Journal of Tropical Ecology

www.cambridge.org/tro

Research Article

Cite this article: Adotey RE and Belford EJD (2021) Assessment of floral composition, structure and natural regeneration of the Tano Offin Globally Significant Biodiversity Area of Ghana. *Journal of Tropical Ecology* **37**, 147–156. https://doi.org/10.1017/S0266467421000304

Received: 17 August 2020
Revised: 18 May 2021
Accepted: 19 June 2021
First published online: 15 July 2021

Keywords:
basal area; canopy closure; floristic composition; forest structure; regeneration; species diversity; Tano Offin GSBA

Author for correspondence:
Ebenezer Jeremiah Durosimi Belford,
Email: ejdbelford.sci@knust.edu.gh

Assessment of floral composition, structure and natural regeneration of the Tano Offin Globally Significant Biodiversity Area of Ghana

Regina Enninful Adotey and Ebenezer Jeremiah Durosimi Belford

Department of Theoretical and Applied Biology, Faculty of Biosciences, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract

Threats of forest degradation of the Tano Offin Globally Significant Biodiversity Area present the need to generate eco-information pertinent for its conservational purposes. Ten 50 m × 50 m plots (tree layer) were assessed for plant life forms with diameter ≥ 10 cm. A 10 m × 10 m plot (shrub layer) was located within each of the 50 m × 50 m plots where plant life forms with diameter < 10 cm were assessed. 1 m × 1 m quadrats (herb layer) were laid at the corners of the 50 m × 50 m plots and its centre for canopy closure and natural regeneration assessments. Plant species (240) belonging to 59 families were identified: 171 trees, 41 lianas, 11 shrubs, 7 herbs, 7 herbaceous climbers, 1 epiphyte, 1 grass and 1 fern. Species diversity (H') of the tree, shrub and herb layers was 2.55, 2.54 and 2.48 respectively. The average maximum tree height was 46.19 m and the basal area was 28.36 m^2/ha, which is below the 35 m^2/ha conventional basal area value of tropical forests. *Celtis mildbraedii* and *Rinorea welwitschii* were the most structurally significant species at the tree and shrub layers, respectively, and a total of 75 tree species were regenerating.

Introduction

Tropical forest provides ecological resources (Antwi 1999) which translates into economic and sociocultural benefits (Abeney 1999). However, the impact of human activities has resulted in remarkable changes in species composition, abundance and diversity of organisms in various ecosystems including tropical forests (FOSA 2002, FRA 2010, Kim & Byrne 2006, Philip 1997). Reports by the 2010 Global Forests Resources Assessment indicated a 2 % annual forest loss from 1990 to 2000 in Ghana (FRA 2010). According to Global Forest Watch, the rate of deforestation exacerbated by 60 % in 2018 compared to 2017 with much of the destruction occurring within protected areas (Gbadamosi 2020). Deforestation of tropical forests threatens the sustainability of its biodiversity, demanding the conservation of remnant species lest these may be subjected to extinction (Myers *et al.* 2000). In this regard, floristic assessment of the forest is indispensable in detecting the risk of extinction, arrival of invasive species and changes in plant diversity over time.

Relatively, limited work has been done in determining the floristic composition and structure of forests in Ghana (Addo-Fordjour *et al.* 2009b, Anning *et al.* 2008, Hall & Swaine 1981, Hawthorne 1993, Pappoe *et al.* 2010, Vordzogbe *et al.* 2005). In 1981, an extensive assessment of the distribution of vascular plants in Ghanaian forests was carried out by Hall and Swaine which included the Tano Offin Forest Reserve (Hall & Swaine 1981). It has been decades now and there is thus the need to generate a carefully compiled up-to-date data on the floral composition of the reserve. More so, inventories by the Forestry Commission of Ghana in the reserve have focused mainly on timber species (Affum-Baffoe pers.comm) which is deficient for conservation purposes.

Furthermore, the Tano Offin forest has been a reserve of bauxite deposits (estimated at 700 million metric tons) which presents a potential threat to its forest diversity (Yoda 2020). In the year 2019, the government of Ghana signed a memorandum with China to explore Ghana's deposits of bauxite found in Tano Offin and Atewa Forest Reserves, which constitutes two exceptional Upland Evergreen forests of Ghana (Gbadamosi 2020). These ecologically sensitive Forest Reserves are viewed as 'scientific gold mine' (Oteng-Yeboah, 2019), and research studies are critically needed to consolidate conservation demands.

With plant species composition and stand structure serving as important indicators in the formulation of conservation measures (Lindenmayer *et al.* 2000, Newton *et al.* 2003), information on the current state of the Tano Offin Globally Significant Biodiversity Area (GSBA) should be useful in enhancing conservation efforts of the GSBA. This is critical for maintaining healthy plant diversity and increasing resilience to environmental challenges (Shah 2009). The study focuses on the specific objectives of determining the floristic composition, structure, composition of natural regeneration and canopy closure of the Tano Offin GSBA. It is anticipated that the research findings will inform on the management and conservation policies of the forest.

Methods

Study site

The study was conducted in the Tano Offin GSBA which is a part of the Tano Offin Forest Reserve of Ghana. Tano Offin Forest Reserve falls within the Moist Semi-deciduous forest zone of Ghana with 34,100 ha of the reserve occurring as an Upland Evergreen forest (Birdlife International 2011, Ntiamoa-Baidu *et al.* 2001). A fraction of the Tano Offin Reserve was designated as a GSBA in 1999 after the discovery of the area's outstanding biological diversity of global conservation importance (FC 2007, McCullough *et al.* 2007). Using the Genetic Heat Index (GHI) – an index of the concentration of rare plants within forest community, the GSBA concept was instituted to promote preservation of forests so as to protect unique flora, fauna and ecosystems (Asamoah *et al.* 2011, McCullough *et al.* 2007). The labelling as GSBA corresponds to IUCN's Category IV designation, that is, a protected area designated mainly for conservation through management intervention (McCullough *et al.* 2007).

The reserve lies between longitudes 1°57' and 2°17' West and latitudes 6°54' and 6°35' North, covering an area of 413.92km² of which the GSBA constitutes 44.5 %, that is, 178.34 km² (FC 2007). As an Important Bird Area, nationally rare bird species have been identified in this reserve and these include *Cercococcyx olivinus* Sassi*, Columba unicinata* Cassin and *Tockus camurus* Cassin (Birdlife International 2011, Ntiamoa-Baidu *et al.* 2001). The area experiences a bi-modal rainfall pattern where it peaks in May–June and September–October; the mean annual rainfall is 1250 mm and the annual mean relative humidity is 80 % (FC 2007).

Plot establishment

Using a compass and a measuring tape, 10 50 m x 50 m sample plots (termed tree layer) were randomly demarcated for the identification and measurement of all trees and lianas with dbh (diameter at breast height) ≥ 10 cm as well as the identification of other plant life forms such as herbaceous climbers. To ensure permanency of the plots, reflective poles were pegged at the corners of the plots, and all trees and lianas with dbh ≥ 10 cm were tagged and painted at the dbh level. A 10 m × 10 m plot (termed shrub layer) was located randomly within each of the 50 m × 50 m sample plots for the assessment of saplings (≤ 3 m high and dbh < 10 cm) and other plant life forms of dbh < 10 m. In addition, five single 1 m × 1 m quadrats (termed herb layer) were laid at the corners of the 50 m × 50 m plots and its centre for the assessment of forest floor vegetation and canopy closure. A Garmin GPS 76 was used to determine the geo-reference positions of sample plots (Supplementary Table 1).

Plant identification methods

Identification while in the forest was made possible by diagnostic factors (Supplementary Figure 1) such as growth habit, a study of the crown shape, tree bole structure, the bark texture and its slash appearance, the smell, taste and a study of the nature of exudates from the slashed bark, the leaves, fruits, and flowers. The aid of a catapult was employed to fetch tree leaves that were not easily within reach. The identity of plant species that could not be determined in the forest were identified with the aid of Hawthorne & Jongkind (2006), Hawthorne & Gyakari (2006) and the herbarium of the Resource Management Support Centre of the Forestry Commission of Ghana.

Tree diameter and height measurement

Within the 50 m × 50 m plots, the dbh of all trees and lianas with dbh ≥ 10 cm were measured using a tree caliper. The dbh of trees with buttresses were measured with a relascope. The diameter of saplings (≤ 3 m high and dbh < 10 cm) and other plant life forms of dbh < 10 cm were also measured in the 10 m × 10 m plot. Within the 50 m × 50 m, the height of all trees and shrubs with dbh ≥ 10 cm was determined with Vertex IV and Transponder III. Trees with broken tops were noted and dead trees were eliminated.

Canopy measurement and regeneration assessment

The concave spherical densiometer (Model C) was used to assess the forest canopy closure. Readings were taken on the 1 m × 1 m quadrats located at the corners and centre of the 50 m × 50 m sample plots. Based on recommendations from literature (Fiala *et al.* 2006, Jennings *et al.* 1999), readings were taken at each of the cardinal direction, resulting in four readings for each point of measurement or quadrat. Seedlings (< 1.5 m high and dbh ≤ 1.5 cm), grasses, herbs and other forest floor vegetation found within the 1 m × 1 m quadrats were identified and counted.

Data analysis

Species richness for each plot was determined, and the total number of genus, families and life forms were assessed. To describe the numerical structure of the forest, diversity quantification tools Simpson's (1-D) and Shannon–Wiener diversity [$H' = -\sum(Pi * \ln Pi)$] indices were used, where $\sum$ is summation, Pi is the proportion of individuals that belongs to species i, and ln is the natural log; $D = \sum(n/N)^2$ with n being the number of individuals of each species, and N is the total number of individuals of all species. The basal area ($G = \pi r^2$) *per* hectare for both plant species with dbh ≥ 10 cm (tree layer) and those with dbh < 10 cm (shrub layer) was computed. The structural significance of tree species was assessed by calculating the Importance Value Index (IVI) of each species as shown below:

$$\textbf{Density} = \frac{\text{Number of species A}}{\text{Area sampled}}$$

$$\textbf{Frequency} = \frac{\text{Numbar of plots in which species A occurs}}{\text{Total number of plots sampled}}$$

$$\textbf{Dominance} = \frac{\text{Total cover or basal area of species A}}{\text{Area sampled}}$$

$$\textbf{Relative density} = \frac{\text{Density of species A}}{\text{Total density of all species}} \times 100$$

$$\textbf{Relative frequency} = \frac{\text{Frequency value for species A}}{\text{Total frequency values for all species}} \times \mathbf{100}$$

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

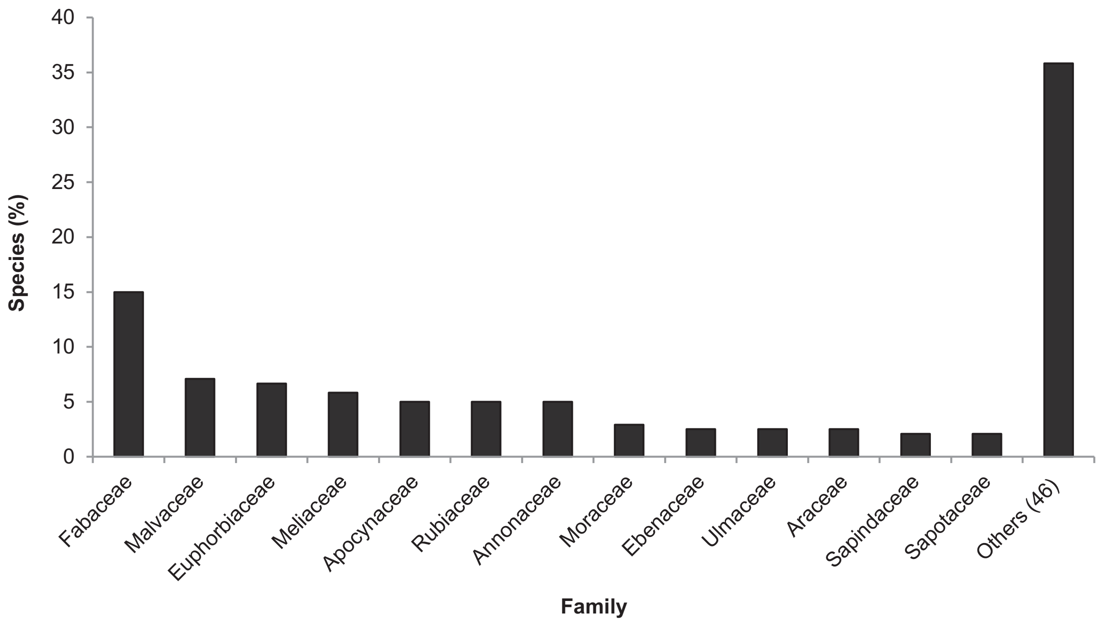

Figure 1. Percentage of plant species represented by families at Tano Offin GSBA.

$$\textbf{Relative dominance} = \frac{\text{Dominance for species A}}{\text{Total Dominance of all species}} \times 100$$

$$\textbf{Importance Value Index} = (\textbf{relative density} + \textbf{relative dominance} + \textbf{relative frequency})$$

The ecological guild (pioneer, non-pioneer light-demanding and shade-bearing) and star rating of the tree species were determined using Hawthorne (1993) and Hawthorne & Gyakari (2006). The star rating consists of black star species (rare internationally and at least uncommon in Ghana); gold star (fairly rare internationally and locally); blue star (widespread internationally but rare in Ghana or vice-versa); scarlet star (common, but under serious pressure from heavy exploitation); red star (common, but under pressure from exploitation); pink star (common and moderately exploited as well as being non-abundant and of high potential value); and green star species (common in Ghana and of no particular conservation concern).

In accordance with Antwi (1999), trees of dbh ≥ 10 cm were classified into four height classes (emergent: > 35 m, upper canopy: > 25–35 m, lower canopy: >15 m–25 m and understorey: ≤ 15 m) to reflect the forest's vertical layer and the species composition of the various layers. The percentage canopy closure for each plot (i.e. 50 m × 50 m) as described by Marchi & Paletto (2010) was calculated. Abundance of seedlings (young tree plant with height < 1.5 m and dbh ≤ 1.5 cm) and saplings (young tree plant with height ≤ 3 m and dbh < 10 cm) were also determined.

Results

Floristic composition

A total of 240 plant species were identified during the assessment (Supplementary Table 2). These comprised of 171 trees, 41 lianas, 11 shrubs, 7 herbs, 7 herbaceous climbers and a species of an epiphyte (*Microsorum punctatum*), grass (*Leptaspis cochleata*) and a fern (*Adiantum vogelii*). The star rating of 222 plant species were determined: 1 black star, 8 gold stars, 17 blue stars, 9 scarlet stars, 7 red stars, 21 pink stars and 159 green stars; the star ratings of 18 plant species were not available (Supplementary Table 2). With the exception of 33 plant species, the guilds of 207 species were determined, namely 42 pioneers, 68 non-pioneer light-demanding species, 93 shade-bearing, 2 swamp species and 2 invasive species (Supplementary Table 2). There were 179 genera and 59 families with Fabaceae being the most contributing family with respect to species richness (15 %) – represented by 36 species (Figure 1). Forty-six families had less than five species (Figure 1). Out of the total 240 plant species, 97 occurred just once (i.e. among the 10 main plots) while *Celtis mildbraedii*, *Culcasia angolensis* and *Strombosia pustulata* occurred on all the 10 main plots (Figure 2). Incidence of plants species decreased with increase in the number of plots such that fewer species were common on most plots (Figure 2).

Forest structure

Tree layer

Measurement in the tree layer constituted lianas and trees with dbh ≥ 10 cm and height > 3 m which were sampled from the 50 m × 50 m main plots. A general summary of the findings of the tree layer is in Table 1.

Diameter class distribution and basal area. The number of individuals in the diameter classes decreased with increasing diameter so that the highest number of plants with dbh ≥ 10 cm was found in the 10–30 cm diameter class (Figure 3). Species found in the > 90–110 cm class include *Antiaris toxicaria*, *Celtis mildbraedii*, *Parkia bicolor*, *Petersianthus macrocarpus* and *Sterculia oblonga*. Species of the highest diameter class (> 110 cm) include *Alstonia boonei*, *Hexalobus crispiflorus*, *Parkia bicolor*, *Sterculia oblonga* and *Triplochiton scleroxylon*.

Height. With respect to classifying individual trees of dbh ≥ 10 cm into height classes, four classes were obtained, namely the

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

Table 1. Summary of the number of individuals, number of species, number of genera, diversity indices and basal area (m^2/ha) as captured at the Tano Offin GSBA.

	Tree layer	Shrub layer	Herb layer
Number of individuals	977 (~391/ha)	418 (4180/ha)	536 (107200/ha)
Number of species	154/2.5ha	95/0.1 ha	102/0.005ha
Number of genera	120/2.5ha	69/0.1/ha	82/0.005ha
Shannon–Wiener index (H')	2.55	2.49	2.54
Simpson's index of diversity (1-D)	0.9	0.83	0.76
Basal area (m^2/ha)	28.356 ± 8.16	3.822 ± 1.02	–

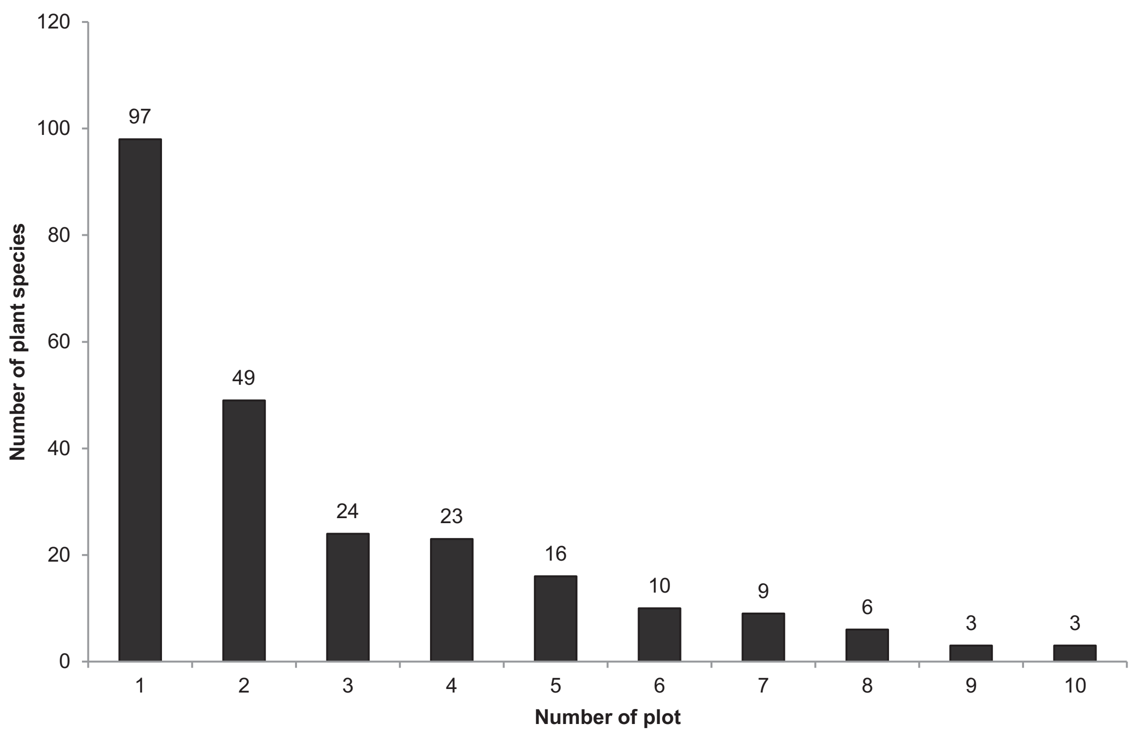

Figure 2. Frequency index of plant species found on the 10 main plots established in the Tano Offin GSBA.

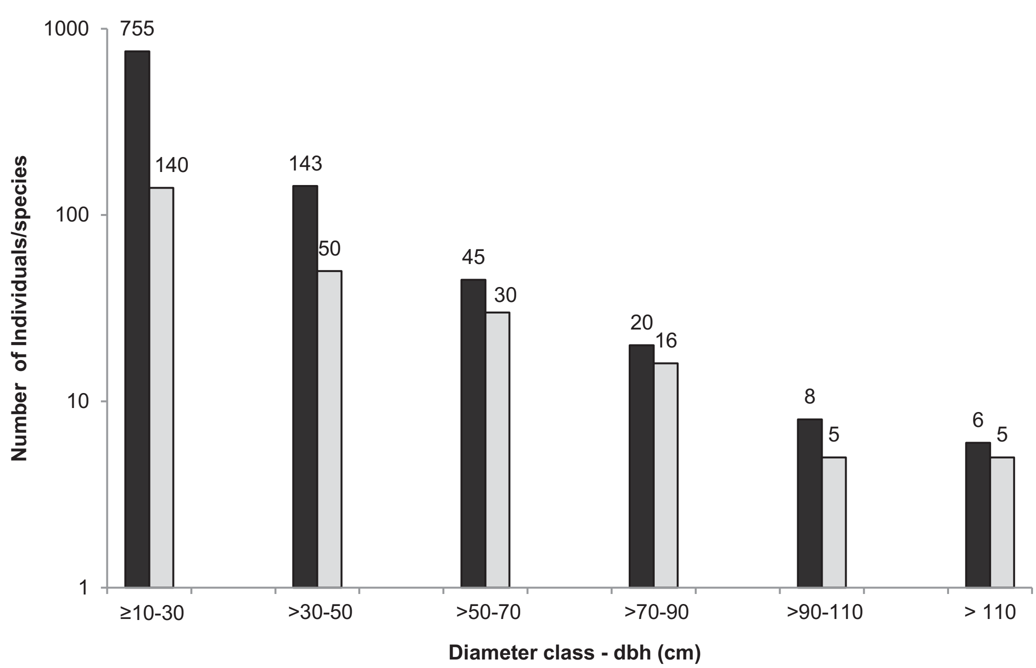

Figure 3. Diameter class distributions of plants (dbh ≥ 10 cm) and the respective number of species at the Tano Offin GSBA. Black columns represent individual plants and grey columns represent species. Values on top of columns represent the actual counted numbers.

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

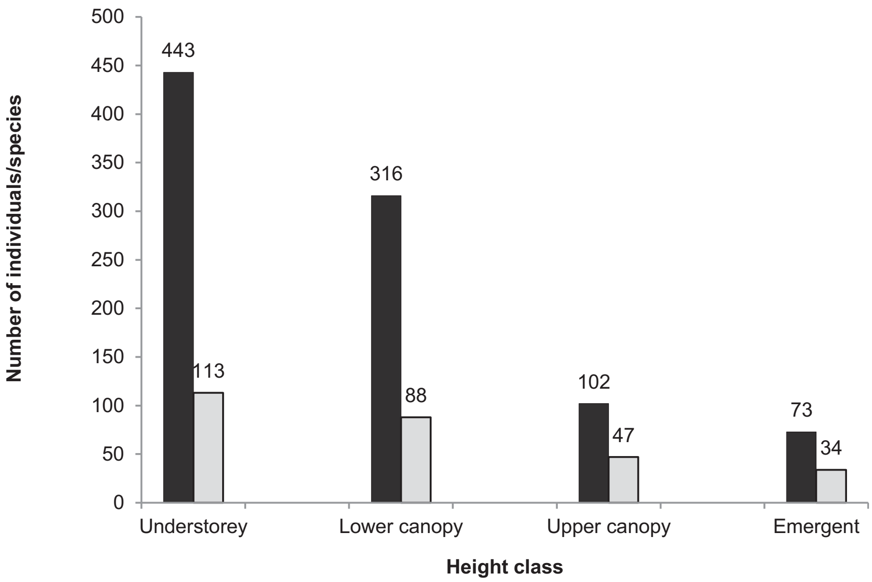

Figure 4. Number of plant species and individual plants (dbh ≥ 10 cm) in various height classes. Black columns represent individual plants and grey columns represent species. Values on top of columns represent the actual counted numbers.

understorey (≤ 15 m) which had the highest individuals, followed by the lower canopy (> 15 m–25 m), the upper canopy (> 25–35 m) and then the emergent layer (> 35 m) which was least in number (Figure 4). While the number of individuals making up the height classes varied across a wider margin (73–443), the number of species varied at a narrower margin (34–113). Thus, unlike the understorey, more species contributed in the make-up of the emergent layer relative to its number of individuals. Average tree height for the understorey, lower canopy, upper canopy and the emergent were 11.22 m, 18.75 m, 29.20 m and 46.19 m respectively. Out of the 34 species that were emergents, 16 were non-pioneer light-demanding, 10 were shade-bearers and 6 were pioneers. Shade-bearers constituted a greater portion of the understorey layer (42.48 %), followed by the non-pioneer light-demanders (28.32 %), while the pioneers constituted 19.47 % of the understorey.

Structural significance of plant species. With the highest density, maximum percent score of frequency (most common) and the greatest dominance, *Celtis mildbraedii* was the most significant species for the tree layer of the Tano Offin GSBA, recording an IVI of 32.16 (Supplementary Table 3). This was followed at a wider margin by *Strombosia pustulata* and *Hymenostegia afzelii* which recorded an IVI of 12.01 and 11.31, respectively. Out of the total 154 species, 53 were available on just a single occasion (i.e. density = 1; frequency = 2.5 %) so that the variation in IVI among these species resulted from differences in only their dominance. *Dalbergia saxatilis* and *Monodora myristica* were the least significant species occurring in the study area (Supplementary Table 3).

Shrub and herb layers

The shrub layer constitutes plant life forms with dbh < 10 cm and height ≤ 3 m that were sampled from the 10 m × 10 m plots. The herb layer refers to the forest floor vegetation which had the height of < 1 m and dbh of ≤ 1.5 cm, captured from the 1 m × 1 m quadrats. A general summary of the findings of these layers is in Table 1.

Diameter class distribution and basal area. In a similar pattern to the tree layer, there was a decrease in the number of individuals in the various diameter groups as sizes increase so that the highest number of plants with dbh < 10 cm was found in the smallest diameter class (Figure 5). The seven species that formed the largest diameter class in the shrub layer (> 8–9.9 cm) are *Blighia sapida*, *Celtis mildbraedii*, *Cola boxiana*, *Dacryodes klaineana*, *Napoleonaea vogelii*, *Rinorea oblongifolia* and *Rinorea welwitschii*.

Structural significance of plant species. With an IVI of 33.94, *Rinorea welwitschii* was the most significant species for the shrub layer in the GSBA, being the most dominant and most abundant; it was followed at a wider margin by *Drypetes chevalieri* (13.46), *Strombosia pustulata* (11.46) and *Greenwayodendron oliveri* (10.37) (Supplementary Table 4). However, *Rinorea oblongifolia* with an IVI of 8.57 was the most frequent (70 %). With a density of 20 individuals *per* 0.1 ha and 10 % frequency level, *Cleidion gabonicum* appeared locally abundant (*per* plot) unlike *Diospyros ferrea* which was relatively widespread (40 %) though of lower abundance (5 individuals per 0.1 ha). Although *Treculia africana* occurred just once, it was far more significant than 75 other species due to its higher dominance. *Pterygota macrocarpa*, *Rothmannia whitfieldii*, *Coffea stenophylla* and *Trilepisium madagascariense* had the lowest IVI stemming from their small dominances (Supplementary Table 4).

Natural regeneration and canopy closure

A total of 75 plant species were found regenerating as saplings and seedlings. Species richness of saplings was 61, while 45 species were seedlings (Supplementary Table 5). Presents among the recruitments were tree species that were encountered only as saplings (*Anthonotha fragrans*, *Drypetes gilgiana*, *Garcinia kola*, *uvariostrum pierreanum* and *Xylopia villosa*) or only as seedlings (*Lecaniodiscus cupaniodes*, *Lovoa trichiliodes* and *Mallotus oppositifolius*) and were thus absent from the adult community. With a mean canopy closure of 87.27 ± 2.12 % (Supplementary Table 1) and with reference to O'Neil *et al.* (2001), the forest canopy of the Tano Offin forest GSBA could be described as a closed canopy.

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

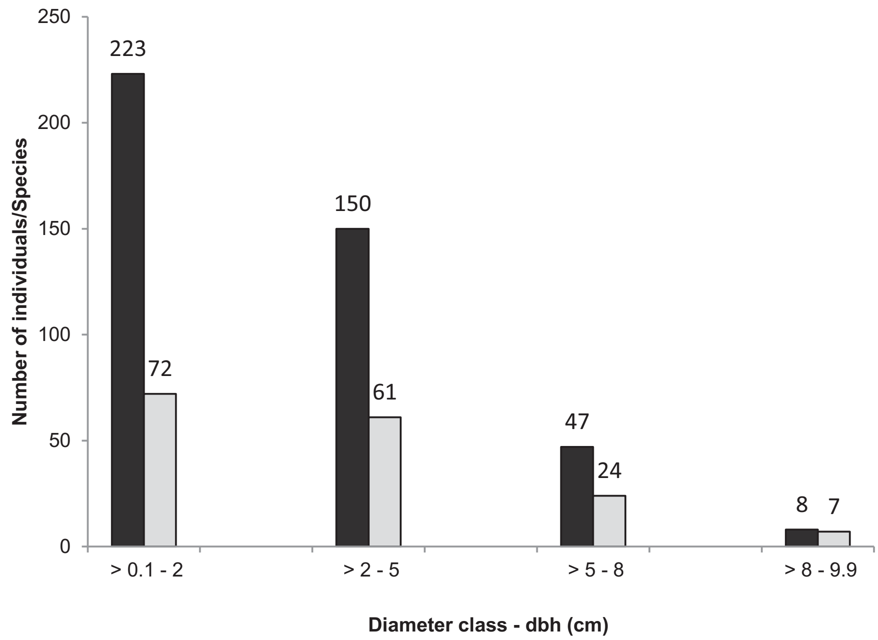

Figure 5. Diameter class distributions of plants (dbh < 10 cm) and the respective number of species at Tano Offin GSBA. Black columns represent individual plants and grey columns represent species. Values on top of columns represent the actual counted numbers.

Discussion

Floristic composition

Trees were the highest in number among the various growth forms and this is consistent with other forest studies at different regions of Ghana (Addo-Fordjour *et al.* 2009a, Anning *et al.* 2008, Hall & Swaine 1981, Pappoe *et al.* 2010, Vordzogbe *et al.* 2005). However, the precise growth form classification for some plants was challenging, since some plant species change their habit in accordance with growing conditions. *Uvaria* and *Combretum* species, for instance, behave and flower as shrubs when growing in open vegetation but become lianas when they live long enough, and forests develop around them (Hawthorne & Jongkind 2006). In this study, there was identification disparity for some species such as *Dichapetalum angolense* which was found growing sometimes as liana and sometimes as a shrub or tree.

The preponderance of Fabaceae family is similar to findings in other tropical forests: a Moist Semi-deciduous forest of Ghana (Addo-Fordjour *et al.* 2009b), a moist forest in Panama (Jiménez *et al.* 2016), Kilengwe tropical forest in Tanzania (Kacholi 2014), a tropical dry forest in India (Gopalakrishna *et al.* 2015) and a tropical deciduous forest in Myanmar (Khaine *et al.* 2017). In a floristic inventory at the Allpahuayo Reserve in Amazonian Peru, 61 families/2 ha were found (Martinez & Phillips 2000) which is similar to 59 families/2.5 ha in this study, with Fabaceae representing ~ 19% akin to the 15% representation in this study. Apart from Australia, the Fabaceae family together with the following families found in this study are also reported to be commonly found in all tropical forests: Rubiaceae, Annonaceae, Euphorbiaceae, Moraceae, Sapotaceae, Myristicaceae and Meliaceae (Banin *et al.* 2015).

The presence of seven red stars and nine scarlet stars could be an indication of serious exploitation activities in the GSBA. Pink stars which are moderately exploited were slightly higher in number (21) than the scarlet (9) and red stars (7). Their higher presence than red and scarlet stars could also be that the values of some pink stars are yet to be ascertained (Hawthorne *et al.* 1997). The incidence of a smaller number of plant species with respect to increase in plot number (Figure 2) is consistent with the observation of Magurran (1988) who attested that majority of plant species are rare within a normal ecological community, a moderate number are common, while only few are very common. While 97 species occurred just once (plot size of 0.25 ha) in this study, Morandi *et al.* (2016) found 142 species out of a total 257 species sampled from 10 plots (1 ha each) to be restricted to only one plot in the Cerrado and Amazonian domains in Brazil.

Forest structure

On *per* hectare basis, the herb layer contained the highest number of individual and species, followed by the shrub layer which was also higher in number and species than the tree layer. Similarly, there were more individual plant species at the shrub layer than they were in the tree layer at the Campo-Ma'an rain forest of Cameroon (Tchouto *et al.* 2004). The greater number of individuals and species in the shrub layer as compared to the tree layer may be due to the many growth forms which make up the shrub layer, namely shrubs, shrublets, small trees (pigmy trees and treelets), immature large trees, liana and hemi-epiphytes, of which some are not usually found in the tree layer.

Species diversity

Diversity indices give a quantitative view of diversity and thus provide information about rarity and commonness of species in a community which is essential for understanding community's numerical structure (Beals *et al.* 1999). Although Shannon–Wiener and Simpson's diversity indices assess different facets of diversity through the relative weighting assigned to evenness and species richness (Magurran 1988), these diversity indices indicated that floristic diversity in all three layers were comparable. With regard to the Simpson's index of diversity values, the tree layer may be more even in its diversity outlook compared with the other two layers. Khaine *et al.* (2017) found the Shannon and Simpson's diversity indices of a tropical deciduous forest in Myanmar to increase with increasing rainfall. In another tropical forests, a Shannon diversity index range of $H' = 2.74–2.99$ is

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

recorded to be indicative of an intermediate type of secondary succession, while a range of $H' = 3.37–3.86$ represented an advanced type of secondary suggestion (Jiménez *et al.* 2016). However, the Shannon diversity index value reported in this study is similar to the Shannon diversity value ($H' = 2.9$) reported for a degraded Moist Semi-deciduous forest in Ghana, where a higher index value ($H' = 3.6$) was reported for its undegraded portions, suggesting degradation, other than a level of secondary succession stage of the Tano Offin GSBA.

Diameter class distribution

Results of other studies conducted in some Moist Semi-deciduous forests of Ghana (Addo-Fordjour *et al.* 2009b, Pappoe *et al.* 2010) agree with findings in the Tano Offin GSBA where there was a similar decrease in the number of individuals in the various diameter groups as tree and liana diameter sizes increased so that the highest number of trees and lianas with dbh ≥ 10 cm were found in the 10–30 cm diameter class. This observation depicts the typical reverse J-shaped diameter class distribution curve of natural tropical uneven-aged forests. In addition, since, tree diameters could suggest tree age (Andreu *et al.* 2009), the abundance of trees and other plant forms in the lower diameter class size imply a dynamic self-regenerating stand.

Basal area

The basal area reported from studies in other tropical forest includes 5.1 m^2/ha in Southern India (Gopalakrishna *et al.* 2015), 7.1 m^2/ha in Tanzania (Kacholi 2014), 18.396 m^2/ha in Panama (Jiménez *et al.* 2016), 25.82 m^2/ha in South-east India (Naidu & Kumar 2016) and 30.66 m^2/ha in Myanmar (Khaine *et al.* 2017). The disparity in basal area of tropical forests is attributable to differences in species composition, tree age, elevation, stage of succession and the level of anthropogenic disturbances (Gopalakrishna *et al.* 2015, Jiménez *et al.* 2016, Kacholi 2014, Khaine *et al.* 2017, Naidu & Kumar 2016). Earlier records of the mean basal area for the Upland and Moist Semi-deciduous forests of Ghana were 26.8 m^2/ha and 24.2 m^2/ha, respectively, which was attributable to high incidence of farming disturbance and logging (Hall & Swaine 1981). With reference to the 35 m^2/ha average value for basal area of tropical forests (Philip 1983), the recorded 28.36 m^2/ha basal area of the Tano Offin GSBA in this study can be described as below average. Over the years, there has been a decline in basal area as a result of logging of the Tano Offin Forest Reserve even before the GSBA was demarcated: between the years of 1990 and 2000, 5 % or 26.76 ha of forest cover of Tano Offin were lost, amounting to 2.76 % reduction in basal area (Djabletey 2005). The annual forest loss of Tano Offin Reserve in general is pegged at 0.3 % and as a result, basal area declined from 24.3 m^2/ha to 18.9 m^2/ha between the years of 1990 and 1996 and then it further declined from 18.9 m^2/ha to 16.9 m^2/ha between 1996 and 2001 (Djabletey 2005). Establishment of the GSBA with logging prohibition may have appreciated the basal area to some extent, although the prohibition it is not completely adhered to (Afriyie 2010, Asamoah *et al.* 2011, The Chronicle 2011). Similarly, a structural analysis of a Moist Evergreen tropical forest of Cameroun presented a basal area of 32 m^2/ha and 29.4 m^2/ha for the part of the forest where past logging activities have happened once and twice, respectively, while the unlogged section recorded a higher basal area of 35.3 m^2/ha (Njepang 2015).

Height

Average tree height of the emergent layer was 46.19 m, similar to the report by FC (2007) where the average maximum height of trees in the reserve was found to be about 45 m. Past findings on the maximum tree height of the Moist Semi-deciduous forests by Hall & Swaine (1981) was > 50 m, while the tallest trees of the Upland Evergreen forests were found rarely to exceed 45 m. Greater constituents of the emergent in the GSBA were non-pioneer light-demanders which are known to include most of the timber species (Wong 1989). Pioneers were least represented in the emergent layer (> 35 m) as they hardly exceed the height of 20–30 m (FAO 2002) and they decline in numbers with respect to increasing size (Hall & Swaine 1988). Most constituents of the understorey were shade-bearers which flourish beneath upper and lower canopies. What could have also compounded the great number of shade-bearers at the understorey might be the presence of cryptic pioneers which are often misclassified as shade-bearers; unlike pioneers, they tolerate shade later in life (Hawthorne 1993). In a cross-continental comparison of forest structure from intact closed-canopy tropical forest, the mean tree height for trees with 10 cm mean stem diameter was 13.3 m, 11.9 m and 10. 6 m for Central Africa, Asia (Borneo) and the Amazonia (Central/ East), respectively; that of trees with 40 cm mean stem diameter was 30.8 m, 30.3 m and 26. 1 m, respectively; and that of trees with 100 cm mean stem diameter was 43.5 m, 46.0 m and 39. 0 m, respectively (Lewis *et al.* 2013).

Structural significance

The representation of *Celtis mildbraedii* as the most significant species in the tree layer is consistent with the reported feature of the Moist Semi-deciduous forests of Ghana: *Celtis mildbraedii* together with *Triplochiton sclerexylon* are known as the most common species of the Semi-deciduous forests of Ghana, although the latter is less frequent (Hall & Swaine 1981). *Pterygota macrocarpa*, *Mansonia altissima* and *Terminalia superba* are reported to be the dominant timber species of the GSBA (FC 2007). Hence, the less favourability of *C. mildbraedii* for timber, compared to *P. macrocarpa*, *M. altissima*, *T. superba* and *T. sclerexylon* perharps must have appreciated its significance. In conformity to exploitation pressure, *M. altissima*, *T. superba*, *P. macrocarpa* and *T. sclerexylon* have all been classified under the reddish star system (Hawthorne 1993). Their exploitation must have necessitated the creation of *P. macrocarpa*, *M. altissima* and *T. superba* plantations in a Taungya system at the reserve (Birdlife International 2011).

The significance of *Celtis mildraedii* was followed at a wider margin by *Strombosia pustulata,* and then *Hymenostegia afzelii*. When present, *Strombosia pustulata* is reported to have high incidence (Hawthorne & Jongkind 2006) and thus not surprising that *S. pustulata* recorded the highest frequency value after *Celtis mildbraedii*. As a characteristic species of the Upland Evergreen forest, Hall & Swaine (1981) similarly recorded a 100% frequency on *Strombosia pustulata*. *Hymenostegia afzelii* when present is reported to occur in abundance (Hawthorne & Jongkind 2006). Therefore, it is also not surprising that it recorded the highest value for density after *Celtis mildraedii*. *Dalbergia saxatilis* and *Monodora myristica* were the least significant species because they were the least dominant species.

Rinorea welwitschii was the most significant species for the shrub layer. Members of the *Rinorea* family are noted to be locally dominant and widespread understorey species (Hawthorne &

https://doi.org/10.1017/S0266467421000304 Published online by Cambridge University Press

Jongkind 2006). This assertion is further confirmed in this study by the highest frequency score attained by *Rinorea oblongifolia*. The local abundance of *Cleidion gabonicum* (all 20 individuals were found on a single plot) at the shrub layer concurs with the view of Hawthorne & Jongkind (2006) who found that *Cleidion gabonicum* is a gregarious understorey tree. Overall, IVI is useful for prioritising plant species conservation (Kacholi 2014).

Natural regeneration

Less than 50 % of the adult population were regenerating as saplings and seedlings in this study. However, findings of Hall & Swaine (1988) indicated 68 % of the adults in their study regenerating and concluded that the Ghanaian forests were generally well represented by juveniles. Saplings had higher species richness than seedlings and a higher value of species diversity index. Most forest trees have recalcitrant seeds and are very unlikely to be found in seed banks. Emergence of seedlings, therefore, might have been challenged by factors such as removal of parent trees and lack of effective dispersal mechanisms. For a successful natural regeneration, a seed source, a suitable microclimate, light, freedom from vegetation competition and browsing are very crucial (Hale 2004, Ward & Worthley 2004).

Constituents of the regeneration flora which occurred exclusively as saplings and seedlings were comparable to findings of Addo-Fordjour *et al.* (2009b), where seven species of the regeneration vegetation were missing from the adult tree population at Tinte Bepo Forest Reserve (Moist Semi-deciduous forest). Seedlings of *Lovoa trichilioides* if present are often found within the vicinity of parent trees (Hawthorne & Jongkind 2006). The red star status of the species (Hawthorne 1993) suggests exploitation pressure on adult trees which might have led to their absence among the adult trees in this study. *Lecaniodiscus cupaniodes* and *Mallotus oppositifolius* may have been new to the community as colonisers. Although *Lecaniodiscus cupaniodes* is purported to be a cryptic pioneer (regenerating in gaps under canopy), both are classified as shade-tolerant species. They are reported to be very common in secondary forests with *Mallotus oppositifolius* exhibiting weedy behaviour (Hawthorne & Jongkind 2006).

Canopy closure

A forest canopy is considered open when 10–39 % of the sky is obstructed by tree canopies, moderately closed when 40–69 % of the sky is obstructed by tree canopies and closed when 70–100 % of the sky is obstructed by tree canopies (O'Neil *et al.* 2001, Portland State University: PSU (2010). The forest canopy of the Tano Offin forest GSBA could thus be described as closed. The structure of the forest is a likely contributing factor to the closed forest canopy of the GSBA. The structure of forests determines to a large extent the amount of light transmitted to the forest floor. The basal area of a stand with many small trees will have a very dense canopy and will transmit less light (greater canopy closure) than a stand with the same basal area but fewer, larger trees (Hale 2004). The closed canopies of the GSBA may have favoured the shade-bearers and non-pioneer light-demanding species that composed a greater portion of the natural regeneration flora.

Conclusion

The study has largely ascertained the threat that forest degradation poses to the Tano Offin GSBA. If serious attention is not given to manage the floral diversity of the GSBA, its conservation value will decrease. Therefore, the star rating system should be updated, especially the reddish star system. This is critical in reflecting the current exploitation pressure on the plant species, so as to accord the necessary conservation attention. Information from the forest structure analysis suggests abundance of young trees to rejuvenate the GSBA into a functionally matured forest in the years to come if degradation on the area is curbed. By the establishment of permanent sampling plots, the study serves as a baseline for future research that pertains to understanding the dynamics of the changing forest resources as well as monitoring impacts of anthropogenic disturbances. Overall, the information generated should be useful in designing conservation measures for the Tano Offin GSBA as well as helpful in managing protected areas.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0266467421000304

Acknowledgement. We are grateful to Canadian International Development Agency (CIDA) for funding this study through the APERL (Agroforestry Practices to Enhance Resource-poor Livelihoods) project. In this regard, we wish to acknowledge Prof. William Oduro (KNUST) and Prof. Naresh Thevathasan (University of Guelph, Canada) for being very supportive in immeasurable ways. We are thankful to Mr. Jonathan Dabo and Mr. Emmanuel Manu both from the Forest Research Institute of Ghana (FORIG) for their technical assistance on the field. Our appreciation also goes to the staff of Resource Management Support Centre (RMSC) – Forestry Commission of Ghana, Kumasi and the staff of Nkawie District of the Forestry Commission.

Competing interests. The author(s) declare none.

References

Abeney EA (1999) The worldwide interest in forests and forestry. Workshop for media personnel on forestry and wildlife reporting proceedings, IRNR-UST, Ghana. Pp 1–13.

Addo-Fordjour P, Obeng S, Addo MG and Akyeampong S (2009a) Effects of human disturbances and plant invasion on liana community structure and relationship with trees in the Tinte Bepo forest reserve, Ghana. *Forest Ecology and Management* **258**, 728–734. doi: 10.1016/j.foreco.2009.05.010.

Addo-Fordjour P, Obeng S, Anning AK and Addo MG (2009b) Floristic composition, structure and natural regeneration in a Moist Semi-deciduous forest following anthropogenic disturbances and plant invasion. *International Journal of Biodiversity and Conservation* **2**, 21–37.

Afriyie MA (2010) Globally Significant Biodiversity Areas (GSBAs) designation and their impacts on livelihoods: a case study of the Tano Offin GSBA in the Atwima Mponua and Ahafo Ano Districts of the Ashanti Region of Ghana. Conservation and Development Foundation (CONDEF). 25 pp.

Andreu MG, Friedman MH and Northrop RJ (2009) The Structure and Composition of Tampa's Urban Forest. University of Florida IFAS Extension, FOR 209. http://edis.ifas.ufl.edu. (Accessed: 11/09/2012 09:23).

Anning AK, Akyeampong S, Addo-Fordjour P, Anti KK, Kwarteng A and Tettey YF (2008) Floristic composition and vegetation structure of the KNUST Botanic Garden, Kumasi, Ghana. *Journal of Science and Technology (JUST)* **28**, 103–122.

Antwi LB (1999) What we have: our forest heritage. In: Workshop for media personnel on forestry and wildlife reporting proceedings, IRNR-UST, Ghana. Pp 24–34.

Asamoah KA, Duah-Gyamfi A and Dabo J (2011) Ecological impacts of uncontrolled chainsaw milling on natural forests. *Ghana Journal of Forestry* **27**, 12–23.

Banin LF, Philips OL and Lewis SL (2015) *Tropical forests*. In Peh KSH, Corlett RT and Bergeron Y (eds), *Routledge handbook of forest ecology*. Oxfordshire, UK: Routledge, pp 56–75.

Beals M, Gross L and Harrell S (1999) Community assessment, Diversity Indices: Simpson's D and E. http://www.scribd.com/doc/8283486/Diversity-Indices. (Accessed: 15/08/2011).

BirdLife International (2011) Important Bird Areas factsheet: Tano-Offin Forest Reserve. http://www.birdlife.org/datazone/sitefactsheet.php?id=6333. (Accessed 22/08/2011).

Djabletey ED (2005) Loss of forest cover and its socio-economic implications: a case study along the Offin River basin of the Ashanti region, Ghana. (unpublished).

Fiala ACS, Garman SL and Gray AN (2006) Comparison of five canopy cover estimation techniques in the western Oregon Cascades. *Forest Ecology and Management* **232**, 188–197. Published by Elsevier B.V. doi: 10.1016/j.foreco.2006.05.069.

Food and Agriculture Organization (2002) Workshop on tropical secondary forest management in humid Africa: reality and perspectives. http://www.fao.org/docrep/006/J0628E/J0628E00.HTM. (Accessed 18/10/2011).

Forest Resources Assessment (2010) Global Forest Resources Assessment, Main report. Food and Agriculture Organization of the United Nations, 2010. 340 pp.

Forestry Commission of Ghana (2007) Tano Offin Globally Significant Biodiversity Area Management Plan, 2007–2011. 66 pp.

Forestry Outlook Study for Africa (2002) Ministry of Lands and Forestry, Ghana. 2nd Draft.

Gbadamosi N (2020) Ghana's Bauxite Boom. FP Argument. https://foreignpolicy.com/2020/01/28/china-investment-bauxite-mining-ghana-infrastructure/, (Accessed 16/02/2020).

Gopalakrishna SP, Kaonga ML, Somashekar RK, Suresh HS and Suresh R (2015) Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, Southern India. *European Journal of Ecology* **2**, 12–27.

Hale S (2004) Managing light to enable natural regeneration in British conifer forests. Information note 1–6. Forest research, Forestry Commission, Edinburgh, UK.

Hall JB and Swaine MD (1981) *Distribution and ecology of vascular plants in a tropical rain forest, forest vegetation in Ghana*. London: Dr. W. Junk Publisher.

Hall JB and Swaine MD (1988) The mosaic theory of forest regeneration and the determination of forest composition in Ghana. *Journal of Tropical Ecology* **4**, 253–269. Cambridge University Press - http://www.jstro.org/stable/2559389 (Accessed: 20/06/2011 09:29).

Hawthorne W (1993) Forest Reserves of Ghana, Graphical Information Exhibitor - FROGGIE, part 2. Ghana Forestry Dept. and Overseas Development Administration (ODA) Forest Inventory and Management Project (FIMP).

Hawthorne W and Gyakari N (2006) Photoguide for the forest trees of Ghana; A tree-spotter's field guide for identifying the largest trees. Oxford Forestry Institute, Department of Plant Sciences, South Parks road, Oxford OX 13 RB, UK. 432 pp.

Hawthorne W and Jongkind C (2006) Woody plants of Western African forests: a guide to the forest trees, shrubs and lianas from Senegal to Ghana. Kew Publishing, Royal Botanic Gardens, Kew Richmond, Surrey, TW9 3AB, United Kingdom. 1023 pp.

Hawthorne WD, Grut M and Abu-Juam M (1997) Forest production and biodiversity conservation in Ghana and proposed international support of biodiversity conservation. The Centre for Social and Economic Research on the Global Environment (CSERGE) Working Paper GEC 98-18.

Jennings SB, Brown ND and Sheil D (1999) Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry* **72**. Institute of Chartered Foresters.

Jiménez JU, Fábrega J, Mora D, Tejedor N and Sánchez M (2016) Composition, diversity, and tree structure of a tropical moist forest in Gamboa, Colon, Panama. *Air, Soil and Water Research* **9**, 29–34. doi: 10.4137/ASWR.S33960.

Kacholi DS (2014) Analysis of structure and diversity of the Kilengwe Forest in the Morogoro Region, Tanzania. *International Journal of Biodiversity* **2014**, 1–8. doi: org/10.1155/2014/516840.

Khaine I, Woo SY, Kang H, Kwak M, Je SM, You H, Lee T, Jang J, Lee HK, Lee E, Yang L, Kim H, Lee JK and Kim J (2017) Species diversity, stand structure, and species distribution across a precipitation gradient in tropical forests in Myanmar. *Forests* **8**, 1–15. doi: 10.3390/f8080282.

Kim KC and Byrne LB (2006) Biodiversity loss and the taxonomic bottleneck: emerging biodiversity science. *Ecological Research* **21**, 794–810. The Ecological Society of Japan, Special issue: Global changes in terrestrial ecosystems. doi 10.1007/s11284-006-0035-7.

Lewis SL *et al.* (2013) Aboveground biomass and structure of 260 African tropical forests. *Philosophical Transactions of the Royal Society B* **368**, 20120295. doi: 10.1098/rstb.2012.0295.

Lindenmayer DB, Margules CR and Botkin DB (2000) Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology* **14**, 941–950.

Magurran AE (1988) *Ecological diversity and its measurement*. Princeton, New Jersey, USA: Princeton University. 179 pp.

Marchi A and Paletto A (2010) Relationship between forest canopy and natural regeneration in the subalpine spruce-larch forest (north-east Italy). *Folia Forestalia Polonica* **52**, 3–12.

Martinez RV and Phillips OL (2000) Allpahuayo: floristics, structure, and dynamics of a high-diversity forest in Amazonian Peru. *Annals of the Missouri Botanical Garden* **87**, 499–527.

McCullough J, Alonso LE, Naskrecki P, Wright HE and Osei-Owusu Y (2007) A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment 47. Conservation International, Arlington, VA.

Morandi PS, Marimon BS, Eisenlohr PV, Marimon-Junior BH, Oliveira-Santos C, Feldpausch TR, Oliveira EAD, Reis SM, Lloyd J and Phillips OL (2016) Patterns of tree species composition at watershed-scale in the Amazon 'arc of deforestation': implications for conservation. *Environmental Conservation* **43**, 317–326. doi: 10.1017/S0376892916000278.

Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB and Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–859. Macmillan Magazines Ltd.

Naidu MT and Kumar OA (2016) Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. *Journal of Asia-Pacific Biodiversity* **9**, 328–334. doi: 10.1016/j.japb.2016.03.019.

Newton A, Oldfield S, Fragoso G, Mathew P, Miles L and Edwards M (2003) Mapping the status and distribution of the world's threatened tree species. Towards a global tree Conservation atlas. UNEP-WCMC/FFI. http://www.unep-wcmc.org/resources/publications/treeatlas

Njepang AD (2015) A structure analysis for ecological management of moist tropical forests. *International Journal of Forestry Research* **2015**, 1–12. doi: 10.1155/2015/161645.

Ntiamoa-Baidu Y, Owusu EH, Daramani DT and Nuoh AA (2001) Important Bird Areas in Africa and associated islands – Ghana. 367–390 pp. (Unpublished).

O'Neil TA, Bettinger KA, Heyden MV, Marcot BG, Barrett C, Mellen TK, Vanderhaegen WM, Johnson DH, Doran PJ, Wunder L and Boula K (2001) *Structural conditions and habitatelements of Oregon and Washington*. In Johnson DH and O'Neil TA (eds), *Wildlife-habitat relationships in Oregon and Washington*, Eugene-Oregon, US: University of Oregon Press, pp 115–139.

Oteng-Yeboah A (2019) Scientific goldmine, Ghana's pact with China for bauxite mining threatens to ravage a biodiverse forest. Quartz Africa. https://qz.com/africa/1692311/ghanas-bauxite-mining-pact-with-china-threatens-atewa-forest/, (Accessed 25/11/2019).

Pappoe ANM, Armah FA, Quaye EC, Kwakye PK and Buxton GNT (2010) Composition and stand structure of a tropical Moist Semi-deciduous forest in Ghana. *International Research Journal of Plant Science* **4**, 95–106.

Philip MS (1983) *Measuring trees and forests*. Wallingford, UK: CAB International. 324 pp.

Philip OL (1997) The changing ecology of tropicalforests. *Biodiversity and Conservation* **6**, 291–311.

Portland State University: PSU (2010) Ecoplexity -Measuring canopy cover. http://ecoplexity.org/node/211. (Accessed 17/12/2012).

Shah A (2009) Why is biodiversity important? who cares? http://www.globalissues.org/article/170/why-is-biodiversity-important-who-cares, (Accessed 01/08/2019).

Tchouto MGP, de Boer WF, de Wilde JJFE, van der Maesen LJG, Yemefack M and Cleef AM (2004) Plant diversity in a Central African rain forest, implications for biodiversity conservation in Cameroon. Available at http://www.tropenbos.org/country_programmes/cameroon/publications?page=2

The Chronicle (2011) Minister arrests chainsaw operators deep in the forest. http://thechronicle.com.gh/minister-arrests-chainsaw-operators-deep-in-the-forest/. (Accessed 12/12/11).

Vordzogbe VV, Attuquayefio DK and Gbogbo F (2005) The Flora and Mammals of the Moist Semi-deciduous Forest Zone in the Sefwi-Wiawso District of the Western Region, Ghana. *West African Journal of Applied Ecology* **8**, 49–64.

Ward JS and Worthley TE (2004) Forest Regeneration Handbook. A Guide for Forest Owners, Harvesting Practitioners, and Public Officials. U. S. forest service, northeast area, state and private forestry. The Connecticut Agricultural Experiment Station, New Haven. Connecticut Department of Environmental Protection.

Wong JLG (1989) Forest Inventory Project, Ghana Forestry Department, Kumasi. Seminar proceedings, Accra 1989. Overseas Development Administration (ODA), UK. Pp 1–101.

Yoda ASS (2020) Ghana's government faces pushback in bid to mine biodiversity haven for bauxite. Mongabay, news & inspiration from nature's frontline. https://news.mongabay.com/2020/02/ghanas-government-faces-pushback-in-bid-to-mine-biodiversity-haven-for-bauxite/, (Accessed 16/02/2020).