FLORISTIC COMPOSITION AND CARBON STOCKS OF TREE SPECIES OF DIFFERENT CONSERVATION STATUS FOLLOWING SELECTIVE LOGGING IN A MOIST SEMI-DECIDUOUS FOREST IN GHANA

Article - January 2018

CITATIONS
0

READS
376

12 authors, including:

Stephen Adu-Bredu
Forestry Research Institute of Ghana
60 PUBLICATIONS 903 CITATIONS

Akwasi Gyamfi
Michigan Technological University
15 PUBLICATIONS 107 CITATIONS

Winston Asante
Kwame Nkrumah University Of Science and Technology
22 PUBLICATIONS 316 CITATIONS

Shalom Daniel Addo-Danso
CSIR-Forestry Research Institute of Ghana (FORIG)
26 PUBLICATIONS 190 CITATIONS

Some of the authors of this publication are also working on these related projects:

- BGCI-Conservation Of Threatened and Endemic Trees of Ghana and Ivory Coast View project
- Nutrient resorption and stoichiometric patterns along a rainfall gradient in Ghana View project

All content following this page was uploaded by James Ampomah on 24 April 2019.

The user has requested enhancement of the downloaded file.
FLORISTIC COMPOSITION AND CARBON STOCKS OF TREE SPECIES OF DIFFERENT CONSERVATION STATUS FOLLOWING SELECTIVE LOGGING IN A MOIST SEMI-DECIDUOUS FOREST IN GHANA

G. D. Djagbletey¹, S. Adu-Bredu¹, A. Duah-Gyamfi¹, E. A. Abeney², W. A. Asante², E. Akyeampong², S. Addo-Danso³, G. K. Ametsitsi¹, E. Amponsah-Manu¹, J. Dabo¹ and J. O. Amponsah¹

¹CSIR-Forestry Research Institute of Ghana, P. O Box 63, Kumasi, Ghana
²Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology
Email: gddjagbletey@csir-forig.org.gh

ABSTRACT

Understanding the impact of commercial logging on composition and carbon storage of functionally different species is critical for sustainability of forest resources. This study assessed the floristic composition and carbon stocks of tree species of different conservation status along a post-logging chronosequence regime within the Bobiri Forest Reserve (BFR). Experimental plots were established in different post-logged sites within BFR, namely: 1-, 10-, 21-, 30-, 43- and 50 years post-logged sites (tagged as Y₁, Y₁₀, Y₂₁, Y₃₀, Y₄₃ and Y₅₀). In addition, plots were established in an unlogged / undisturbed area which shows the characteristics of a strict nature reserve (tagged SNR) as control. Data was collected in 10 randomly selected temporary sampling plots (TSPs) in each site. The main sample plot (MSP) i.e. 50 m x 50 m (2500 m²) was divided into four sub-plots (SP) of size 25 m x 25 m (625 m²) and the sub-plots were further subdivided into sub-sub plots (SSP) of size 12.5 m x 12.5 m (156.25 m²), to form a nested sample plot design. Tree species in the stands were identified and classified according to their conservation status/ star rating. The results of the study indicated that proportional abundance of species with different star ratings was significantly different with green and pink stars generally dominant across the stands. Carbon stock estimates increased from 193.5 ± 36.4 in the SNR to 293.3±45.1 in Y₅₀, but was not significantly different. However, carbon storage among star categories was significant (p < 0.05) despite the low abundance of species in some of the categories. This phenomenon was due to the high proportions of carbon stocks in large and medium trees of species belonging to the green, pink, red and scarlet stars. The high carbon stocks of scarlet and red star species despite their low densities calls for management interventions to enhance their stocking levels within the reserve.

Keywords: Abundance, carbon, post-logging chronosequence, star rating, sustainability

Introduction

Vegetation and soil hold approximately 75% of total terrestrial carbon (Edmondson et al., 2015). Tropical forests alone account for over two-thirds of live terrestrial plant biomass, (Pan et al., 2013) and exchange more carbon dioxide (CO₂) with the atmosphere than any other biome (Beer et al., 2010). Thus, tropical forests play critical roles in global carbon cycle and mitigation of climate change. Despite their
importance, tropical forests are under severe threat particularly from landuse changes such as logging, agricultural expansion, fuel-wood and charcoal burning, cultivation and overgrazing. These have considerably reduced forest and tree cover and contributed significantly to the depletion of global forest carbon stocks (Dosso, 2014; UNEP, 2012).

Selective logging is one of the dominant land-use change phenomena in the tropics and is a major driver of biodiversity loss and extinction (Laurance, 2007). In recent years, the threat posed by selective logging has received increased attention as large tracts of tropical forests have been converted to production areas (Blaser et al., 2011). With the growing demand for timber, concern has increased about the impact of selective logging on ecosystem function, such as carbon storage and biodiversity conservation. The need to conserve species with special interest in tropical forest ecosystems is crucial to ensure sustainable flow of essential ecosystem services, which include carbon sequestration, nutrients cycling, water and air purification and the maintenance of wildlife habitat (Githae et al., 2007).

Given the extent of logged forests in the tropics and the imminent threat of conversion to other land uses, an understanding of plant diversity (biological value) and carbon stocks is critical for conservation and sustainable forest management. Yet, recovery of tropical forests in terms of carbon stocks, plant diversity and floristic composition is not fully understood. Most studies have highlighted the relationship between carbon stocks and species richness following selective logging (Berry et al., 2010; Medjibe et al., 2011; Martin et al., 2015). The results of these studies have been mixed, consequently several meta-analyses and reviews about the impact of selective logging on the species richness-aboveground biomass relationships report a negligible or no impact of logging (Berry et al., 2010; Putz et al., 2012) suggesting that selective logging may be compatible with biodiversity conservation.

These discrepancies have prompted ecologists to consider the relationship between other measures of plant diversity and carbon storage. For example, species dominance in both forests (Cavanaugh et al., 2014) and plantations (Salisbury and Potvin, 2015) and ecological species guilds in logged and unlogged forests (Asase et al., 2012) have been shown to be important determinants of forest carbon storage. However, studies on the influence of species conservation status on carbon storage is limited. This is particularly important in Ghana where species have been classified on star ratings (black, blue, green, gold, pink, red and scarlet) according to their level of extinction (Hawthorne, 1995).

There is extensive inventory data on Ghana’s forests but the emphasis has been on direct value of biodiversity, particularly timber. For example, the Ghana Forest Inventory Project, which was implemented between October 1985 and March 1989 had one of its main objectives as providing data for the formulation of a sustained yield policy. The data revealed the over-exploitation of certain timber species (DFID, 2004). Given the extent of logging in Ghana, understanding the species conservation status, floristic composition and carbon stocks of trees along the forest recovery trajectory (succession) is critical for conservation, understanding forest restoration processes and in designing forest management strategies. Using forests along the succession trajectory or chronosequence allows the description of differences along the trajectory through the quantification of floristic composition and carbon stocks for sites similar in soil and other environmental conditions.

The aim of this study was to assess species diversity and their contribution to carbon stock after selective logging within a moist semi-
deciduous forest. Specifically, the study was conducted to: (1) examine floral species composition with regards to species conservation status (star ratings) across post-logged years (PLY) and (2) quantify the carbon stock contribution of species within different conservation categories.

**Methodology**

**Study area**

The study was carried out in the Bobiri Forest Reserve (BFR) a moist semi-deciduous southeast sub-type, with total area of 5,445 ha in southern Ghana (Hall and Swaine, 1981; Hawthorne and Abu-Juam, 1995). The reserve has been divided into management units based on their uses: butterfly sanctuary, production, research and strict nature reserve (protection) (Figure 1). It is located three kilometres north-west off the Kumasi–Accra main road, close to the Kubease community, which is 34 km from Kumasi. It lies between latitudes 6°39’ and 6°44’N and longitudes 1°15’ and 1°22’W.

**Vegetation**

The forest structure of BFR is characterised by an upper canopy layer consisting of a mixture of deciduous and evergreen species in approximately equal proportions (Hall and Swaine, 1981). Average canopy height is estimated as 40 m with emergent trees up to 60 m tall (Hall and Swaine 1981). Common species and their important value indices (IVI) are: *Celtis zenkeri* (15.8), *Celtis mildbraedii* (14.5), *Triplochiton scleroxylon* (10.8), *Sterculia rhinopetala* (10.6), *Funtumia elastica* (10.5), *Baphia nitida* (9.7), *Cleidion gabonicum* (9.4), *Nesogordonia papaverifera* (7.8), *Hymnostegia afzelii* (6.6), *Turrantenhus africanus* (6.4) and *Trichilia prieuriana* (5.7) (Djagbletey, 2015).

**Climate and topography**

Annual rainfall from 2002 to 2010 ranged from 1243 to 1807 mm, with 1427 mm as the annual mean. Mean annual maximum temperature during the period ranged between 30.9 and 31.6 °C with the average being 31.1°C. Relative humidity was in the region of 85% (weather data was obtained from the weather station of the CSIR-Forestry Research Institute of Ghana located at Fumesua, about 10 kilometres from BFR). The landscape is gently undulating with a slope of about 6–7% and an elevation between 180 m and 245 m above sea-level (Foggie, 1947). The soils vary from sandy loams to clay loams, passing into a grey leached sandy or silty soil (Foggie, 1947; Foli and Pinard, 2009).

**Site selection and sampling design**

Six compartments in the production and research units of BFR were selected chronosequentially: 1-, 10-, 21-, 30-, 43-, and 50-year post-logged sites/stands (Figure 1). Selected compartments were tagged as $Y_1$, $Y_{10}$, $Y_{21}$, $Y_{30}$, $Y_{43}$, and $Y_{50}$, respectively to ascertain post-logging effects on composition and diversity, and carbon storage among species with different conservation/star categories. For comparative analysis, samples were also selected from the Strict Nature Reserve (SNR) (Figure 1), which is under protection from logging and other anthropogenic disturbances. Ten (10) temporary sampling plots (TSPs) were randomly selected in each site. At each site, a main sample plot (MSP) of size 50 m x 50 m (2500 m$^2$) was demarcated, divided into four sub-plots (SP) of size 25 m x 25 m (625 m$^2$) and the sub-plots were further subdivided into sub-sub plots (SSP) of size 12.5 m x12.5 m (156.25 m$^2$).
Figure 1: Map of Bobiri Forest Reserve showing the compartments selected for the study.
Table 1: Summary of the star categories of conservation priority for species.

<table>
<thead>
<tr>
<th>Star Rating</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>Urgent attention to conservation of population needed. Rare internationally and at least uncommon in Ghana. Ghana must take particular care of these species</td>
</tr>
<tr>
<td>Gold</td>
<td>Fairly rare internationally and / or locally. Ghana has some inescapable responsibility for maintaining these species.</td>
</tr>
<tr>
<td>Blue</td>
<td>Widespread internationally but rare in Ghana or vice-versa. It may be in Ghana’s interest to pay attention to protecting some of these species</td>
</tr>
<tr>
<td>Scarlet</td>
<td>Common but under serious pressure from heavy exploitation. Exploitation needs to be curtailed if usage is to be sustainable. Protection on all scale vital</td>
</tr>
<tr>
<td>Red</td>
<td>Common but under pressure from exploitation. Need some control and some tree by tree and area protection</td>
</tr>
<tr>
<td>Pink</td>
<td>Common and moderately exploited. Also non-abundant species of high potential value</td>
</tr>
<tr>
<td>Green</td>
<td>No particular conservation concern</td>
</tr>
<tr>
<td>Others</td>
<td>Non forest species, excluded from the analysis for other reasons</td>
</tr>
</tbody>
</table>


This nested sample plot design was adopted to enable us capture trees/plants with different diameters. Tree species exceeding 20 cm diameter at breast height (dbh) of 1.3 m were identified and their dbh measured in the MSP. For trees with buttresses higher up the bole, diameters were measured at 50 cm above the buttress (Hall et. al., 2003). One of the sub-plots (25 m x 25 m plots) was randomly selected for the assessment of plant species with dbh exceeding 10 cm but less than 20 cm. For plant species with dbh less than 10 cm but with height greater than 2.0 m, one of the sub-sub-plots (12.5 x 12.5 m plots) was selected for the assessment. Five one metre squared quadrats were diagonally laid in a ‘Z-shape’ within the main plot to account for seedlings less than 2.0 m in height and herbs.

Data analysis

Patterns of abundance, composition and distribution of species with different star categories

To determine species composition of the selected sites, we examined how patterns of abundance and composition among species with different star rating differed across the post-logged years. The abundance (proportion) of trees in the star categories across sites was tested for independence with chi-square tests for contingency tables (Townsend, 2002; Dytham, 2003). To assess the effects of post-logged years
and conservation status on species abundance, we selected the best model using a generalized linear model (GLM) with Poisson error distribution (Crawley, 2013) on (1) post-logged year; (2) star category; (3) post-logged year, star category and their interaction. Model selection was based on the Akaike’s Information Criterion (AIC) approach (Burnham and Anderson, 2002).

To quantify and contrast species dominance among and within post-logged years, we calculated the Importance Value Index (IVI), which is an index that profiles the structural role of a species in a stand. It is useful for making comparisons among stands with reference to species composition and stand structure (Roberts-Pichette and Gillespie, 1999; Anin et al., 2008). IVI for each species was estimated as:

\[ IVI = \frac{(RD+RDo+RF)}{3} \]  

(1)

Where RD is relative density; RDo is relative dominance and RF is relative frequency. The RD reflects the stocking density or abundance of a species relative to all species in a stand or a given community. RDo is defined as an area a species occupies in a stand, in terms of basal area, as a percentage of the total basal area occupied by all species. RF reflects distribution of a species relative to all species and estimated by dividing the number of sampling units in which a species occurs by the total number of sampling units. Following the estimation of IVI, we then plotted in decreasing order, species which constituted the top 90-95% combined IVI in each stand and subsequently identified the dominant species which represented the top 45-50% combined IVI in at least four of the post-stands.

For structural characterisation, we grouped the star ratings across sites into 20-cm-wide diameter classes. This procedure allowed us to assess the similarity in the distribution of dbh classes among star categories using a non-parametric statistical analysis, two-sample Kolmogorov-Smirnov (KS) test. Further, to test for differences in the density of categories within stands, trees were stratified into 20-cm-wide dbh classes except for > 60 cm dbh class.

Vegetation carbon stock

Above-ground phytomass, \( W_a \) (kg) of the individual trees was estimated from dbh, \( d \), and wood density, \( \rho \), using the allometric equation developed by Chave et al. (2005) for moist tropical forests as:

\[ W_a = \exp (1.499+2.148x \ln (d) + 0.207x \ln (d)^2 - 0.0281 x (\ln (d))^3) \]  

\[ R^2=0.996 \]  

(2)

Below-ground phytomass, \( W_b \), (kg) was estimated from the knowledge of the above-ground phytomass based on the revised equation of Cairns et al. (1997) for tropical forest (cf. Pearson et al., 2005) as:

\[ W_b = \exp (-1.0587 + 0.8836 x \ln (W_a)), \]  

\[ R^2 = 0.83 \]  

(3)

Above ground phytomass for liana (\( W_l \)) (kg) was estimated using allometric equation by Saldarriaga et al. (1988), Alves et al. (2012) and Mascaro et al. (2012) as:

\[ W_l = \exp 1.484+2.657 \ln (d) \]  

(4)

Stand biomass (\( B \) (Mg ha\(^{-1}\)) was calculated by summing up the individual tree and liana phytomass per plot as:

\[ B = \sum_{a=1}^{n} (W_a + W_b) \times \frac{10000}{A} \]  

(5)

where \( A \) (m\(^2\)) is area of the sample plot and \( n \) is number of trees and lianas in the plot. Carbon stored in each plot was estimated as 0.4748 x \( B \) (Adu-Bredu et al., 2010).

We examined the distribution of carbon stock among star ratings across the sampled stands using a Non-Metric Dimensional Scaling (NMDS). The NMDS is a non-parametric ordination analysis that maximizes the rank-order correlation between distances thereby reducing a multidimensional dataset into one-
dimension space grouping plots with similar composition together (McCune and Grace, 2002). Unlike other indirect (e.g. principal components analysis) or direct (e.g. canonical correspondence analysis) ordination techniques, NMDS does not make any assumptions about the nature of the data, including assumptions about the linear relationship among variables. Thus, it is often viewed as an appropriate multivariate analysis for ecological data (McCune and Grace, 2002). Prior to the analysis, the carbon data for star categories were transformed using a Hellinger transformation (Legendre and Gallagher, 2001). The NMDS was then run in R 3.2.1 (2015) using the package vegan. Then, we used a Kruskal-Wallis one-way ANOVA to determine whether the patterns of carbon stored in star categories across sites were different.

Following the NMDS, we used mixed effects (non-linear mixed effect, nlme) model to assess the effect of stand, star category and their interaction on carbon storage among post-logged years.

**Results**

**Vegetation structure and floristic composition**

A total number of 8,127 individual plants representing 58 families, 161 genera and 201 species were identified and recorded across the seven stands. Stem density ranged from 378 stems ha\(^{-1}\) in the SNR to 608 stems ha\(^{-1}\) in Y\(_{50}\) (Table 2).

**Table 2: Summary of stand characteristics of the study plots.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>SNR</th>
<th>Y(_{1})</th>
<th>Y(_{10})</th>
<th>Y(_{21})</th>
<th>Y(_{30})</th>
<th>Y(_{43})</th>
<th>Y(_{50})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (stem ha(^{-1}))</td>
<td>378</td>
<td>424</td>
<td>365</td>
<td>516</td>
<td>480</td>
<td>477</td>
<td>608</td>
</tr>
<tr>
<td>Basal area (m(^{2}) ha(^{-1}))</td>
<td>22.3</td>
<td>20.5</td>
<td>18.3</td>
<td>24.8</td>
<td>28.8</td>
<td>25.8</td>
<td>31.4</td>
</tr>
<tr>
<td>Star category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Blue</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Gold</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Green</td>
<td>308</td>
<td>316</td>
<td>287</td>
<td>396</td>
<td>368</td>
<td>370</td>
<td>419</td>
</tr>
<tr>
<td>Pink</td>
<td>44</td>
<td>80</td>
<td>43</td>
<td>74</td>
<td>74</td>
<td>72</td>
<td>136</td>
</tr>
<tr>
<td>Red</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>18</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Scarlet</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>17</td>
<td>15</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Diversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species richness</td>
<td>102</td>
<td>121</td>
<td>102</td>
<td>126</td>
<td>102</td>
<td>106</td>
<td>104</td>
</tr>
<tr>
<td>Shannon index</td>
<td>3.92</td>
<td>3.99</td>
<td>3.89</td>
<td>3.88</td>
<td>3.81</td>
<td>3.91</td>
<td>3.63</td>
</tr>
<tr>
<td>Black</td>
<td>0.04</td>
<td>0.02</td>
<td>0.06</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>Blue</td>
<td>0.04</td>
<td>0.05</td>
<td>0.08</td>
<td>0.06</td>
<td>0.05</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>Gold</td>
<td>0.01</td>
<td>0.01</td>
<td>-</td>
<td>0.03</td>
<td>-</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>Green</td>
<td>3.06</td>
<td>2.91</td>
<td>2.92</td>
<td>2.81</td>
<td>2.76</td>
<td>2.91</td>
<td>2.46</td>
</tr>
<tr>
<td>Pink</td>
<td>0.52</td>
<td>0.71</td>
<td>0.50</td>
<td>0.59</td>
<td>0.64</td>
<td>0.63</td>
<td>0.76</td>
</tr>
<tr>
<td>Red</td>
<td>0.11</td>
<td>0.14</td>
<td>0.19</td>
<td>0.20</td>
<td>0.18</td>
<td>0.07</td>
<td>0.16</td>
</tr>
<tr>
<td>Scarlet</td>
<td>0.15</td>
<td>0.15</td>
<td>0.14</td>
<td>0.17</td>
<td>0.16</td>
<td>0.20</td>
<td>0.16</td>
</tr>
<tr>
<td>Mean C (Mg ha(^{-1}))</td>
<td>193.5±36.4</td>
<td>178.8±45.9</td>
<td>165.9±40.0</td>
<td>222.1±44.8</td>
<td>267.7±45.4</td>
<td>240.5±53.2</td>
<td>293.3±45.1</td>
</tr>
</tbody>
</table>
In terms of conservation status (star rating), the green and pink star species constituted over 90% of the stems ha\(^{-1}\) across all sites with the green star consistently dominant in all the PLY and the SNR (Table 2). In addition, there were clear differences among post-logged years in the proportional abundances of species with different conservation status (KW: \(\chi^2 = 161.7, df = 36, p < 0.05\); (Figure 2).

The best model for species abundance included effects of star category and the interaction between PLY and conservation status (Table 3). While species abundance was largely accounted for by green \((p < 0.001)\), pink \((p < 0.001)\), red \((p < 0.05)\) and scarlet \((p < 0.001)\) star species, the interaction between \(Y_{43}\) and green \((p < 0.05)\), pink \((p < 0.05)\) and scarlet \((p < 0.05)\) stars explained variation in species abundance (Table 3). Additionally, there was a significant interaction between red star and \(Y_{21}\) \((p < 0.05)\). Of the 201 species sampled, IVI analysis revealed that only three species *T. scleroxylon* (scarlet), *C. mildbraedii* (pink) and *C. zenkeri* (pink) comprised the top 45-50% of dominant species in at least four of the seven sites (Figure 3). In general, the pink star species was the dominant category in the 20 most dominant species, ranked by percent IVI (Figure 3).

---

**Figure 2:** Proportion of star categories in Strict Nature Reserve (SNR), \(Y_1\), \(Y_{10}\), \(Y_{21}\), \(Y_{30}\), \(Y_{43}\) and \(Y_{50}\) of the Bobiri Forest Reserve. Proportions of star categories in each stand are indicated by their corresponding colours on the chart.
The distribution of the number of stems ha$^{-1}$ (dbh classes) of the star categories across sites was consistent with most of the stems in the $\leq 40$ cm dbh class and the least in the $> 60$ cm dbh class. Y$_{50}$ harboured most of the young stems, 1,303 (19%) of the total number of 6,918 young stems inventoried in our assessments. On the other hand, Y$_{43}$ had the highest number of large stems, 74 (20%), out of the total stems (379) recorded for this dbh class across stands. Focusing on the tree size distribution of each star category within stands, the dbh classes showed a reverse $J$-shape distribution for only green and pink and to some extent red star categories at all sites (Figure 4), while the distribution pattern for black, blue, gold and scarlet star species did not follow any clear trend (Figure 4). Together, the $\leq 20$ cm and $20 \leq x \leq 40$ cm dbh classes had significantly higher stems ha$^{-1}$ (about 90%) across sites ($p < 0.05$), while the $40 \leq x \leq 60$ cm and the $\geq 60$ cm dbh classes each represented 5% of the total stems ha$^{-1}$ (Figure 4).

Figure 3: Species composition of Strict Nature Reserve (SNR) and Y$_1$, Y$_{10}$, Y$_{21}$, Y$_{30}$, Y$_{43}$ and Y$_{50}$. (Species are arranged in decreasing order of percent Importance Value Index (IVI). Only species that comprised the top 90-95% IVI in each site are shown. Dominant species that constituted the top 45-50% IVI in at least four sites are indicated by an asterisk. Letters in parenthesis indicate star ratings as follows: G = green; P = pink; R = red; S = scarlet).
Figure 4: Distribution of the number of trees per diameter class for each star category in (a) Strict Nature Reserve (SNR) and (b) Y50 in the Bobiri Forest Reserve. This distribution pattern was similar across stands.
Relative contribution of plants under various star rating conservation status to C stock

Mean aboveground carbon stock estimates for the stands ranged from 193.5 ± 36.4 in the SNR to 293.3 ± 45.1 in Y50 (Table 2). Clearly, there was an increase in carbon stocks along the post-logged chronosequence regime, however, this increase was not significant among the stands (KW: $\chi^2 = 7.8$, df = 6, $p = 0.254$). This result is supported by the high overlaps among stands in the two-dimension NMDS ordination based on carbon stocks (Figure 5). NMDS ordination explained 72% of the carbon stocks among stands with NMDS axis one explaining 65%.

With respect to contribution to the carbon stock by the species with different conservation status, the green star accounted for 46% ($p < 0.001$) of the total carbon stock even though it comprised 76% of the plant population, while pink star accounted for 16% ($p < 0.001$) of the plant population but contributed 29% of the carbon stock. Scarlet and red star species contributed 14% ($p < 0.001$) and 5% ($p < 0.05$) of the carbon storage, respectively, and each represented only 3% of the total plant population (Table 2). The blue and black star species each comprised 1% of the plant population, however, the blue star accounted for 2% of the carbon stock while the contribution by black star species was negligible. For the gold star species, the contributions to both carbon stock and plant population were negligible. Intriguingly, the non-linear mixed effect model revealed a significant interaction between Y43 and the following star categories: green ($P < 0.05$), pink ($P < 0.05$) and scarlet ($P < 0.05$). There was also an interaction between Y1 and red star ($P < 0.05$) (Table 3).

At the individual tree level, large (dbh > 60 cm) and medium (40 cm ≤ x ≤ 60 cm) trees of the star categories contributed substantially more to carbon stocks, however, this was not consistent across post-logged years.

Table 3: Results of the GLM for abundance with star category and selected stands at the Bobiri forest reserve. Non-significant results are not shown.

| Source of variation | $z$     | $Pr (>|z|)$ | AIC     |
|---------------------|---------|------------|---------|
| Star conservation status |         |            |         |
| Green               | 12.32   | <0.001     |         |
| Pink                | 7.09    | <0.001     |         |
| Scarlet             | 3.38    | <0.001     |         |
| Red                 | 2.52    | <0.05      |         |
| Star x PLY          |         |            |         |
| Green x Y43         | 1.99    | <0.05      |         |
| Pink x Y43          | 2.26    | <0.05      |         |
| Scarlet x Y43       | 2.30    | <0.05      |         |
| Red x Y21           | 2.16    | <0.05      |         |

For instance, while large trees stored most of the carbon in Y50 (52%), medium-size trees were dominant in Y1 (42%) (Figure 6). In contrast, large and medium trees both substantially contributed to carbon stocks in Y43 (Figure 6). Trees of the commercial species, *T. scleroxylon* (scarlet), represented 20.1% of the total carbon storage by large trees. Other species that contributed substantially to total carbon stock by large trees included *C. gabunensis* (pink, 9.2%), *S. rhinopetala* (pink, 7.0%), *N. papaverifera* (pink, 6.7%) and *P. africanum* (red, 6.6%). Species that contributed substantially to total carbon storage by medium-size trees included *C. mildbraedii* (pink, 18.0%), *C. zenkeri* (pink, 14.7%), *N. papaverifera* (pink, 10.0%), *S. rhinopetala* (pink, 9.1%) and *T. africanus* (pink, 6.4%).
Figure 5: Carbon stock similarity in SNR, Y1, Y10, Y21, Y30, Y43, Y50 of the Bobiri Forest Reserve summarized in two dimensions derived from the NMDS ordination based on Bray-Curtis distance. Groups are shown by ellipses with 95% confidence interval around the group centroid. Each plot is represented by a point in the graph. Stands are distinguished by the different symbols.

**Discussion**

**Population dynamics of species conservation of undergrowth vegetation**

Our results show that years after logging altered patterns of abundance of species with different star conservation such that logged forests were the denser in terms of species with different star categories. In general, the density of the star categories across stands was driven by the overwhelming abundance of green and pink star species. This may be attributable to the patterns of response of species belonging to these star categories to logging disturbances. Logging creates canopy gaps thereby increasing sunlight, which favours the germination and growth of light-demanding species (Swaine and Whitmore, 1988; Peters, 1994). Later in succession when the canopy closes, slow-growing species become the dominant species. In Ghana, the green and pink star species are the most dominant species and consist of a vast array of species with different responses to light along the succession trajectory. The high species richness of green and pink star species (Table 2) compared to black, blue, gold, red and scarlet species along the post-logged chronosequence may have accounted for their high density in this study. With an increasing number of functionally different species (e.g. varied ecological species guilds), the probability increases that some of these species could respond differently to the changing environmental conditions along the post-logged chronosequence.
Figure 6: Mosaic plots derived from contingency analyses of the proportion of carbon storage in large, medium and small size trees in (a) Y₁, (b) Y₅₀, and (c) Y₄₃.
Further, the higher number (11) of pink star species, belonging to different ecological species guild viz. C. mildbraedii (shade bearer), S. rhinopetala (non-pioneer light demander) and P. macrocarpus (pioneer), in the top 20 species, ranked by IVI corroborates the high diversity.

The reverse J-shape dbh size classes exhibited by green and pink star species at all sites is an indication of a self-maintaining population in which young trees of both green and pink star species would eventually replace the older trees (Peters, 1994). For the black, blue, gold, red and scarlet star species, the distribution of dbh size classes was similar for both large and small size trees and was generally low. This is particularly serious for the economic timber species most of which belong to the red and scarlet star species. For instance, we found that the commercial timber species, T. scleroxylon, a scarlet star, stored most of the carbon in large trees and also had the highest IVI across stands. However, it has a low density across all stands. Moreover, it has been found that the availability of substantial quantities of scarlet, red and pink star species in a site signifies that the site is potentially of economic importance (FC, 2016). The sites are poorly stocked with both red and scarlet star species except the pink star species. This result or trend might have stemmed out of the fact that the preferred timber species were mostly of the red and scarlet star category and the mother trees might have been removed through periodic exploitation. Removal of mother trees might have resulted in absence of germplasm/propagules. This is consistent with the assertion by Zang and Ding, (2009); Veenendaal et al., (1996); Garwood, (1989) that forest regeneration after logging depends mainly on seeds and seedlings present at the time of tree felling and lack of on-site plant propagules after topsoil removal during logging could lead to a reduction in population of certain plant species (Redondo-Brenes et al., 2004; Pinard and Cropper, 2000; Malmer and Grip, 1990; Uhl et al., 1989; Brokaw 1985).

Other factors may also account for the sparse distribution of dbh size classes particularly the black, blue and gold star species. Since the SNR exhibited a similar pattern, it is likely that the reserve is generally low with respect to the abundance of these star categories. Therefore, silvicultural interventions such as enrichment planting, liberation thinning could be strictly enforced as management interventions following the logging of red and scarlet star species.

**Relative contribution of trees under various star rating to carbon stock**

Mean above-ground carbon estimates for the seven stands (193.5±36.4–293.3±45.1 Mg ha⁻¹) were similar to IPCC (2006) estimates for moist tropical forests (210–280 Mg ha⁻¹) and values reported by Medjibe et al. (2011) for northwestern Gabon (210 Mg ha⁻¹) and Malhi et al. (2006) for the Brazilian Amazon (200–350 Mg ha⁻¹). Our results suggest that carbon stored among the sites was not significantly different even though there was an increase from SNR to Y₅₀. This increase was largely explained by the NMDS ordination axis 1, nonetheless, there was considerable overlap among stands in carbon storage. This is an indication of the similarity among stands in carbon storage as found earlier. Our result concurs with Asase et al. (2012) who found no significant difference in carbon stored by ecological species guild in logged and unlogged forests in Ghana. The authors concluded that the logged forest might have recovered in terms of carbon stocks 14-29 years after logging. This could account for the no significance difference in carbon stocks between the SNR and Y₅₀-Y₁₀ in the current study. However, for Y₁₀ and Y₁, floristic composition might have accounted for the insignificant difference in carbon stocks with the SNR. The importance of species composition on carbon stocks has been shown in several studies in the
Floristic composition and carbon stocks of three species in Ghana

G. D. Djagbletey et al.

Despite the lack of significant effects of site on carbon storage, we found a significant impact of species star rating on carbon stocks. Carbon storage was influenced by green, pink, red and scarlet star species, yet there were marked differences in the overall abundance of these star categories. For instance, the green star species formed the largest proportion (> 70%) of the plant population inventoried, while the red and scarlet star species each represented about 3% of the total plant population. The low densities of red and scarlet star species is likely a reflection of their higher exploitation rate compared to the other star categories. While the scarlet star species have exploitation rates less than 50% of their annual allowable cut (AAC), in contrast red star species have exploitation rates greater than 200% of the AAC (Hawthorne et al., 2011). Consequently, Hawthorne et al. (2011) advised that the exploitation of the red star species be carefully controlled using tree by tree and area protection.

Given the inconsistencies between the abundance and carbon storage among green, pink, red and scarlet star species, the overriding factor may be trees of a specific size of the star categories. In our study, carbon storage was driven by large and medium size trees (Figure 7) of the aforementioned star categories despite the low densities providing strong evidence that total abundance per se may not be a good indicator of carbon storage but the proportions of carbon stocks in large and medium trees of species of green, pink, red and scarlet stars along the chronosequence. Large trees have been found to store substantial amounts of forest carbon in the tropics (Brown et al., 1995; Malhi and Grace, 2000; Pearson et al., 2007; Jacobs et al., 2009; Henry et al., 2010; Medjibe et al., 2011; Tierra Resources, 2012; Mazzei et al., 2010; Sist et al., 2014; Djagbletey, 2015). The differences in the proportions of large and medium trees accounted for the patterns of carbon storage observed along the post-logged chronosequence. This explains the interaction between Y23 and most of the star categories observed in this study. We found that Y23 had the most number of large trees followed by Y21. Therefore, the interaction between Y21 and red star species, which were mostly large is understandable. Our results suggest that impacts of logging on large trees of species with different star categories could negatively affect forest carbon storage in the study area.

**Conclusion**

This study has shown that logging enhanced the population of green and pink star species while the populations of red and scarlet star species was sparse. There is the need for management interventions to promote the regeneration and growth of seedlings/saplings of the red and scarlet star species, if exploitation is to be sustained at the current rate. Forest carbon storage was largely determined by large and medium trees of green, pink, red and scarlet star species. The implication of this result is that a holistic understanding of species conservation status and floristic composition is crucial for designing forest management protocols for forest restoration and carbon conservation.

**Acknowledgment**

We are grateful to the Director General of Council for Scientific and Industrial Research (CSIR), Prof. V. K. Agyeman, for his logistical support and encouragement. Mention must be made of Mr. Adu Opoku-Ameyaw, Mr. Christian Opoku-Kwarteng, Mr. Mickey Boakye, Miss Abigail Kusi, Mr Williams Duah, Mr. Michael Adu Sasu, Miss Lydia Serwaa Bonsu, Miss Uget Konadu Yiadom, Mr. Elvis Nkrumah, Ms. Leticia A. Asamoah, Mr. Francis Wilson Owusu (all of CSIR) and Mr.
Samuel Adu-Poku (Retiree, CSIR-FORIG), who assisted in diverse ways. The support from Mr. Kofi Affum- Baffoe (The Production Manager, Resources Management Support Centre (RMSC) of the Forestry Commission-FC) and his team, Mr. Noble Isaac Eshun, Mr. Charles Aninagyei, Mr. Odame and Mr. Sowah (the draughtsman at Forest Services Division, FC-FSD, Kumasi) has been very overwhelming.

References


allocation in the world's upland forests


Floristic composition and carbon stocks of three species in Ghana

G. D. Djangbletey et al.

Floristic composition and carbon stocks of three species in Ghana

G. D. Djangbletey et al.


relations in and around a forest gap in West Africa during the dry season may influence seedling establishment and survival. *Journal of Ecology*, 84 (1): 83 - 90.