XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Title

Assessing Tree Succession, Species Diversity and Carbon Sequestration Potentials in Off-Reserve Secondary Forests for REDD+ Implementation in Ghana.

Jacob Amoako[1,2*], Juergen Blaser[2] , Boateng Kyereh[1]

[1]Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ashanti, Ghana.
[2]Berner Fachhochschule, Bern, Bern, Switzerland.
*Corresponding author: jacobamoako2012@gmail.com

Abstract

Ghana is losing its primary forest, mostly forest reserves at an alarming rate. Secondary forests play a vital role in tropical landscapes, but few studies exist to assess their regeneration pathways and carbon sequestration in Ghana. We sought to find out the regeneration potentials, species diversity and carbon stocks accumulation of off-reserve secondary forests in the Moist Semi-deciduous and Dry Semi-deciduous zones. Four age classes were studied; 0-5, 6-10, 11-15 and 15+ years. Four plots with three replications were used for each age class. Nested plots were chosen; 33 m x 33 m for trees (dbh≥ 5 cm) 10 m x 10 m for saplings (≥1m tall and dbh <5cm) and 2 m x 2 m for seedlings. Age had significant differences in tree (dbh≥ 5 cm) density and basal area between the sites but not on sapling and seedling densities. A total of 129 tree species with dbh ≥5cm belonging to 95 genera and 40 families were identified. Mean Shannon-Weiner diversity index of trees (dbh ≥ 5cm) was 3.6±0.2 and 3.3±0.3 for the Moist Semi-deciduous and Dry Semi-deciduous zones respectively. Both age and forest site had significant effect on aboveground carbon accumulation with age of forest having more significance than climatic conditions. Age of a secondary forest has more effect on the species composition than climate. The secondary forest depicts the characteristic of young growth where the tree densities of most trees are confined to dbh= 5-10cm in both zones and the potential of rapid recovery of species and carbon accumulation represents an important source of timber and carbon sink. The strong presence of regeneration portrays the potential for carbon sequestration under Reducing Emissions from Deforestation and forest Degradation (REDD+) if secondary forests are managed well in Ghana. Collaborative management of secondary forests with farmers and good forest polices can help Ghana achieve benefits such as timber, woodfuel, and carbon to participate in REDD+.

Keywords: [Deforestation and forest degradation, REDD+, secondary forest, Climate change, Landscape management]

Introduction, scope and main objectives

Forests have been on the global discussion table as mitigation efforts are pursued for climate change. Forests store considerable amounts of carbon depending on their physical conditions such as successional stage, disturbance history, tree community composition, and site factors especially climate and soil fertility (Ngo *et al.* 2013). Secondary forests are often important in shifting cultivation agricultural systems in the tropics involving clearing of land usually with assistance of controlled burning followed by phases of cultivation and secondary forest regeneration during fallow periods for the purposes of soil restoration (van Breugel 2007). Secondary forests, in all its successional stages comprise a large and growing proportion of the forest cover in Ghana. It is reported that only 8% of Ghana's forest is still primary (FAO 2010), the remaining are either degraded forests (in forest reserves) or secondary re-growth (Oke *et al.* 2010) that exist at different levels of succession. Few studies have been done on secondary re-growth in Ghana to assess their potential for forest management, carbon sequestration and carbon storage. This lack of data as suggested by ITTO (2002), affects the perceptions of people especially policy makers leading to low prioritization and consequently poor management and inappropriate conversion of the resources in them. This study seeks to estimate carbon stored in the above ground biomass of various successional stages of secondary forests in the Semi-deciduous Forest zone of Ghana and their potential to promote the agenda of REDD+ in Ghana. Specific objectives are:

i. To determine successional changes in secondary forests of different ages and ecological locations in areas outside forest reserves in the semi-deciduous forest zone of Ghana.
ii. To estimate carbon stored in the above ground biomass of various successional stages of secondary forests in the semi-deciduous forest zone

Methodology/approach

Study Area

The study was carried out in two sites, Adwafo, in the Adansi south district (6 01.220 W1 34.640 N) and Kwaman (7 00.275 N 1 15.899 W) in the Sekyere district found in the Moist Semi-deciduous and Dry Semi-deciduous forest sites respectively in the Ashanti Region of Ghana (Hall and Swaine 1981). In these two sites, inhabitants rely on slash-and-burn agriculture, with land rotation as key strategy of allowing the land to fallow to regain fertility. Patches of current slash-and-burn farm plots, usually less than 3 ha in extent, and successional forests growing on abandoned agricultural fields are dispersed throughout the landscape. Moist semi-deciduous forest area receives an annual rainfall of between 1500mm and 1750mm and mean monthly minimum and maximum temperatures varying between 26°C and 29°C respectively. The dry semi-deciduous forest area receives an annual rainfall between 1,250 mm and 1,500 mm. Mean maximum temperature is 33°C whilst mean minimum temperature is 18°C.

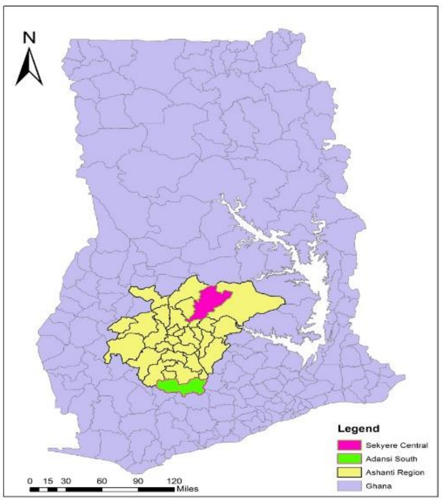

Figure 1: Map of Ghana showing the study areas

Establishment of sampling plots

Stratified sampling was used for this study. Stratification was done on the basis of ecological zones(sites) and age of secondary re-growth. Four age classes were used for the study; 1-5 (Age class 1), 6-10 (Age class 2), 11-15 (Age class 3) and 15+ years (Age class 4). Plots of sizes 33 x 33m giving rise to an area 0.1089 ha were established on the selected sites in the two ecological zones. The plots were established, to capture variability of the particular stand characteristics.

Four plots each for an age class were used in each site. Three replication of each plots summing up to 12 plots for each age class was used. In all, 96 plots of 33 x 33m were used for the study, 48 plots in each site. In each transect, the diameter at breast height (d) of trees (d≥5 cm) were identified and measured in 33m*33m continuous quadrants.

Biomass and Carbon Estimation

Biomass and carbon estimation was done for trees (d≥5cm). Wood density of tree species used for the calculations where obtained from the Global Wood Density Database (Chave *et al.* 2009). When no regional default data was available for a certain species, the average of the other regional default data for this species was taken. Lianas, bamboos and palms were excluded from biomass and carbon calculations. Using the Chave *et al.*(2005), allometric equation for moist tropical forest species, the aboveground live dry biomass (AGB in metric tons) of a single tree was calculated as:

*AGBtree= (p*exp(-1.499+(2.148*ln(D))+(0.207*ln(D)2)-(0.0281*ln(D)3))+0.001),* where D is the diameter (cm) of the tree.

The AGB values calculated for each tree were added to obtain an estimate of the total AGB for the sample plot. This was later extrapolated to hectare basis by the formula;

$AGB_h = (A_h/A_p) * AGB_p$,

where AGB_h is the estimate of aboveground biomass in metric tons per hectare, A_h is the area of one hectare in square meters (10,000), A_P is the area of the plot in square meters (33mx33m) and AGBp is the plot level estimate of aboveground biomass in metric tons. A conversion factor of 0.47 was applied to the aboveground biomass to obtain carbon accumulated for the plots in the secondary forests . All analyses were performed with R statistical package version 3.0.3 and Microsoft Excel 2010.

Results

Secondary Forest Structure

Mean density of trees (d ≥ 5cm) increased with stand age for both sites with the exception of age class 4 in the sample plots of the Moist Semi-deciduous Forest site. The same was found for total basal area where only age class 2 deviated from the linear increase of basal area with age.

Table 1: Mean ± standard deviation and coefficient of variation of number of stems (N/ha), basal area G (m2/ha) and frequency of species grouped per age classes for trees (d ≥ 5cm) in the Moist Semi-deciduous and the Dry Semi-deciduous Forest sites

Variable	Age class 1	Age class 2	Age class 3	Age class 4
	(1-5years)	(6-10 years)	(11-15 years)	(15^+ years)

N/ha (Moist)	262±131 (50%)	351±197 (56%)	600±222 (37%)	533±181 (34%)
N/ha (Dry)	172±128 (74%)	387±146 (38%)	538±171(32%)	588±150 (26%)
G(m^2/ha) (Moist)	4.63±2.78 (59%)	7.89±4.29 (54%)	11.89±3.59 (30%)	18.18±8.89 (49%)
G(m^2/ha) (Dry)	4.37±1.06 (24%)	3.19±0.67(21%)	13.81±3.19(23%)	15.59±1.99(13%)

Table 2: Analysis of variance table

Variable	Independent variable	P-value	Significance
Tree density (N/ha)	Age	8.891e-13	***
Tree density (N/ha)	Zone	0.51	ns
Tree density (N/ha)	Zone*Age	0.148	ns
Basal area G (m^2/ha)	Age	2e-16	***
Basal area G (m^2/ha)	Zone	0.10160	ns
Basal area G (m^2/ha)	Zone*Age	0.03405	*

ns- Not significant (P > 0.05), *significance difference (P ≤ 0.05), **significance difference (P ≤0.01), ***significance difference (P ≤0.001)

- **Diameter Distribution**

Error! Reference source not found., displays the characteristic of young growth of the secondary forests where the tree densities of most trees are confined to d= 5-10cm in both zones. Tree frequencies decreased with the increase in diameter. Diameter distribution of trees in age class 1 of both zones had high variation with the minimum diameter of 5cm for both site and maximum diameter of 100cm and 115cm for Moist and Dry Semi-deciduous respectively. These big trees are remaining trees from former (primary) forests (**Error! Reference source not found.**). They do not represent the true structural growth of the age classes' of young secondary forests.

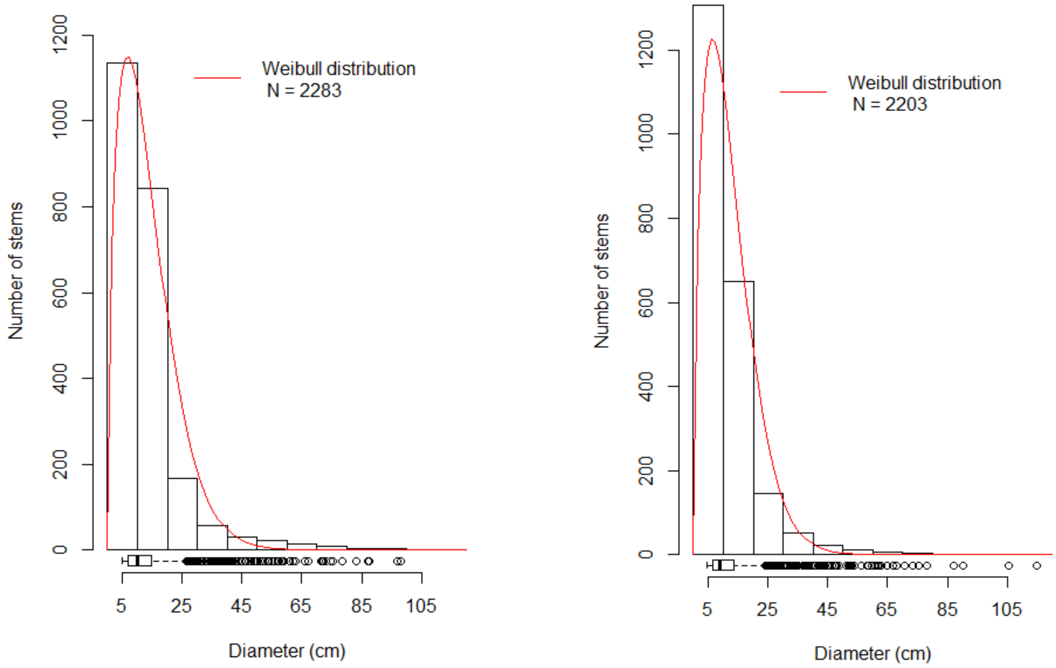

Figure 2:Tree diameter distribution for Moist Semi-deciduous site (left) and Dry semi-deciduous forest site (right) with boxplots beneath the bars showing the percentiles of the data

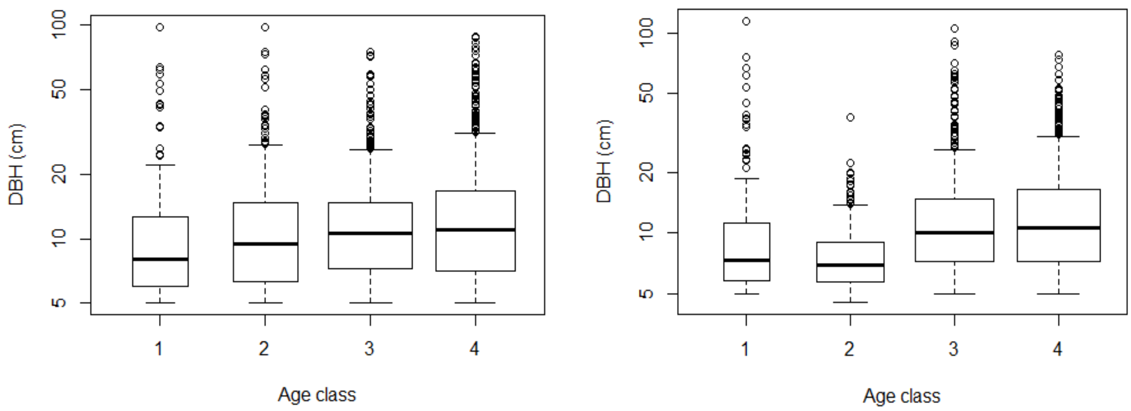

Figure 3:Tree diameter distribution by age classes for Moist Semi-deciduous site (left) and Dry Semi-deciduous site (right).

Species composition, abundance and occurrence

A total of 129 species of trees (d ≥ 5cm) belonging to 40 families were found for this study. The maximum number of tree species (17) belongs to the family of Fabaceae which accounts for 13% of the total individuals encountered in the study sites. *Albizia zygia* is the most widely occurring species from this family.

Species Accumulation

Species accumulation curves show the likely number of species to be sampled at a point in time based on the area being sampled. Examination of species accumulation curves as a function of sampled area indicate that for tree richness is consistently lower in the Dry Semi-deciduous zone than in Moist Semi-deciduous secondary forest stands.

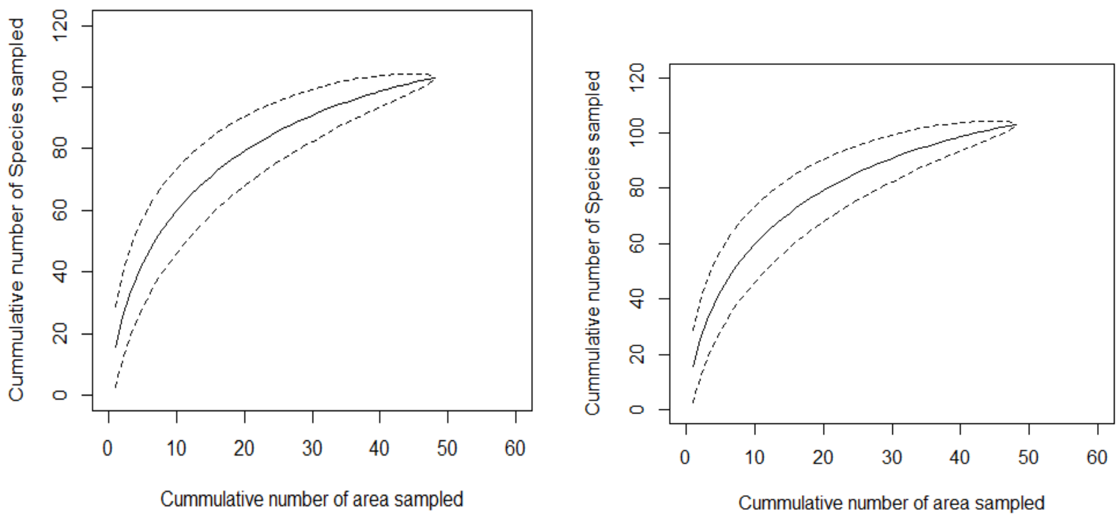

*Figure 4:Species accumulation curves for trees in the moist semi-deciduous zone (left) and dry semi-deciduous zone (right) in 48 (33*33m) sampled plots. Dashed lines indicate 95% confidence intervals for species richness based on sample-based rarefaction*

Species diversity and similarity

Jaccard similarity index for trees was 61% between the Moist and Dry sites. This similarity of species between the sites reduced for the seedlings to 50 % and further down at the sapling category to 44%. Within the zone, similarity of secondary forests was higher in the Moist Semi-deciduous zone compared to the Dry Semi-deciduous zone. The Shannon-Weiner diversity index of trees (d ≥ 5cm) was higher 3.6±0.2 in the moist semi-deciduous compared to dry semi-deciduous zone 3.3±0.3 with mean species evenness of 0.82. Therewas however no significance of Shannon-Weiner diversity index with zone effects (P-value= 0.391).

Carbon Accumulation

The aboveground carbon accumulation of the stand increased with age from 15.5±8.3 in 1-5 years secondary forest to 79.4 ± 43.9 in 16-25 years in the Moist Semi-deciduous Forest site. The same was observed for the Dry Semi-deciduous Forest site where carbon increased from 18.9 ± 6.3to 51.2 ± 9.5. Both age and zone had significant effects on carbon accumulation. To estimate the contribution of remnant trees to aboveground biomass and carbon, analysis was done for carbon accumulation by limiting the sizes of huge trees which are perceived to be from the previous primary forest/old secondary forest. A limit of diameters for each age class was set as follows; (d≤ 20cm for age class 1), (d≤ 40cm for age class 2) and (d≤ 60cm for age class 3). There was no limit for age class 4 as these where considered old enough and separating remnant trees and regenerated trees will be difficult.

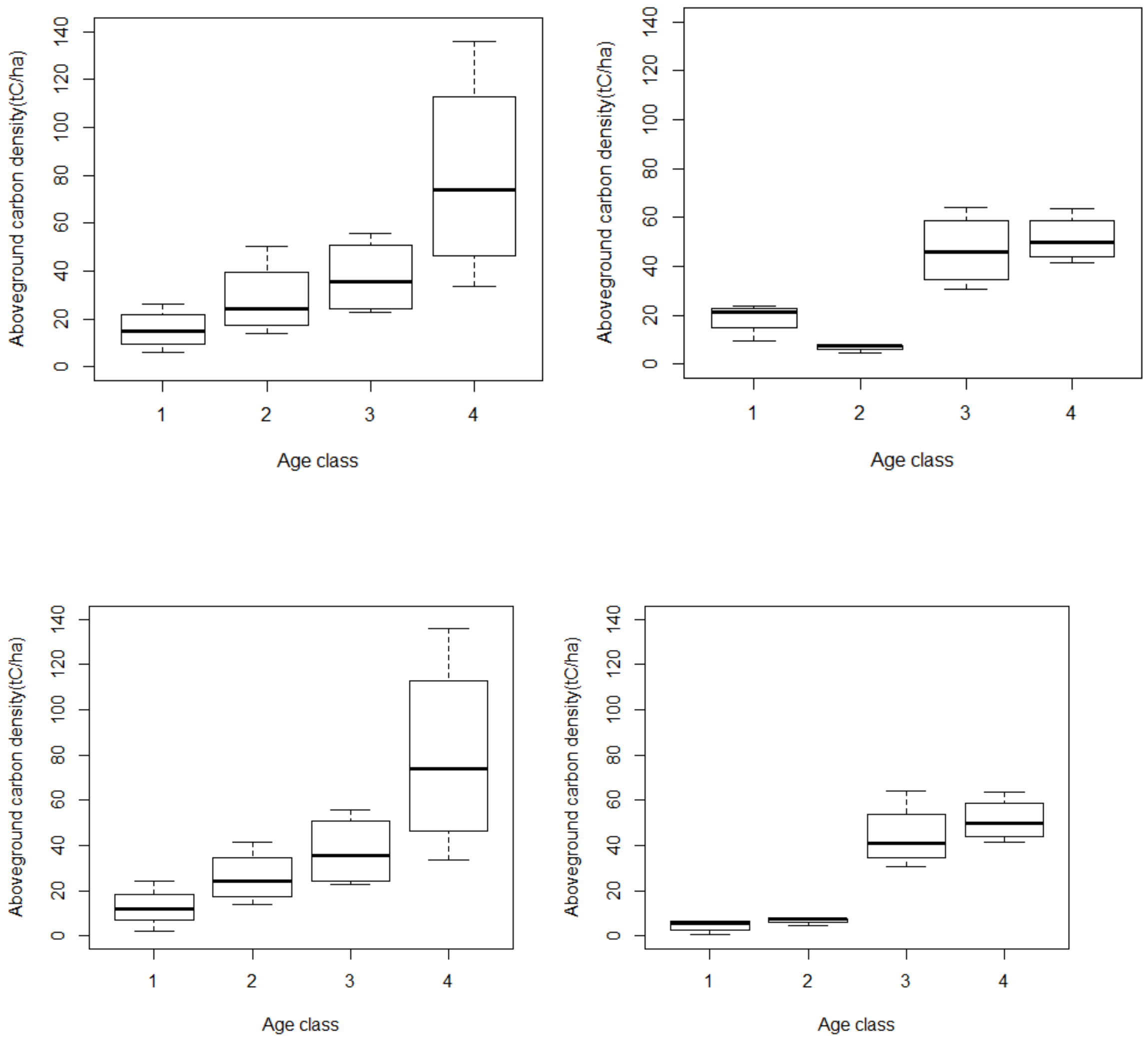

Figure 5: Aboveground carbon density for age classes without a limit to diameter range (top) and Aboveground carbon density for age classes with limits to the diameter range for an age class (down) for both moist semi-deciduous (left) and dry semi-deciduous (right)

Table 3: Aboveground carbon density (ACD, t/ha) for trees (d ≥5cm) in both Forest site per age classes

Limit	**Variable**	**Age classes**			
		1	2	3	4
All trees (no diameter limit)	ACD (t/ha) Moist	15.5±8.3 (54%)	28.2±15.9 (56%)	37.3±15.9 (42%)	79.4±43.9 (55%)
	ACD (t/ha) Dry	18.9 ± 6.3 (33%)	7.4± 1.3 (19%)	46.6 ± 14.9 (32%)	51.2 ± 9.5 (19%)

Diameter limit applied	ACD (t/ha) Moist	12.6±9.1 (72%)	27.8±11.8 (42%)	37.3±15.9 (42%)	79.4 ± 43.9 (55%)
	ACD (t/ha) Dry	4.5 ± 2.7 (60%)	7.4± 1.3 (19%)	44.3 ± 14.3 (32%)	51.2 ± 9.5 (19%)

Discussion

- ### Changes in forest structure

Increase of tree density as the secondary forest aged corroborate the findings of Holz et al.(2009) who found tree density to increase with age of secondary forest in tropical forest in Northern Argentina. Klanderud et al. (2010) study also found an increase in the number of trees when fallows aged in a slash-and-burn agriculture in a tropical rainforest in Madagascar.

The inconsistencies in results of increase or decrease in stem density suggest a lack of a generalizable pattern in linking tree density to stand age in secondary forests. Density of individuals is affected by multiple factors which influence recruitment, growth and mortality of individuals (Holz et al. 2009).

- ### Species richness

The species accumulation curves for the trees had reached a plateau and relatively less or no species could be found with increase in plot number. It can therefore be concluded that the number of sample plots selected for this study were enough to fully characterise the possible tree species composition of the two secondary forest sites. These results reinforce the views of Letcher and Chazdon(2009)that to explain patterns of succession in the tropics, an adequate level of replication is needed at each point in the time series and relatively large plots enhances the chances of capturing variations in floristic diversity. A progressive increase in the number of species per hectare for trees is observed as the forest becomes more mature. Secondary forest species composition became relatively stable between 13- 25 years after abandonment of agriculture. Only a few species are recruited as the forest grows from this stage.

Species diversity and similarity

Shannon-Weiner diversity index of trees (d≥ 5cm) was higher 3.59±0.16 in the Moist Semi-deciduous zone compared to Dry Semi-deciduous zone 3.27±0.32. This was as a result of the higher species richness of the moist semi-deciduous which also had a fair distribution of the relative abundance of the different species making up the richness of the area i.e. evenness of species richness. In assessment of similarity of species between age classes, it was found that younger forests were similar to other younger forests but differed when compared to their older counterparts. The same was true for older forests as forest of age between 11-15 years was more similar to 16- 25 years than compared to 1-5 years old secondary forests. These differences in similarity especially during the early successional stages can be attributed to the distinct absolute and relative abundance of individuals initially established and by presence of remnant trees.

- **Carbon accumulation**

Carbon accumulation was higher in the Moist Semi-deciduous than the Dry Semi-deciduous forest site for the study. This is consistent with the fact that humid forests are generally more productive than forests in drier conditions (Brown and Lugo 1982). Aboveground carbon accumulation increased with age of stand. This was attributed to the presence of remnant trees from the former primary/old secondary forests. When the effects of the remnant vegetation were excluded by setting a limit to the diameter of the trees, these abnormalities were curtailed and carbon accumulation corresponded with increase in stand age. A similar observation was made by Guariguata *et al.*(1997).

Conclusions/ wider implications of findings

The rapid accumulation of carbon with age by secondary forests as seen from the results of this study presents a potential for off-reserve secondary forests in Ghana under REDD+ scheme. Permanence of carbon and its risks as well as monitoring in terms of leakages will be at stake here. From the study, the contribution of remnant trees to carbon stocks is high. This suggests that management practices can be improved to increase carbon stocks in secondary forests especially stocks available in large remnant trees. Direct planting of trees on farms prior to the fallow phase (from which secondary forests develop) is proposed.

It can be concluded from the results that the successional stage of a secondary forest has more effect on the species composition and regeneration processes of the forest than the effects of climatic conditions. Also the study concludes that the amount of carbon stored in forests varies considerably depending on forest conditions (age and site conditions).

On the basis of the above conclusions, the study recommends further research which integrates the intensity and type of land use history prior to abandonment and soil properties as these also can affect regeneration and carbon accumulation.

Acknowledgements

This work was supported by the African Forest Forum through the HAFL- AFF Scholarship project phase 1 coordinated by Bern University of Applied Sciences.]

References

Brown S, Lugo AE, 1982. The Storage and Production of Organic Matter in Tropical Forests and Their Role in the Global Carbon Cycle. Biotropica, 14 (3), 161.

Brown S, Lugo AE, 1990. Tropical secondary forests. Journal of Tropical Ecology, 6 (01), 1.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure J, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T, 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145 (1), 87–99.

Chave J, Coomes D, Jansen S, Lewis SL, Swenson NG, Zanne AE, 2009. Towards a worldwide wood economics spectrum. Ecology letters, 12 (4), 351–366.

Chazdon RL, 2014. Second growth. The promise of tropical forest regeneration in an age of deforestation. The University of Chicago Press, Chicago, Ill.

FAO (Food and Agriculture Organization), 2010. Global Forest Resources Assessment 2010. Main report. Food and Agriculture Organization of the United Nations FAO, Communication Division, Rome, 340 S.

Guariguata MR, Chazdon RL, Denslow JS, Dupuy JM, Anderson L, 1997. Structure and floristics of secondary and old-growth forest stands in lowland Costa Rica. Plant Ecology, 132 (1), 107–120, accessed on 18.07.2015.

Guariguata MR, Ostertag R, 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. Forest Ecology and Management, 148 (1-3), 185–206.

Hall JB, Swaine MD, 1981. Distribution and ecology of vascular plants in a tropical rain forest. Forest vegetation in Ghana. Springer Netherlands, Dordrecht, 1 online resource (xvi, 383.

Holz S, Placci G, Quintana RD, 2009. Effects of history of use on secondary forest regeneration in the Upper Parana Atlantic Forest (Misiones, Argentina). Forest Ecology and Management, 258 (7), 1629–1642, accessed on 18.07.2015.

ITTO (International Tropical Timber Organization), 2002. Guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. International Tropical Timber Organization, Yokohama, 84 S.

Kalacska M, Rivard B, Calvo-Alvarado JC, Sanchez-Azofeifa GA, Ortiz-Orti D, Arroyo-Mora JP, Journet AR, 2004. Leaf area index measurements in a tropical moist forest: A case study from Costa Rica. Remote Sensing of Environment, 91 (2), 134–152.

Ngo KM, Turner BL, Muller-Landau HC, Davies SJ, Larjavaara M, (Nik Hassan, Nik Faizu bin), Lum S, 2013. Carbon stocks in primary and secondary tropical forests in Singapore. Forest Ecology and Management, 296, 81–89, accessed on 18.07.2015.

Oke DO, Onyekwelu JC, Yirdaw E, 2010. Secondary Forests in West Africa: a Challenge and Opportunity for Management. In: Mery G, Katila P, Galloway G, I. Alfaro R, Kanninen M, Lobovikov M, Varjo J (eds.). Forests and society. Responding to global drivers of change. IUFRO, Vienna, p. 335–354.

(R Core Team), 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

van Breugel M, 2007. Dynamics of secondary forests. Dynamiek van secundaire bossen. Univ., PhD thesis--Wageningen, 2007, Wageningen, 240 p.

van Breugel M, Martínez-Ramos M, Bongers F, 2006. Community dynamics during early secondary succession in Mexican tropical rain forests. Journal of Tropical Ecology, 22 (06), 663.