volume (ob) of *Tectona* generated by plots is given in **Figure 6**.

Species	Mean DBH (cm)	Mean height (m)	M. BA (m^2 ha^{-1})	Wood volume ob (m^3 ha^{-1})	M. D. DBH (cm)	M. D. ht (m)	Stem count (stem ha^{-1})
G. arborea	29.01	20.34	18.73 (±1.28)	157.88 (±10.42)	43.97	24.01	264
T. grandis	21.56	15.81	9.71 (±0.79)	144.23 (±11.67)	35.4	20.44	240
Plantation	25.38	18.13	14.22	151.06	39.7	22.23	253

Values in the table are means ± CI = confidence interval at 95%. M. BA is mean basal area; M. D. DBH is mean dominant diameter at breast height; M. D. ht is mean dominant height; ob is over bark; ub is under bark.

Table 1.
Wood production parameters for Kasewe plantation forest.

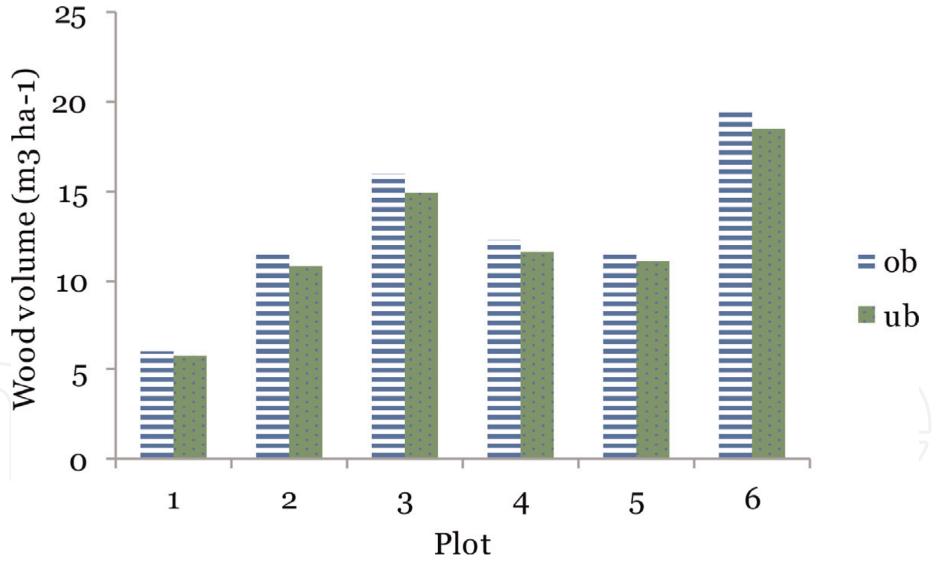

Figure 5.
Volume of Gmelina by plots at Kasewe plantation forest.

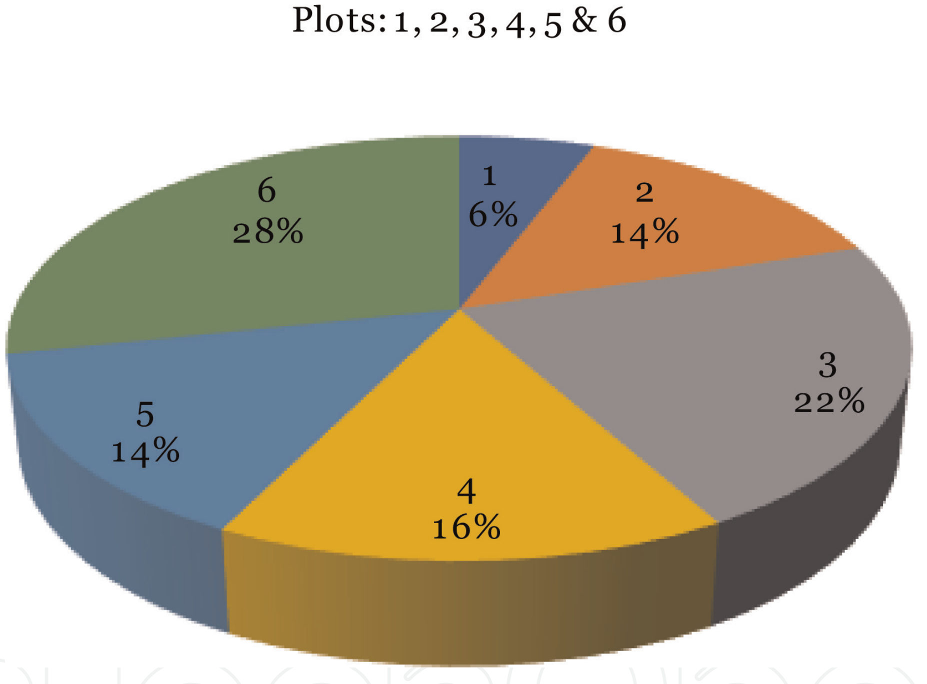

Figure 6.
Percentage volume (ob) of Tectona by plots at Kasewe plantation forest.

3.1.2 Stem count and basal area

The stem density of the plantation forest at Kasewe was 253 stems per ha; 264 and 240 stems per ha were recorded for *Gmelina* and *Tectona* stands, respectively (**Table 1**).

The mean basal area of the Kasewe plantation forest was 14.22 m^2 ha^{-1} (**Table 1**).

3.1.3 Relationship among different growth parameters

The number of *Gmelina* stems enumerated was 143, with a minimum DBH of 13.80 cm and maximum of 52.90 cm; and the tree height ranged from 16.61 to 26.20 m. A positive and linear correlation was found between the wood volume of *G. arborea* and the basal area (**Figure 7**), which implies that the basal area is a good

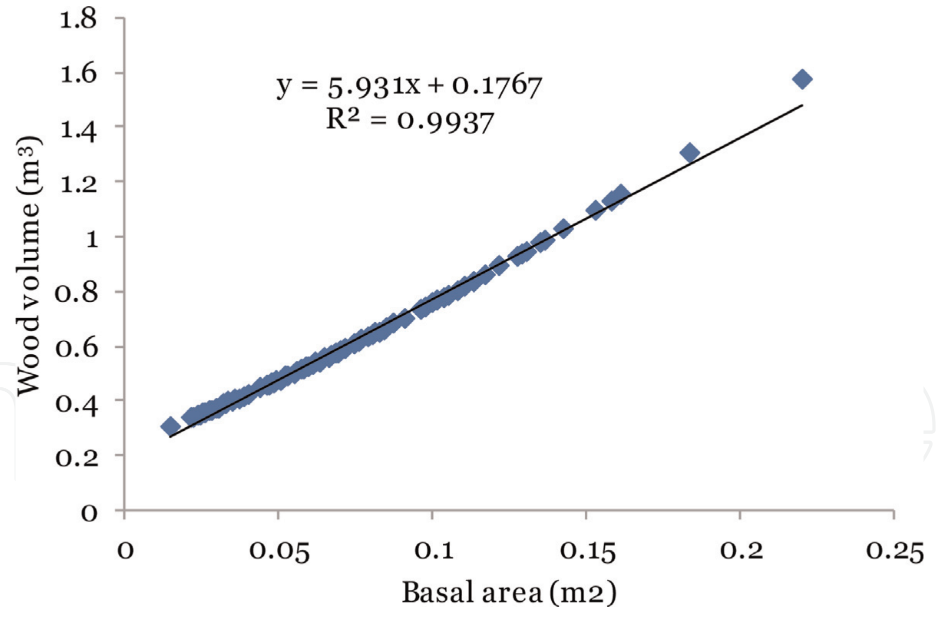

Figure 7.
Linear correlation between basal area and volume of G. arborea standing trees of Kasewe plantation forest.

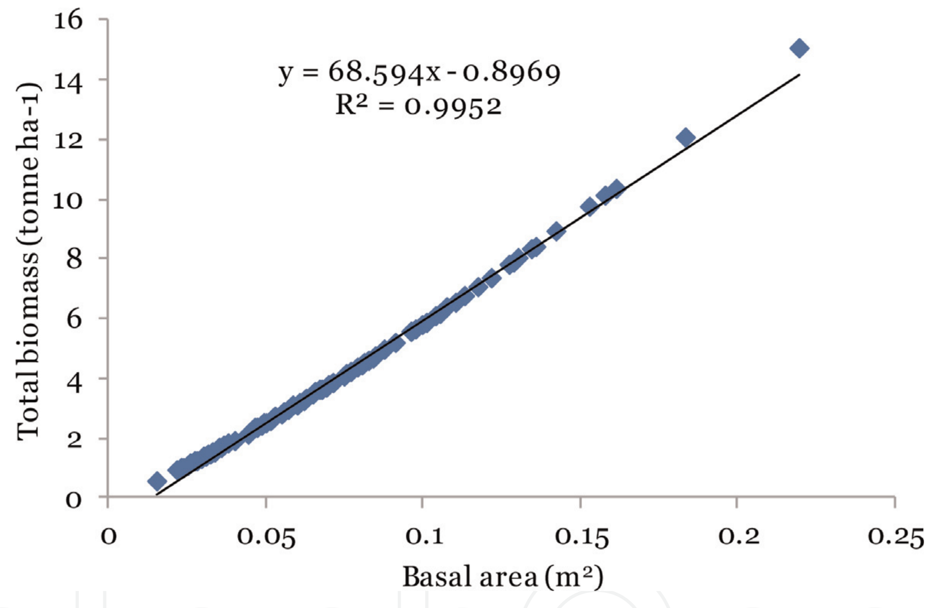

Figure 8.
Linear correlation between basal area and biomass of G. arborea trees at Kasewe plantation forest.

predictor of volume (R^2 = 0.9937). The basal area explains 99% of the variation in volume.

Similar to the volume, the total biomass of trees varied positively and linearly with variation in its basal area (**Figure 8**). The basal area explains slightly higher proportion (i.e. 99.5%) of variation recorded in total biomass than the volume.

The carbon stock of trees of *G. arborea* varied positively and linearly with variation in its total biomass (**Figure 9**). The biomass explains the highest proportion (i.e. 100%) of variation recorded in total carbon stock, denoting perfect and positive correlation.

3.1.4 Accumulated biomass and carbon in Gmelina *trees*

The estimated net biomass of the stems and roots (total biomass) ranges from 51 to 136 tonne ha^{-1} with a mean of 94.26 tonne ha^{-1}; the carbon stock ranges from

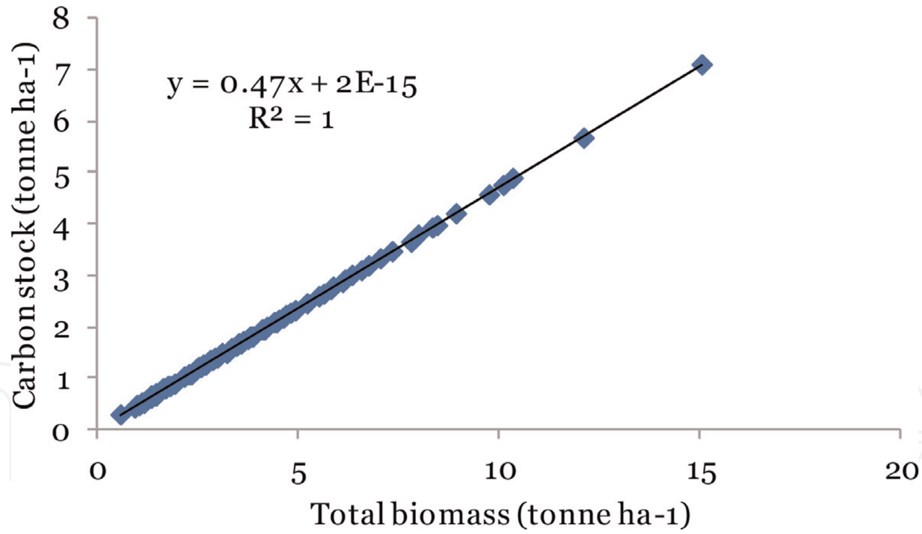

Figure 9.
Perfect and positive linear correlation between total biomass and carbon stock of G. arborea trees at Kasewe plantation forest.

Plots	DBH (cm)	Height (m)	AGB ($t\ ha^{-1}$)	BGB ($t\ ha^{-1}$)	Total biomass ($t\ ha^{-1}$)	Carbon stock ($t\ ha^{-1}$)	CO_2 ($t\ ha^{-1}$)
1	26.33	19.69	30.75	7.23	37.97	17.85	52.98
2	29.70	20.51	65.42	15.37	80.80	37.97	112.75
3	32.98	21.32	104.94	24.66	129.60	60.91	180.84
4	30.00	20.59	73.38	17.24	90.62	42.59	126.45
5	26.26	19.67	61.39	14.43	75.82	35.63	105.79
6	28.14	20.13	122.08	28.69	150.77	70.86	210.39
Total	173.41	121.91	457.95	107.60	565.57	265.82	789.21
Mean	**29.0**	**20.34**	**76.33 ±34.30**	**17.94 ±8.06**	**94.26 ±42.36**	**44.30 ±19.91**	**131.53 ±59.11**

Values in the table are mean ± CI = confidence interval at 95%; AGB = aboveground biomass; BGB = belowground biomass; Av = average per plot.

Table 2.
Biomass and carbon stock in standing trees of Gmelina arborea of Kasewe plantation forest.

24 to 64 tonne ha^{-1} with a mean of 19 tonne ha^{-1}; and the CO_2 sequestered ranges from 72 to 190 tonne ha^{-1} with a mean of 131.21 tonne ha^{-1} (**Table 2**).

3.1.5 Accumulated biomass and carbon in teak trees at Kasewe plantation forest

As in the case of *G. arborea*, the accumulated biomass and carbon contained in the standing trees of teak were estimated by individual trees and by plots. The estimated total biomass ranges from 47 to 141 tonne ha^{-1} with a mean of 94 tonne ha^{-1}; the carbon stock ranges from 22 to 66 tonne ha^{-1} with a mean of 44 tonne ha^{-1}; and the CO_2 sequestered ranges from 66 to 197 tonne ha^{-1} with a mean of 131 tonne ha^{-1} (**Table 3**).

3.1.6 Estimation of wood volume, biomass and carbon stock in standing trees of teak of Kasewe plantation forest

Estimation of volume, biomass and carbon stock using DBH and height was highly significant ($p = 0.000 < 0.0001$) according to ANOVA of the regression,

Plot	DBH (cm)	Height (m)	AGB (t ha^{-1})	BGB (t ha^{-1})	Total biomass (t ha^{-1})	Carbon stock (t ha^{-1})	CO_2 (t ha^{-1})
1	19.16	14.86	26.17	6.15	32.31	15.19	45.09
2	21.90	15.95	64.39	15.13	79.52	37.37	110.96
3	24.32	16.90	101.56	23.87	125.43	58.95	175.02
4	22.54	16.20	70.91	16.66	87.58	41.16	122.20
5	19.15	14.86	64.91	15.25	80.17	37.68	111.87
6	21.36	15.73	131.62	30.93	162.55	76.40	226.82
Total	128.43	94.50	459.56	108.0	567.55	266.75	791.97
Mean	**21.41**	**15.75**	**76.59 ±37.87**	**18.00 ±8.90**	**94.59 ±46.77**	**44.46 ±21.98**	**131.99 ±65.27**

Values in the table are mean ± CI = confidence interval at 95%; AGB = aboveground biomass; BGB = belowground biomass; Av = average per plot.

Table 3.
Biomass and carbon stock in standing trees of teak of Kasewe plantation forest.

Vegetation type	Av. DBH (cm)	Av. height (m)	Av. basal area (m^2 ha^{-1})	Av. stocking (stems ha^{-1})	Av. wood volume (m^3 ha^{-1})
Forest regrowth	15.85	12.40	6.33 ±0.07	283	54.94 ±0.72
Secondary forest	21.87	18.45	26.65 ±0.40	637	308.55 ±4.99
Whole forest	20.02	16.59	16.49 ±0.13	920	181.75 ±1.58

Values in the table are mean ± CI = confidence interval at 95%, Av = average per forest ecology.

Table 4.
Wood volume, basal area and stocking for Singamba natural forest.

which implies that variability in volume or biomass was regulated by the independent variables of DBH and height. From the model summary table, R^2 is 0.998 meaning that 99.8% of the variability in carbon stock was accounted for.

3.2 Results for Singamba natural forest

3.2.1 Diameter and height

The overall mean diameter for all the trees enumerated in the whole forest was 20.02 cm; the mean diameter for the secondary forest ecology was 21.87 cm, and the forest regrowth ecology was 15.85 cm. The overall mean height for the entire forest was 16.59 m, 18.45 m for the secondary forest and 12.40 m for the forest regrowth.

3.2.2 Wood volume, basal area and stocking of Singamba natural forest

The mean wood volume is summarized in **Table 4**. The overall wood volume and basal area for the entire forest were 181 and 16 m^2 ha^{-1}, respectively, and the stocking was 920 stems ha^{-1}.

Ecology	Mean DBH (cm)	AGB (t ha^{-1})	BGB (t ha^{-1})	Total biomass (t ha^{-1})	Carbon stock (t ha^{-1})	CO_2 (t ha^{-1})
Forest regrowth	15.85	44.72 (±11.33)	10.51 (±2.66)	55.22 (±13.99)	25.95 (±6.57)	77.06 (±19.52)
Secondary forest	21.87	240.01 (±77.98)	56.42 (±18.32)	296.41 (±96.31)	139.31 (±45.26)	413.62 (±134.39)
Whole forest	20.02	142.36 (±49.12)	38.45 (±11.54)	175.82 (±60.66)	82.63 (±28.51)	245.34 (±84.65)

Values in the table are mean ± CI = confidence interval at 95%; AGB = above ground biomass; BGB = belowground biomass.

Table 5.
Biomass and carbon stock of Singamba natural forest.

Wood production parameters	Plot count	Mean (value ha^{-1})	Variance	Standard error
Basal area (m^2/ha)	40	16.50	0.159	0.063
Volume (m^3/ha)	40	181.75	24.454	0.782
AGB (t/ha)	40	142.31	23590.442	24.285
AGC (t C/ha)	40	66.91	5211.129	11.414
CO_2 (t/ha)	40	245.34	70060.732	41.841
BGB (t/ha)	40	33.43	1302.782	5.707
BGC (t C/ha)	40	15.72	287.785	2.682
Total biomass (t/ha)	40	175.82	35980.733	29.992
Total carbon (t C/ha)	40	82.63	7948.144	14.096

Table 6.
Means and variances for selected wood production parameters in Singamba natural forest.

3.2.3 Accumulated biomass and carbon sequestration in Singamba natural forest

The biomass and carbon stock of the natural forest are presented in **Table 5**. For the whole forest, the estimated biomass ranges from 115 to 236 tonne ha^{-1} with a mean of 60.66 tonne ha^{-1}; the carbon stock ranges from 54 to 111 tonne ha^{-1} with a mean of 28.51 tonne ha^{-1}; and the CO_2 sequestered ranges from 160 to 330 tonne ha^{-1} with a mean of 84.65 tonne ha^{-1}.

3.2.4 Estimation of wood volume, biomass or carbon stock for the entire Singamba forest

ANOVA of the regression showed that estimation of wood volume, biomass or carbon stock using DBH, height or basal area was significant ($p < 0.05$), denoting that variation in volume or biomass was regulated by the independent variables of DBH and height. Statistic is shown in **Table 6**.

4. Discussion

4.1 Stand yield of plantation species

4.1.1 Stand volume

In the present study, it was found that volume and biomass and subsequently the carbon stock increased with growth of DBH and height of the stems of all the plantation species. Various allometric equations for volume and biomass (developed by different researchers) were used to estimate these parameters. Of the two species in Kasewe, *Gmelina arborea* proved better in terms of vertical and horizontal growth with mean DBH and height of 29.0 cm and 20.34 m, respectively, compared to *Tectona grandis* with mean DBH and height of 21.57 cm and 15.81 m, respectively. The results were in agreement with the findings of [12, 13] in Nigeria and [14] in India.

The results showed that the *G. arborea* stand produced a higher yield than the *T. grandis* in Kasewe plantation forest, both species being of the same age. This may be as a result of *Gmelina* being a fast growing species [32] of *Verbenaceae* family. It is a medium to large deciduous tree that attains a height of 35 m or more, with a DBH of over 120 cm in natural stands in tropical and subtropical regions of Asia [30, 31]. In Oyinmo forest (Nigeria), the estimated volume for both *Gmelina* and teak stands ranges from 347.92 to 508.33 m^3 ha^{-1} and from 21.25 to 259.06 m^3 ha^{-1}, respectively [13]; similarly, in Oluwa State [12] report a volume of 422.8 m^3 ha^{-1} (10 years) and 1023.4 m^3 ha^{-1} (25 years) for *G. arborea* and 445.8 m^3 ha^{-1} (10 years) and 978.3 m^3 ha^{-1} (25 years) in Omo State in Nigeria for the same species. This high productivity in Nigeria is attributed to the management practices leading to fast growth rate and high stand density [11]. The increase in the yield in their result could be attributed to the proper management of their plantation sites as there were intensive silvicultural treatments adopted, whereas the management of Kasewe plantation forest (14 years) is poor; thinning and clearing are most times not done which have led to the development of undergrowth, thus competing with trees for nutrients, space and water. As reported, plantations receiving various silvicultural treatments such as pruning, irrigation, fertilization and inter-cultivation have better growth and timber productivity than sole trees or poorly managed plantations [33].

4.1.2 Basal area

Basal area is known to be an indication of site potential [23] which gives support to the growth rate of trees in the forest. The result of this research for Kasewe is in agreement with those of other researchers, for example, in Nigeria. A basal area of 17.5–20.0 m^2 ha^{-1} was recorded for *Gmelina* and 9.0–10.0 m^2 ha^{-1} for teak; similar result was also obtained by Adekunle et al. [13] in Nigeria's rainforest ecosystem, and they reported the basal area in *G. arborea* stand to be 46.41 m^2 ha^{-1}, while the basal area per hectare ranged between 9.50 and 27.81 m^2 ha^{-1} in the *T. grandis* stand. Onyekwelu et al. [12] obtained mean basal area of 45.6 m^2 ha^{-1} (10 years) and 80.7 m^2 ha^{-1} (25 years) in the *Gmelina* stands at Oluwa, while 44.4 m^2 ha^{-1} (10 years) and 77.8 m^2 ha^{-1} (25 years) were obtained at Omo State, respectively, in Nigeria. The basal areas reported by [2, 13] are larger than those for Kasewe forest which can be as a result of better site quality in those forest stands in Nigeria. If age and management are similar, good sites are capable of supporting more species of trees, higher densities of trees and larger, faster growing trees as compared to poor sites [13].

4.1.3 Stocking

The estimated stem density for Kasewe plantation forest was 253 stems per ha; *Gmelina* (with mean DBH and height of 29.01 cm and 20.34 m, respectively) contributed 52%, while *T. grandis* (with mean DBH and height of 21.56 cm and 15.81 m, respectively) contributed 48%. The former was more better stocked than the latter, not only for its higher proportion of stems, but this could be attributed to

Gmelina stand having larger-sized stems than the teak stand. This resulted to higher volume yield of wood for *Gmelina* stand than that of teak. In other words forest yield depends mainly on the size and age of the stand [23, 31]. By comparing growth variables, *Gmelina* grows faster than *T. grandis* [12–14].

4.1.4 Biomass and carbon stock of plantation stands

As already stated, volume and biomass and subsequently the carbon stock increased with the increase in growth of DBH and height of the stems of all the plantation species. The range of coefficient of determination was found to be 98 and 99% for *Tectona grandis* and *Gmelina arborea*, respectively. This could be explained by the fact that volume and aboveground components of trees were highly dependent upon DBH and height [14].

The means of carbon stock of living trees (stems DBH $\geq$ 10 cm and roots), in the present study, from all plots were 94.26 and 94.59 t ha^{-1} for *Gmelina* and teak, respectively. The carbon stock appears to be the same for the two species since the initial estimation of biomass differed in allometric equations applied. They are, however, efficient in storing carbon. These results are comparable to those obtained by [14] in India—185 and 139 for 10-year-old plantation of *Gmelina* and teak, respectively.

4.2 Natural stands

4.2.1 Forest productivity

The estimated wood volume was 245.24 m^3 ha^{-1}. Within Singamba forest the secondary forest ecology was found to be more productive than the forest regrowth, meaning the former has more usable trees than that of the latter. The basal area was 21.87 m^2 ha^{-1} for Singamba forest. This parameter estimate seems to be relatively high for Singamba forest and can be compared with other tropical areas [31], generally serving as an indication for good site potential for wood production. As suggested before, deforestation was actively reducing the potential wood production of Kasewe plantation forest as a result of intensive sawmill and farming activities, and farming was also evident in Singamba natural forest.

The wood volume and basal area of Singamba forest are in close agreement with that for Gola rainforest [17]. This could be attributed to these two being natural forests which have higher soil nutrient for tree growth from litter fall, decomposition and high rate of microbial activities. Also, they could be less undisturbed than the forests of National Agricultural Training Centre (NATC), Njala University [32] and Kasewe plantation forest in Sierra Leone and are of high stand density and species diversity [32] which can help in increasing growth variables such as height and diameter at breast height which are responsible for the volume and basal area measurement.

The quantitative estimates of current and future wood volume and biomass of timber and other forest products are essential for forest management practices. Thus the information (e.g. mean height, DBH, volume and stem density) derived from the natural stands could be used by forest managers, researchers and policy makers at national and local levels.

4.2.2 Biomass and carbon stocks of the natural stand

The present study has attempted to provide the first estimate of tree biomass and carbon stock in Singamba based on representative field sampling. This has demonstrated how carbon density can vary across a disturbed forest ecosystem [17] with respect to human activities. Patterns of biomass [17] largely reflected past farming history in Singamba forest, demonstrating impact of disturbance on forest biomass, as had been noted for logging impact on Gola forest [17]. Despite human disturbance in the forest in the recent past (forest regrowth), there is clearly an indication (secondary forest) that the Singamba forest still retains substantial carbon stocks and can accumulate further if left undisturbed.

The estimates of C stock for the entire Singamba forest (from all 40 plots) were found to be 82 t C ha^{-1} (**Table 5**), and this included all above- and belowground biomass of living trees over 10 cm DBH but excluded standing dead wood, woody debris and leaf litter [17]. There was variation in C biomass for the plots and ecology, but the higher biomass was found in the secondary forest which seems relatively stable.

The overall C stock for Gola forest was 160 t C ha^{-1} [17], but the overall carbon stock for Singamba was far lower than that of Gola in the present study. Although values of Singamba did not accord well with those for Gola, if disturbance by the forest edge communities is minimized, especially the slash and burn farming; this could improve the carbon stock for Singamba.

5. Conclusion

Timber inventory using simple hand tools is an efficient measure to manage these resources especially for land owners. One hundred percent enumeration of trees in a discrete forest is tedious, time-consuming and not economical. Hence forest sampling is professionally accepted.

Management of forest carbon is a concern across the globe for mitigation of global warming. The two plantation species being studied at Kasewe, *Gmelina arborea* and *Tectona grandis* have high yield of volume and biomass and exhibited significant carbon sequestration.

This chapter enhances foresters and related technicians to be able to estimate and give account of carbon stocks in the forests of West Africa which are undergoing rapid deforestation, degradation and even encroachment [17]. In Sierra Leone, community-based forestry and forest inventory at national level are recommended for sustainable exploitation and conservation of forests.

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