Journal of
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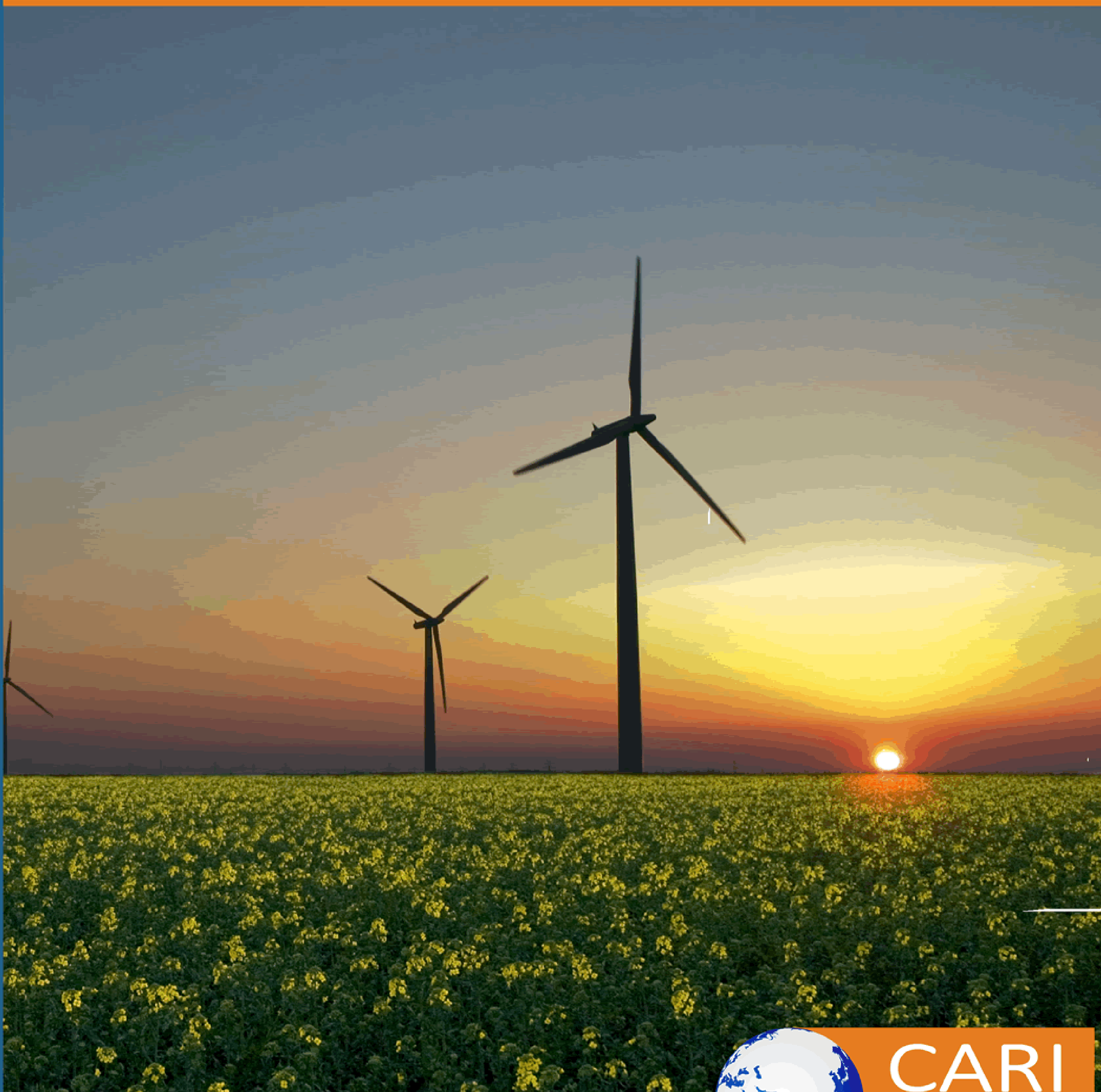

Journal of Environment
ISSN 2789-3863 (Online)
Vol. 5, Issue No. 3, pp 62 – 75, 2025
www.carijournals.org

Plantation of Native *Swintonia floribunda* Griff and its Contribution to Carbon Storage

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Accepted: 26th Apr, 2025, Received in Revised Form: 26th May, 2025, Published: 26th June, 2025

Abstract

Purpose: The study aimed to estimate the biomass and organic carbon storage of *Swintonia floribunda Griff*, a fast-growing and ecologically significant native tree species in Bangladesh, known for its carbon sequestration potential.

Methodology: A non-destructive, systematic methodology was applied to assess tree parameters, including diameter at breast height (DBH), height, and mean annual increments across age groups ranging from 15 to 55 years.

Findings: The findings revealed that 50-year-old trees recorded the highest DBH (65.45 cm) and height (31.52 m), while 15-year-old trees showed the highest mean annual diameter (1.75 cm) and height (0.92 m) increments. Biomass and carbon content ranged from 418.80 kg/tree to 5,253.60 kg/tree and 209.40 kg/tree to 2,626.80 kg/tree, respectively. Statistical analysis confirmed significant variation ($p < 0.05$) in biomass and carbon stock among age classes, with a strong positive correlation ($r = 0.99274$) between age and carbon storage. The study provides empirical evidence of the species' capacity to enhance carbon storage over time, offering valuable insights for policymakers, conservationists, and forest managers.

Unique Contribution to Theory, Practice and Policy: Its unique contribution lies in promoting a sustainable, non-destructive approach for assessing carbon stocks in endangered native species, supporting climate change mitigation and sustainable forest management in Bangladesh.

Keywords: *Swintonia floribunda, Biomass Estimation, Carbon Sequestration, Non-destructive Method, Forest Conservation, Bangladesh*

Introduction

Swintonia floribunda Griff. It is a native forest tree species of Bangladesh, which is found in Chittagong, Cox's Bazar and Chittagong Hill Tracts natural forest areas. *Swintonia floribunda* Griff. belongs to the family Anacardiaceae. Civit is the trade name of this species, and it is well known as a fast-growing forest tree species. Civit is a tall tree with a straight, cylindrical bole and height attains up to 25 m with a clear bole and 2.50- 2.80 m in girth (Das and Alam, 2001). Civit is a lofty evergreen glabrous and the lower part of the stem is often very fluted with long buttresses. The bark is grayish smooth with shallow vertical fissures, blaze pinkish. Leaves crowded towards the ends of the branches, Inflorescence of 15-30 cm long panicles. Bisexual flowers 3-4 mm across and pale yellow. Fruit is a drupe in nature. Flowering and fruiting from February to May (Motaleb and Hossain, 2010). Globally, civit is found in South and Southeast Asia. It is grown in the lowland and hill forests of Myanmar, Bangladesh, the Andaman and Nicobar Islands, Thailand, Vietnam, Peninsular Malaysia and Sumatra (Lemmens et al., 1995; Hossain, 2008). Civet is found in natural and plantation hill forests of Bangladesh, such as Chittagong Hill Tracts, Chittagong, Cox's Bazar, Tangail, Habiganj, Moulvibazar, Sylhet, Gazipur and Mymensingh district. The top canopy of this species reaches a height of 45-50 meters in the tropical wet evergreen forests and 25-57 meters in the tropical semi-evergreen forests (Hossain, 2008).

This species was widely used in plywood manufacture and used in boat building. It also produces a good quality pulp (Razzaque and Das, 1969). Civit orchards are found sporadically in different reserved and protected natural forest areas of Bangladesh. About 25 years old planted orchard was found in front of Padua rest house of Padua Range under Chittagong South Forest Division, Bangladesh. Another orchard was found in Hyanko Rubber Estate Hyanko, Chittagong, under Chittagong North Forest Division, Bangladesh. Civit is naturally found in Fulchari and Fasiakhali Range under Cox's Bazar, North Forest Division, Bangladesh. Most of the trees are mature, over-matured and scattered in the forest areas (Hossain, 2015). Civit is the most important native and fast-growing timber-producing forest tree species in the South Asia tropical forest areas. Trees attains from 11.00 to 13.10 meters clear bole within 16-15 years old plantation. Climatic conditions and edaphic criteria are the most favourable for the regeneration of *Swintonia floribunda* in the wet evergreen forests of Bangladesh. It contains recalcitrant seeds and falls from trees automatically in May to June. But unfortunately, civit orchards are under serious threat due to deforestation, encroachment, illegal felling etc. The major causes of forest degradation in Bangladesh are conversion of forest lands for agriculture crops, over-extraction of wood and non-wood resources, population growth, deforestation, settlement, urbanization and anthropogenic interferences etc. (Hossain, 1998; Salam *et al*., 1999; Hasan and Alam, 2006).

S. floribunda plays a vital role in improving the sound ecosystem of forest areas of Bangladesh. The species has high biodiversity values as it provides habitat for the nesting of the winged duck. For this reason, civit is included under the plantation program for the sustainable development of forest resources. So, carbon storage can be estimated for the implementation of plantation

Journal of Environment
ISSN 2789-3863 (Online)
Vol. 5, Issue No. 3, pp 62 – 75, 2025
www.carijournals.org

programs. The present study will help create awareness about endangered species conservation for better ecosystems. Keeping this point in mind, the present study has attempted to estimate the biomass and carbon stock of *S. floribunda* in Banga Bandhu Safari Park, Fasiakhali Forest Ranges under the Cox's Bazar North Forest Division, Cox's Bazar, Bangladesh.

2 Materials and Methods

2.1The study areas

The study area lies at 21°.78´ to 21.58° N latitudes and 92°.08 ´ to 92°.05 ´ ´E longitudes. It is located at Fulchari and Fasiakhali Forest Range under the Cox's Bazar North Forest Division. The whole study area is 15 hectares in two Forest Ranges and under their beat offices. The landscape of the study area is flat to gentle slope sandy, sandy loam, and acidic soil. The elevation of the study area ranged between 3 and 20 meters mean sea level.

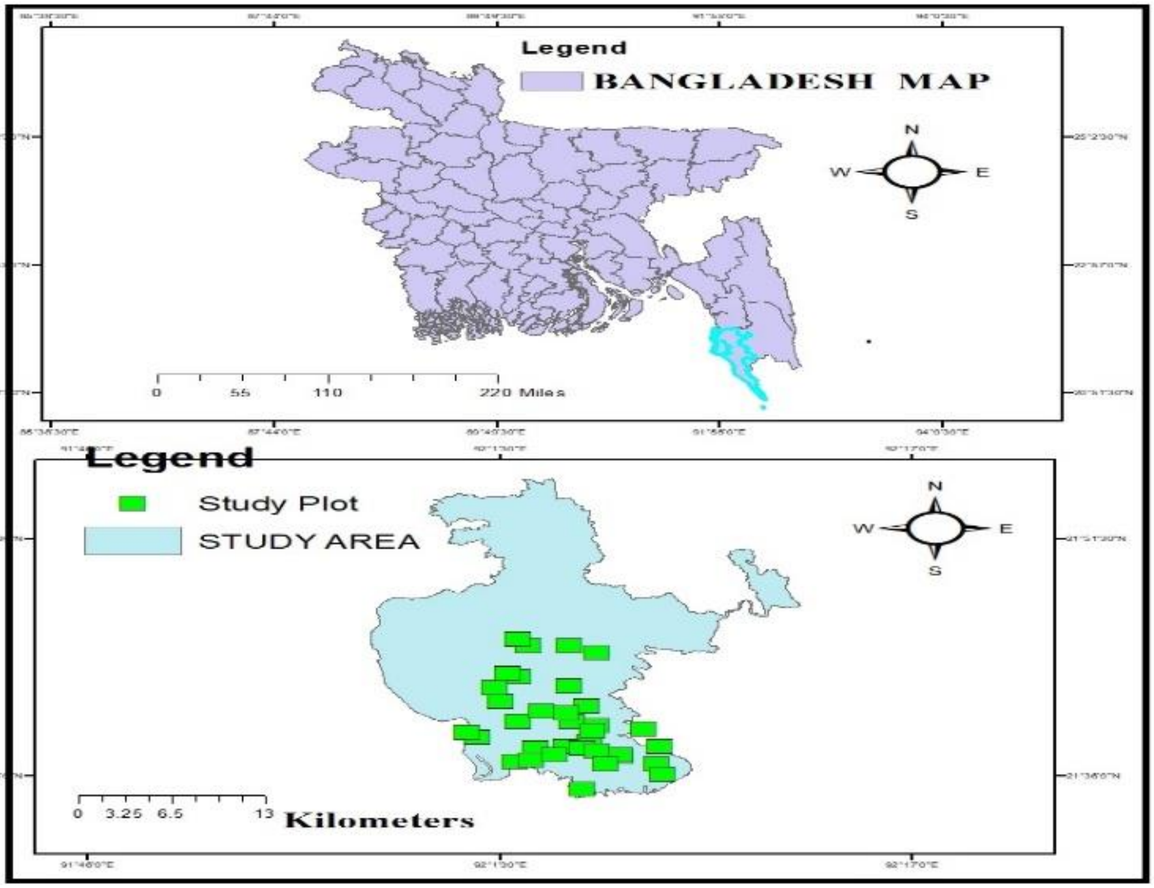

Figure 1: The location of the study area

2.2 Climatic conditions

The summer comes from March and continues up to the end of May. The rainy season starts in June and continues up to October. About 84% of rainfall occurs during this season. The main rain starts in the middle of June and continues up to the middle of July, and an average of 4500 mm of rainfall occurs during this time. The climate is tropical in nature. The climate is pleasant and balanced. Winter begins in mid-November and lasts until the end of February. From October to February, the weather is mild with low rainfall. The minimum and maximum mean temperature vary from 18.10° to 42.50° C in December and May respectively. In June, the highest humidity is 88%, while the minimum humidity is 55% in February (Bangladesh Meteorological Department, 2024).

2.3 Selection of plots

The study was based on sites selection, measurement of growth parameters of trees as well as determining carbon contents in different ages of *Swintonia floribunda*. Field studies were done from January 2024 to June 2024. There were one hundred twenty eight (128) plots distributed throughout the whole study areas. The plots were situated in varying locations, elevations and different age's forests. The coordinates were recorded using the Global Positioning System (GPS). A systematic sampling method was used for the selection of each plot with the help of global positioning system which is recognized all over the world. (Pearson *et al*., 2007). The whole study area was divided into 512 sub- plots which were 500 meters apart from each other. Four sub - plots (10 m radius) were set at 100 m intervals from the center of each plot in north-south and east-west directions.

2.4 Growth and biomass measurement of tree

After laying out of the plots, the number of trees in each plot were counted and recorded. The trees were measured for height and diameter at breast height (DBH). Each tree was marked and numbered to prevent double counting. A diameter tape was used to measure the DBH (1.30 m above from the ground level) of all the trees in each plot. Height of the trees having DBH equal or greater than 5 cm was measured with a Hega- altimeter. Trees on the border was included in a plot if > 50 % of their basal area fell within the plots and excluded if < 50 % of their basal area fell outside the plot (Rana *et at.*, 2012). Trees overhanging the plots were excluded, but with their trunk inside the sampling plots, and branches outside were included. Care was taken to ensure that the diameter tape was put around the stem exactly at the measurement point.

2.5 Estimation of tree biomass

A non-destructive method was used to measure the aboveground biomass of an individual tree. The model of Brown *et al.* (1989) was used to determine the AGB of each tree from its height and DBH values. This method is considered one of the most suitable methods for biomass estimation in tropical forests (Alves *et al*., 1997; Brown, 1997; Schroeder *et al*., 1997; Rahman, *et al*., 2021). The model for aboveground biomass is as follows.

AGB=exp. {-2.4090+0.9522ln (D^2HS)}

Where, AGB is the aboveground biomass (kg),

H is the height of the trees (m), D is the diameter at breast height (cm), and S is the wood density (kg /m^3) for specific species.

Wood density values of the species of the present study were obtained from Sattar *et al*. (1999). Aboveground biomass per plot, per track and per hectare were calculated by the following formulas:

AGB per plot = Summation of the AGB values of all the trees in a plot.

AGB per track = Summation of AGB values of all the plots in a track.

AGB per hectare = Sum of AGB values of all the plots in a track. Total area in all the plots in a track ×10,000

BGB was considered to be 15 % of the aboveground biomass as suggested by Mac Dicken (1997).

The formula is given below: BGB= AGB × (15 / 100).

The aboveground and belowground biomass was added to get the total biomass of a tree. Total biomass (TB) per plot and per hectare was calculated by the following formulas:

TB per plot = Summation of the total biomass values of all the trees in a plot.

TB per hectare = Summation of total biomass values of all the plots.

2.6 Carbon stock in trees

The carbon stock of a tree was estimated by assuming that biomass contained 50 % carbon (Brown *et al*., 1989). Carbon stocks per track and per hectare were also calculated. Carbon stock per track = Sum of carbon stocks of all trees in a plot carbon stock per hectare = Sum of biomass of all the plots (m^2) × total number of plots × 10,000×0.50**.**

2.7 Data analysis

Descriptive statistics were calculated to describe biomass and carbon densities in trees and their variations among different ages through a two-factor analysis of variance (ANOVA). Duncan's multiple range tests were used to determine the significance of the variation in mean. Statistical Package for Social Science (SPSS) version 21 was used to perform these analyses.

3 Results and Discussion

3.1 Determination of diameter at breast height and the total height of Swintonia floribunda

Swintonia floribunda is mainly found in the naturally protected forest areas of Bangladesh. The present study was indicated that average values of diameter at breast height and total height in different ages of *S. floribunda*. The findings indicated that diameter at breast heights were 26.21, 32.15, 36.54, 42.30, and 48.08, 54.21,60.19, and 65.45 (cm) respectively. The total heights were 13.80,16.55, 20.30, 22.50, 24.44, 26.20, 29.15, and 31.52 (m) at 15, 20, 25, 30, 35, 40, 45, and 50 years old plantation, respectively. The highest diameter at breast height and height were 65.45 (cm) and 31.52 (m) in 50 years old trees (Table -1). The lowest diameter at breast height and height were 26.21(cm) and 13.80 (m) in 15 years old trees (Table- 1). The values of diameter at breast height and height were increased slowly with the increasing of ages and their correlation was also a positive (r = 0.99274).

Table- 1: Determination of diameter at breast height and the total height of *S. floribunda*

Name of species	years	DBH (cm)	Height(m)
S. floribunda	15	26.21±0.10	13.80±0.08
	20	32.15±0.21	16.55±0.11
	25	36.54±0.12	20.30±0.06
	30	42.30±0.09	22.50±0.11
	35	48.08±0.11	24.44±0.07
	40	54.21±0.15	26.20±0.23
	45	60.19±0.04	29.15±0.19
	50	65.45±0.22	31.52±0.11

**DBH=Diameter at breast height (cm), H= Height (m)

3.2 Determination of mean annual diameter increment and mean annual height increment of *S. floribunda*

The maximum mean annual diameter increment was 1.75(cm) in 15-year-old trees, and the minimum mean annual diameter increment was 1.31(cm) in 50-year-old trees. On the other hand, the highest mean annual height increment was 0.92 (m) in 15-year-old trees and the lowest mean annual height increment was found at 0.63 (m) in 50-year-old trees (Table 2).

Table 2: Determination of MADI and MAHI of *S. floribunda*

Journal of Environment
ISSN 2789-3863 (Online)
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Name of species	Age (yrs.)	MADI (cm)	MAHI (m)
S. floribunda	15	1.75± 0.50	0.92± 0.15
	20	1.56± 0.70	0.83± 0.09
	25	1.46± 0.40	0.81± 0.17
	30	1.41± 0.34	0.75± 0.10
	35	1.37± 0.28	0.70± 0.14
	40	1.36± 0.21	0.66± 0.05
	45	1.34± 0.19	0.65± 0.08
	50	1.31± 0.11	0.63± 0.16

**MADI=Mean annual diameter increment and MAHI= Mean annual height increment

Diameters at breast height and height increased with age, and the rate of increase was higher in the initial stages. The present study indicated variations in mean annual increment diameter and mean annual increment height. A study by Rahman (2022a) reported that the mean yearly height increment was 1.73 m and the mean annual diameter increment was 1.84 cm of *Casuarina equisetifolia*. Another study was conducted by Rahman (2022b) and reported that the mean yearly height increment was 0.93 m and the mean annual diameter increment was 1.01 cm of *Acacia auriculiformis.* The findings show that mean yearly height increment and mean annual diameter vary from species to species.

3.3 Determination of basal area of *S. floribunda*

The research was conducted on different ages of *S. floribunda* and revealed that the average value of the basal area of each tree was 0.05. 0.08, 0.10, 0.14, 0.18,0.23,0.28, and 0.34m^2/tree at 15, 20, 25, 30, 35, 40, 45, and 50 years old trees respectively (Figure 2).

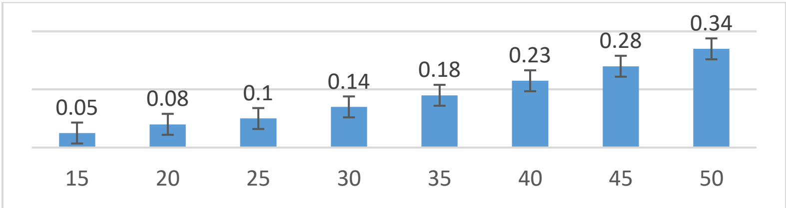

Figure -2: Basal area of *S. floribunda* of different ages

3.4 Relationship between diameter and the total height of *S. floribunda*

The biomass was determined based on diameter at breast height and the total height. The present research indicated a positive correlation between diameter and the total number of trees(r=0.992522). Statistical analysis revealed that diameter and height varied significantly in different ages(p<0.05).

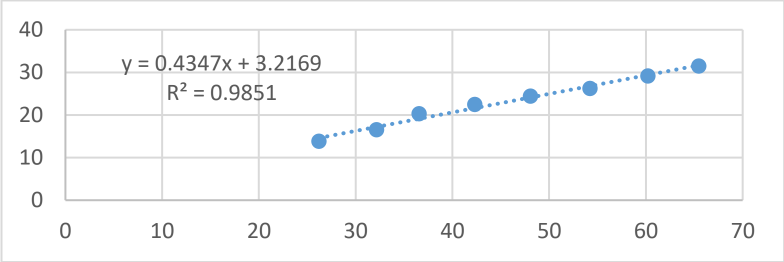

Figure 3: Regression between diameter and height of *S. floribunda*

Figure 3 indicated that the diameter at breast was increased 0.4347 and there was a positive linear relationship between diameter and height. The R^2 value was 0.9851, mean 98% of height was explained by diameter.

3.5 Relationship between diameter and biomass of *S. floribunda*

Diameter at breast height of tree is an essential parameter for the determination of biomass and carbon storage. The present research indicated that there was a positive correlation between diameter and biomass. In this case, correlation(r) value was 0.991733 between diameter and biomass. Statistical analysis revealed that diameter, and biomass values were greatly significant in different ages of trees ($p<0.05$).

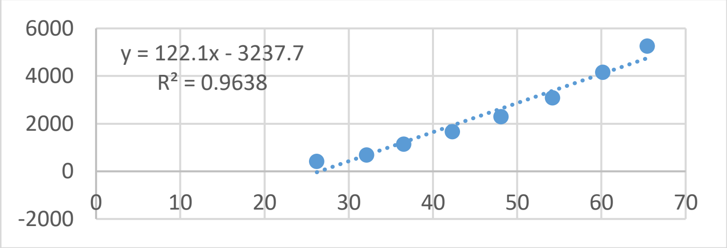

Figure -4: Regression between diameter and biomass of *S. floribunda*

Figure- 4 indicated that diameter at breast height was increased 122.10 and there was a positive linear relationship between diameter and biomass. The R^2 value was 0.9638 mean 96% biomass was explained by diameter.

4.6 Relationship between height and biomass of *S. floribunda*

The total biomass was depended on the total height of trees. The present study revealed that there was a positive correlation between height and biomass. In this case, correlation (r) value was 0.964416 between height and biomass. Statistical analysis revealed that height and biomass were greatly significant in different ages($p<0.05$).

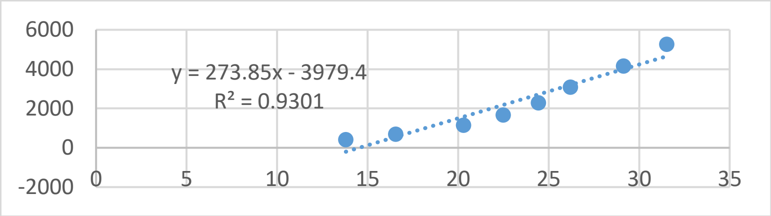

Figure -5: Regression between height and biomass of *S. floribunda*

Figure 5 indicates that the height increased by 273.85, and a positive linear relationship exists between height and biomass. The R^2 value was 0.9301, meaning 93 of % biomass was explained by height.

4.7. Determination of biomass of *S. floribunda*

The present study was conducted on *S. floribunda* tree species at different ages for the estimation of biomass and carbon storage. The maximum, minimum biomass and carbon were recorded at 5253.60, 418.80, 2626.80 and 209.40 kg/tree in 15 to 55-year-old trees, respectively (Table 4.8.3). The total biomass of *S. floribunda* of different ages is presented in Table 3.

Table -3: Aboveground biomass, belowground biomass and total biomass of different ages of *S. floribunda*

Name of species	Ages (yrs.)	AGB (kg/tree)	BGB (kg/tree)	TB (kg/tree)
S. floribunda	15	349.00±2.93	69.80±2.11	418.80
	20	567.48±3.44	115.30±1.95	682.78
	25	948.93±8.09	189.80±2.07	1138.70
	30	1383.10±7.46	276.60±2.33	1659.70
	35	1909.80±5.43	382.00±3.21	2291.70
	40	2563.50±6.27	512.70±3.25	3076.20
	45	3464.60±5.41	692.90±3.29	4157.50
	50	4378.00±5.09	875.60±2.88	5253.60

**AGB=Aboveground biomass, BGB=Belowground biomass, TB= Total biomass

The results revealed that the aboveground biomass, belowground biomass and the total were 349.00, 567.48, 948.93, 1383.10, 1909.80, 2563.50, 3464.60, 4378.00 and 69.80,115.30,189.80,276.60,382.00,512.70,692.90 875.60 and 418.80, 682.78, 1138.70, 1659.70, 2291.70, 3076.20, 4157.50 and 5252.60 kgtree^{-1} at 15, 20, 25, 30, 35, 40, 45, and 50 years old respectively.

4.8 Determination of carbon of *S. floribunda*

The research revealed that the aboveground carbon, belowground carbon and the total carbon were174.50, 283.74, 474.47, 691.55, 954.90, 1281.75, 1732.30, 2189.00 and 34.90, 57.65, 94.90, 138.30, 191.00, 256.35, 346.45, 437.80 and 209.40, 341.39, 569.37, 829.85, 1145.90, 1538.10, 2078.75 and 2626.80 kgtree^{-1} at 15, 20, 25, 30, 35, 40, 45, and 50 years old respectively (Table-4).

Table- 4: Aboveground carbon, belowground carbon and total carbon *of S. floribunda*

Name of species	Age (yrs.)	AGC (kg/tree)	BGC (kg/tree)	TC (kg/tree)	Carbon tree^{-1}year^{-1}(kg)
S. floribunda	15	174.50	34.90	209.40	13.96
	20	283.74	57.65	341.39	17.07
	25	474.47	94.90	569.37	22.77
	30	691.55	138.30	829.85	27.66
	35	954.90	191.00	1145.90	32.74
	40	1281.75	256.35	1538.10	38.45
	45	1732.30	346.45	2078.75	46.19
	50	2189.00	437.80	2626.80	52.54

**AGC=Aboveground carbon, BGC=Belowground carbon, TC= Total carbon

4.9 Determination of carbon sequestration capacity of *S. floribunda*

The present research indicated that the total capturing carbon dioxide values were 51.23, 62.65, 83.58, 101.52, 120.16, 141.12, 169.54 and 192.81 kgtree^{-1}year^{-1} at 15, 20, 25, 30, 35, 40, 45, and 50 years old, respectively (Table 4.8.5). The research also indicated that the total releasing oxygen values were 37.40, 45.73, 61.02, 74.11, 87.71, 103.71, 123.76 and 140.75 kg tree-1 year-1 at 15, 20, 25, 30, 35, 40, 45, and 50 years old, respectively (Table 5).

Table-5: Carbon storage, capturing CO_2 and releasing O_2 tree^{-1}year^{-1} of *S. floribunda* in different ages

Name of species	Ages (yrs.)	Carbon storage tree^{1}year^{-1}	Capturing CO_2tree^{1}year^{-1} (kg)	ReleasingO_2 tree^{1} year^{-1}(kg)
S. floribunda	15	13.96	51.23	37.40
	20	17.07	62.65	45.73
	25	22.77	83.58	61.02
	30	27.66	101.52	74.11
	35	32.74	120.16	87.71
	40	38.45	141.12	103.71
	45	46.19	169.54	123.76
	50	52.54	192.81	140.75

The highest amount of capturing carbon dioxide and releasing oxygen were 192.81 and 140.75 kgtree^{-1} found in *S. floribunda* at 50 years old respectively. The lowest capturing carbon dioxide and oxygen were 51.23 and37.40 kg tree^{-1} found in *S. floribunda* at 15 years old respectively. A 50-year-old tree had the highest biomass and carbon, while a 15-year-old tree had the lowest biomass and carbon. Statistical analysis revealed that the biomass and carbon stock (tC/tree) varied significantly ($p < 0.05$) among the different age's trees.

A study was conducted on biomass and carbon storage of *Swietenia macrophylla* in the Rajshahi University campus area and reported that the maximum aboveground biomass, belowground biomass and carbon values were 1100.80, 165.10 and 632.94 kg/tree in 50 years old plantation. The lowest aboveground biomass, belowground biomass and carbon values were 166.12, 63.35 and 95.52 kg/tree in 15 years old plantation. The mean aboveground biomass and belowground biomass, total biomass and total carbon values were 642.11, 69.32, 738.43 and 184.61kg/tree in 15 to 50 years old plantation (Rahman *et al.*, 2023). In this case, mean aboveground biomass and belowground biomass, total biomass and total carbon values were 1945.55, 389.34, 2334.87 and 1168.01kg/tree in 15 to 50 years old plantation of *Swintonia floribunda.*

A study was conducted in the Kaptai National Park of Bangladesh (Rahman *et al*., 2021) and observed that above ground biomass (AGB) per tree was the highest in *Dipterocarpus turbinatus* (647.29 kg/tree) and the lowest was found in *Gmelina arborea* (206.15kg/tree). The maximum below ground biomass value was found in *Dipterocarpus turbinatus* (97.09 kg/tree) and the minimum value was present in *Gmelina arborea.* The total biomass followed the order *Dipterocarpus turbinatus>Swietenia macrophylla > Tectona grandis >Acacia auriculiformis > Lagerstroemia speciosa > and > Gmelina arborea*. The maximum and the minimum values were 744.39 and 237.07 kg/tree in *Dipterocarpus turbinatus* and *Gmelina arborea*. Wide variation in the biomass potential of a tree species may occur due to differences in provenances, stand density, tree age, site characteristics and management etc. Carbon storage capacity of *Tectona grandis, Albizia lebbeck, Butea monosperma, Azadirachta indica and Eucalyptus citriodora* were 1.92, 2.42, 12.27, 3.35 and 1.81t/tree respectively in the North Maharashtra University campus in India (Suryawanshi *et al.*, (2014). The total above ground biomass ranges were 9.36-306.01kg/tree for *Gmelina arborea* and 7. 25- 314.61 kg/tree for *Swietenia mahagoni* in Philippines (Kawahara *et al*., 1981). It was also observed that total above ground biomass of *Acacia auriculiformis* ranged from of 15.71- 49.08 kg/tree and 9.18- 68.58 kg/tree in Philippines (Buante, 1997). A study was conducted on Badamalai Hill forest in India and reported that a single tree contained less values of biomass and carbon than compared to the present findings. The present study indicated that the ranges of total above ground biomass were 418.80-2334.87 kg/tree which was better than other forest tree species.

5. Conclusion

Swintonia floribunda is one of the most critical forest tree species in tropical regions such as Bangladesh. Recognized as a native and environmentally friendly species, it plays a significant role in ecological balance and carbon sequestration. However, natural populations of this species—commonly found in natural and protected forest areas—are under severe threat due to deforestation, land encroachment, and illegal logging. This study has demonstrated that *S.*

floribunda has a significantly higher carbon storage capacity compared to other commonly planted timber species such as *Lagerstroemia speciosa*, *Litchi chinensis*, and *Tectona grandis*. The findings highlight the tree's substantial potential to mitigate the effects of climate change and contribute to reducing global warming. Thus, *S. floribunda* is vital for biodiversity conservation and long-term forest sustainability and climate resilience in Bangladesh.

Recommendations

1. **Conservation and Restoration**: Immediate efforts should be taken to conserve *S. floribunda* in its natural habitat. Restoration programs should prioritize this species in reforestation and afforestation activities.
2. **Policy and Governance**: Policymakers and forest administrators should recognize the ecological and environmental value of *S. floribunda* and incorporate it into national forest development plans.
3. **Awareness and Education**: Mass awareness campaigns should be initiated to educate the public, especially local communities and planters, about the importance of conserving this endangered species.
4. **Scientific Management**: Application of scientific and non-destructive monitoring methods should be encouraged to track growth, biomass, and carbon storage without harming the trees.
5. **Public-Private Partnerships**: Private entrepreneurs and NGOs should be engaged to promote large-scale planting and sustainable management of *S. floribunda* as a commercially viable and ecologically beneficial species.
6. **Further Research**: Continued research should be undertaken to explore genetic improvement, adaptability, assessment of ecological contribution and long-term carbon sequestration potential of *S. floribunda* under changing climate conditions.

Acknowledgement

The author is extraordinarily grateful to Professor Dr. Mohammed Kamal Hossain, Forestry and Environmental Sciences, Chittagong University, Chittagong, for providing some important information on *Swintonia floribunda* and its location in different regions of Bangladesh. The author thanks the staff of Fulchari and Fasiakhali Forest Ranges under the Cox's Bazar North Forest Division for their endless help during the data collection period. The author is grateful to the Tropical Forest Conservation project implementing entities for providing their experience and information in preparing this manuscript.

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