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Population Structure of African Mahoganies in Four Forest Reserves: Implications for Conservation and Management in Ghana

Jones Abrefa Danquah[1], Mark Appiah[2], Lawrence Damnyag[1] and Ari Pappinen[1]

[1]University of Eastern Finland, Faculty of Science and Forestry, School of Forest Sciences, Joensuu, Finland.
[2]Viikki Tropical Resources Institute, University of Helsinki, Finland.

ABSTRACT

Tropical trees in the genera Khaya and Entandrophragma are the principal sources of most valuable tropical hardwood under trade name African mahogany. Although species of these genera are the focus of increasing conservation concern information on their status and population structure is lacking. Data from (2000-2001) national forest inventory (NFI) were used to assess their population structure and status of African mahoganies in four forest reserves (Bobiri, Tintin Bepo, Draw and Bowiye) in Ghana. We analyzed NFI data using one-way ANOVA and coefficient of skewness. The results indicated that size distributions or population structures of African mahoganies significantly varied within species (P=0.014), among population (P=0.002) and across different forests type (P=0.003).In addition, the result indicated the size distributions of African mahoganies consist of relatively high proportions of individuals in larger dbh classes. However, *Entandrophragma cylindricum occurs at relatively low numbers across the four forest reserves, suggesting that, Entandrophragma cylindricum population is threatened in these forest reserves. Moreover, Khaya ivorensis recorded significantly ($P<0.05$) the highest mean number of individuals per each dbh size-class. In line with strict compliance to minimum felling limit in Ghana, K. ivorensis is the only mahogany species which could be selectively extracted from Bowiye and Draw forest reserves. Based on these results, we conclude that for conservation and management purposes, restriction should be placed on extraction of Entandrophragma species in these forest reserves.*

KEY WORDS: *Khaya* and *Entandrophragma* species, forest reserves, skewness, diameter distributions, management.

INTRODUCTION

The genera *Khaya* and *Entandrophragma (*Family*: Meliaceae)* are the main source of African mahogany [46]. *Khaya and Entandrophragma* species are found in all timber producing areas of West Africa, Central Africa, and parts of East Africa [29]. African mahoganies are valued as high quality timber resource. Mahoganies are major source of tropical hardwood exports and foreign exchange earner in the countries where they are found [39]. In Ghana the exploitation of African mahoganies as commercial wood dates back as far as 19th century. The first export of African mahogany from Ghana appeared on the British market around 1833 and ever since their importance had increased [40]. In fact, mahoganies used to be leading export timber species in Ghana until 2006, *Tectona grandis* became leading export species by volume and value [47]. Because of their commercial value and uses in traditional medicine, African mahoganies have been overexploited and even threatened. This problem is aggravated as result of lack of detail knowledge of life history and demographic information to ensure sustainable utilization of this valuable timber resource. Very little however, is known about African mahoganies population structure and whether structure changes across forest type.

However, Peters (1996) [41] mentioned four major ecological criteria for guiding sustainable management of any given species. These are life cycle characteristics, uses and kinds of resources produced, abundance in different forest types, and size-class distribution of the populations [41]. Population size structure can assist in the understanding key ecological variables of that merit major attention for implementation of management regimes [8]. Since ecological variables define population size structure differ by habitat type [48], it is plausible to evaluate a given species in multiple habitats or forest type in which they occur. Evaluating population structure in different habitats is a necessary precondition for assessing sustainability of harvesting in different habitat types [41]. Population structure in most forestry and ecological studies has been defined in terms of size-class or diameter distribution of individuals [36].

***Corresponding Author:** Dr. Jones Abrefa Danquah, Jones Abrefa Danquah, School of Forest Sciences, University of Eastern Finland, Post Office Box111, Fin-80101, Finland. Email: abrefad@gmail.com

Diameter at breast height (dbh) size-class is the easiest tree measurement and is used in almost every forest inventory. Dbh class distribution of trees in a stand may be used as crude estimator of the relative age structure and state of a forest when no growth data is available [38, 32]; regeneration status of dominant tree species [36, 18, 14] and as an indicator of a natural or man induced disturbance history [34, 12]. The number of individuals that falls within each tree dbh size class varies considerable in forests [9].Tree size distribution often has been used to describe successional pathways and structural development [50], and in predicting future forest stand structure[16]. Population size structure is also an important tool to understand plants strategies to survival according to light availability [49].

In this study we employed National Forest Inventory Data (NFI) to understand population structure and status of African mahoganies in four forest reserves in high forest zone of Ghana. The study seeks to add to existing body of knowledge on that application of dbh information in assessing population structure. The main of objectives of this study were to understand the nature of population structures and current status of African mahoganies and to assess level of variability in forest types in Ghana.

MATERIALS AND METHODS

2.1 Study sites

Four forest reserve sites were studied. These were Bobiri, Tintin Bepo, Draw and Bowiye forest reserves. Bobiri forest reserve (6°41' N, 1°21' W) is in Ashanti region of Ghana about 35km from Kumasi (Fig.1). It falls within the tropical moist semi-deciduous south east_forest zone and has a mean precipiatation of 1750mm [23].The reserve covers an of about area of 54.6km2. Tinte Bepo forest reserve (7o04´, 2o06´W) is located in the Ahafo Ano South District, Ashanti Region of Ghana (Fig.1). The reserve is classified as moist semi-deciduous forest [23], with mean annual rainfall of about 1288mm.The forest reserve covers an area of 115.5km2 [23]. The reserve is made up of three forest types, namely, intact primary forest without any form of disturbances, the disturbed forest which has experienced past and recent degradation in the form of illegal logging activities, and the disturbed-invaded forest in which both illegal logging and farming activities are taken place[2]. Draw river forest (5o20´N, 2o33´W) is located in the western region of Ghana, about 128.6km from Takoradi (Fig.1). Draw river forest reserve covers an area of 235 km². The reserve falls with within Wet Evergreen forest type with mean annual of rainfall 2250 mm [22, 44].Bowiye range forest reserve (5o72´N, 2o02´W) is located at Dunkwa District of Moseaso in Western region of Ghana (Fig.1). The reserve covers an area of 120km2. The forest reserve is Moist Evergreen forest type [22]. This area records annual precipitation amount of about 1775mm.

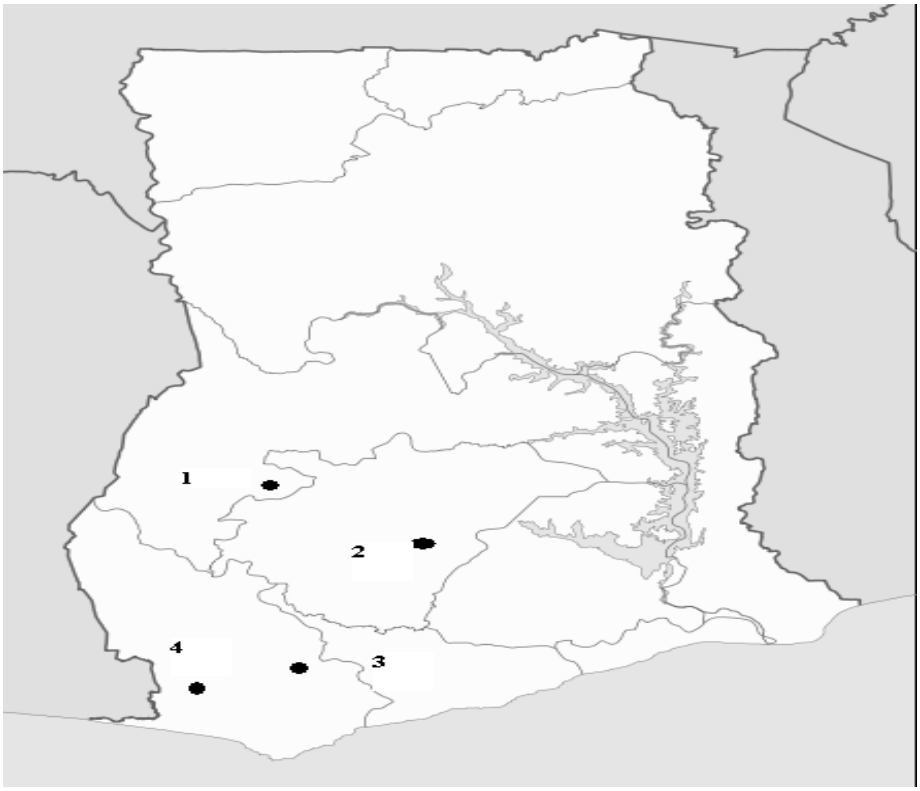

Figure1. The location of the four forest reserves studied in Ghana: These are Tinte Bepo (1), Bobiri (2), Bowiye Range (3) and Draw River (4) forest reserves.

2.2 Study species

The three principal species of African mahoganies selected for the study were *Khaya ivorensis* A.Chev. , *Entandrophragma cylindricum* (Sprague) and *Entandrophragma angolense* (Welw.) C. DC. These three species were selected on the basis of

relative abundance or commonness in all the four forest reserves studied. *E. cylindricum* is scattered in semi-deciduous forests from Guinea to Congo. *E. cylindricum is only deciduous towards the end of raining season [24*]. In comparison with other species of *Entandrophragma*, this species can occur in drier habitats, including abandoned fields [25]. *E. cylindricum is* heavily exploited throughout its range and genetic erosion caused by the large-scale depletion of mature individuals from populations has taken place in some countries [25, 24]. *E. angolense* is one of the main sources of African mahogany. The species occurs widely on better-drained sites in moist semi-deciduous forests from Guinea to Sudan and throughout central Africa [24]. *E. angolense* is deciduous plant with thick buttresses and sometimes large surface roots [26, 24]. *K. ivorensis* is found in various habitat types in west and central Africa but is most abundant in wet undisturbed evergreen forest. *K. ivorensis* is more or less restricted to lowland riverine basin or riparian environment in semi-deciduous forests zones. The species is very rare in dry semi-deciduous forest zone in Ghana. [4, 13, 24]

2.3 Population inventory

During 2001-2002 Multi Resource Inventory (MRI) of nationwide forest reserves was conducted by Resource Management Support Centre of Ghana Forestry Commission. The main objective of the inventory was to gain an understanding of the distribution of species and stocking rates in each ecological zone. The high forest zones of Ghana where timber extraction is carried out have been classified on the basis of annual precipitation amounts [23]. The methodology of National Forest Inventory (NFI) which serves as bases for data generation of this study has been described in detail by Affum-Baffoe(2011,unpublished).[3]

2.4 Data analysis

For the three species of African mahoganies, population structure diagrams were constructed for all the four forest reserve to show ecological zone variability. Adequate numbers of individuals are required to construct these diagrams using a number of classes. Tree size class were grouped into 30-39.9,40-49.9,50-59.9,60-69.9,70-79.9,80-89.9,90-99.9,100-109.9,110-119.9 and over 120 cm dbh. Size distribution diagram were analysed for trends using Shapiro-Wilk Test ($\alpha < 0.05$) and Pearson Skewness to size class. The symmetry of dbh size distributions was used as a synthetic measure of population size structure. A negative coefficient Pearson skewness (if skweness < -0.20 severe left skewness) indicates inverse J-shaped curve, a size distribution diagram characteristics of many species. A positive Pearson coefficient of skweness value (If skweness > +0.20 severe right skewness) indicates a structure whereby only few small individuals are present while many more large ones are found. Shapiro-Wilk test was used to evaluate the normality of the distribution. A one-way ANOVA with post-hoc Tukey HSD test ($P<0.05$) was used to check for significant differences in dbh classes within and among species, and population as well as across forest reserves. The statistical analyses were performed using XLSTAT -2009 for Windows (Addinsoft SARL, Paris, France) on excel platform.

RESULTS

3.1 Population structure of the species

Population structure diagrams are shown for each of the three species and four sites studied (Figure 2). The diagrams show large variability in the distribution of the three species of African mahoganies. None of the species African mahoganies studied show a typical inverse J-shaped distribution. The diameter of populations of *K. ivorensis* and *E. cylindricum* in Bobiri Forest reserve were normal distributed (W=0.891, *P*=0.173; W=0.872, *P*=0.105 respectively), with exception of *E. angolense* which was considered not to be normally distributed (W=0.772, *P*=0.002) (Table 2). The skewness coefficient (g1) for the three species of African mahoganies in Bobiri Forest reserve were g1 = 0.772, g1=0.344 and g1=0.173 in *E. angolense, E. cylindricum* and *K. ivorensis* respectively. These confirming distributions with long tails to the right (all g1>0).Virtually no trees were recorded in the dbh classes100-109.9, 110-119.9 and over 120 cm. The annual felling limit for *Khaya* species and *Entandrophragma* species is 110cm. In Bowiye Forest reserve however, only *K. ivorensis* was considered to be normally distributed (W=0.860, *P*=0.076), the other two species of *Entandrophragma* were not normally distributed (W=0.815, *P*=0.022; W= 0.818, *P*= 0.024 in *E. cylindricum and E. angolense* respectively).The level of skewness in the diameter distributions of African mahoganies in Bowiye Forest reserve is one of the highest amongst the four forests reserves studied. *Khaya ivorensis* recorded g1 value of 0.869 whereas *E. cylindricum* recorded g1 value of 1.96. Moreover, *E. angolense* recorded the highest g1 value (1.345) among three species of African mahoganies studied in Bowiye Forest reserve. The dbh class size distribution in Bowiye forest reserve did not follow characteristic inverse J-shaped distribution.

In the case of Tinte Bepo Forest Reserve disruptive distribution was observed. Greater proportions of trees recorded were in dbh classes 30-39.9, 40-49.9 and 50-59cm (Figure 2). However, no trees were recorded in dbh classes 60-69.9, 70-79.9, 90-99.9, and 110-119.9 and < 120cm (Figure 2). There is highly fluctuating distribution in the populations of African mahoganies in Tinte Bepo Forest Reserve is an indicative of level of anthropogenic disturbances in the reserve. Nevertheless, from the analyses populations of these three species of African mahoganies were not normally distributed (W=0.659, *P*=0.000; W=0.581, *P*=0.0001; W=0.515, *P*=0.024 in *K. ivorensis, E. cylindricum* and *E. angolense* respectively).The skewness coefficient for dbh distribution were g1=1.895, g1= 1.945 and g1=1.502 in *K. ivorensis, E. cylindricum* and *E. angolense* respectively (Table 2).

Draw forest Reserve had well defined distribution of dbh classes (Figure 2), with almost every class interval recording some amount of trees. However, the distribution was such that only *K. ivorensis* was normally distributed (W=0.888, *P*=0.161). The two species of *Entandrophragma* were not normally distributed (i.e. W=0.637, *P*=0.000; W=0.629, *P*=0.000 in *E. cylindricum* and *E. angolense* respectively) (Table 2). *E. angolense* recorded the highest coefficient of skewness (g1) value (2.015), followed by *E. cylindricum* (g1=1.339).The least g1 at this site was recorded by *Khaya ivorensis* (g1).The gradation in dbh classes distribution from small class intervals to larger class intervals is indicative of less anthropogenic disturbances. Moreover, the positive values of g1 confirmed right skewed (g1>0) distributions with long tails.

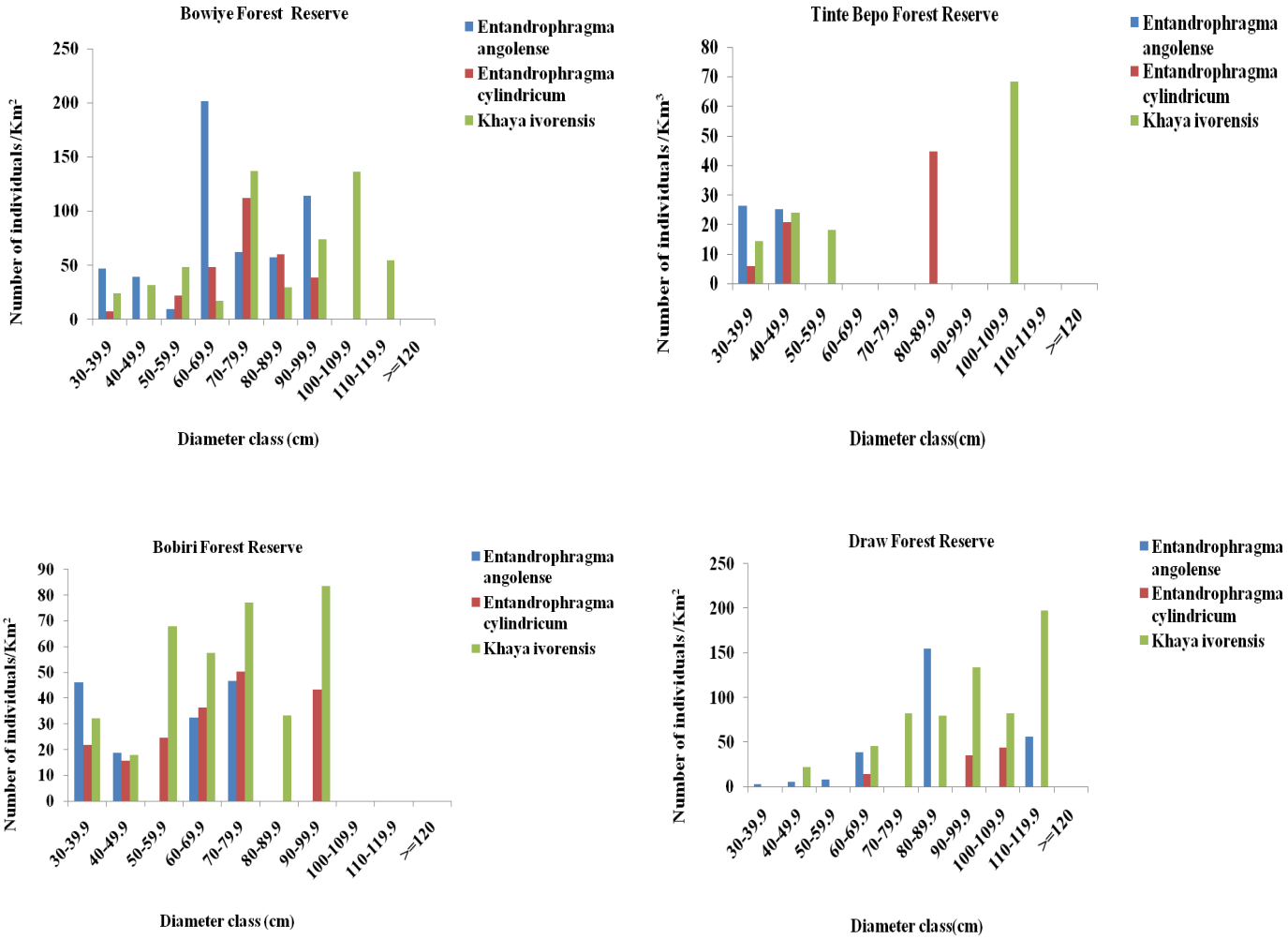

Figure 2. Size class distributions of *Entandrophragma angolense, Entandrophragma cylindricum* and *Khaya ivorensis* in four forest reserves (Bowiye, Draw, Tinte Bepo and Bobiri) studied.

Table 1. Summary of one-way ANOVA to compare changes in dbh size class across forest types, within species and among populations. Mean number of individuals per each dbh class size with corresponding standard error (S.E.)

(a)		**Variable Forest Reserves**		***F***	***P***
Bobiri Forest Reserve	**Bowiye Forest Reserve**	**Tinte Bepo Forest Reserve**	**Draw Forest Reserve**	4.907	0.003
Mean±S.E.	Mean±S.E.	Mean±S.E.	Mean±S.E.		
23.53±4.72$^{(ab)}$	45.78±9.19$^{(a)}$	8.25±2.94 $^{(b)}$	33.39±9.46 $^{(ab)}$		
(b) Forest Reserve		**Variable Population**		***F***	***P***
	Khaya ivorensis	***Entandrophragma cylindricum***	***Entandrophragma angolense***	2.899	0.002
	Mean±S.E.	Mean±S.E.	Mean±S.E.		
Bobiri Forest Reserve	36.92±10.35$^{(ab)}$	19.22± 6.13$^{(ab)}$	14.42± 3.37 $^{ab)}$		
Bowiye Forest Reserve	55.33±15.06$^{(ab)}$	28.87±11.64$^{(ab)}$	53.14± 20.15 $^{ab)}$		
Tinte Bepo Forest Reserve	12.47± 6.68$^{(ab)}$	7.41± 4.46$^{(b)}$	5.15± 3.43$^{(b)}$		
Draw Forest Reserve	64.24± 20.55$^{(a)}$	9.03± 2.24$^{(b)}$	26.61± 15.53$^{(ab)}$		
(c)		**Variable Species**		***F***	***P***
Khaya ivorensis	***Entandrophragma cylindricum***	***Entandrophragma angolense***		4.425	0.014
Mean±S.E.	Mean±S.E.	Mean±S.E.			
42.24±7.50$^{(a)}$	16.13±3.84$^{(ab)}$	24.83±6.51$^{(b)}$			

Variables with the same superscript along the same row are not significantly different from Tukey's post hoc test ($P<0.05$)

Table 2. The results of Shapiro-wilk test of normality and coefficient of skewness for each species in four forest reserves in Ghana. (Bobiri Forest Reserve, Bowiye Forest Reserve Tinte Bepo Forest Reserve and Draw Forest Reserve).

Forest Reserve	Tree Species	Shapiro-Wilk Test[#]		Coefficient of Skewness
		W	*P*-value	g_1
Bobiri Forest Reserve	*Khaya ivorensis*	0.891	0.173	0.153
	Entandrophragma cylindricum	0.872	0.105	0.344
	Entandrophragma angolense	0.772	0.002*	0.772
Bowiye Forest Reserve	*Khaya ivorensis*	0.860	0.076	0.869
	Entandrophragma cylindricum	0.815	0.022*	1.196
	Entandrophragma angolense	0.818	0.024*	1.345
Tinte Bepo Forest Reserve	*Khaya ivorensis*	0.659	0.000*	1.895
	Entandrophragma cylindricum	0.581	0.0001*	1.945
	Entandrophragma angolense	0.515	0.0001*	1.502
Draw Forest Reserve	*Khaya ivorensis*	0.888	0.161	0.785
	Entandrophragma cylindricum	0.637	0.000*	1.339
	Entandrophragma angolense	0.629	0.000*	2.015

*Alpha for Shapiro-wilk test (W) with corresponding the level of significant ($P<0.05$): Species with *P* -values greater than 0.05 have normal distribution. Species with *P*-values less than or equal to 0.05 are not normally distributed.

3.2 Variation in diameter distribution

The species occurrence is highly variable at the four forest reserves. There was significant difference ($F=4.907$, $P=0.003$) in average number of individual species recorded in each diameter class across the four forest reserves (Table 1a). Bowiye forest reserve recorded highest number of individual (45.78±9.19) per each diameter class amongst the four forest reserves studied. This was followed by Draw River (33.39±9.46) and Bobiri (23.53±4.72) forest reserves (Table 1a). The least number of individuals (8.25±2.94) per each diameter class was observed in Tinte Bepo forest reserve.

Analysis of variance was partitioned for each species at population level in each forest reserve. The mean number of individuals in each cluster of Mahogany species across four forest reserves was highly significant different ($F=2.899$, $P=0.002$) (Table 1b).The populations of *Khaya ivorensis* recorded highest numbers of individuals in each diameter class for four forest reserves studied. Thus depicting high level of commonness in these four forest reserves. This was followed by *E. angolense* and the least was observed in the populations of *E. cylindricum* (Table 1b). The populations of Mahogany species in Bowiye forest reserve recorded the highest average number of individual in each diameter class amongst the four forest reserves. At Bowiye forest reserve, *K. ivorensis* recorded the highest mean number of individuals (55.33±15.06) in each diameter cluster as compared to two other species of African mahoganies (Table 1b). The second highest species at Bowiye forest reserve was *E. angolense* (53.14±20.15), and this was followed by *E. cylindricum* (28.87±11.64). Tinte Bepo forest reserve recorded least average numbers of individuals in each diameter class at population level for all the three species of African mahoganies studied (Table 1b). The pooled analysis of average number of individuals in each diameter class for all the three species African mahoganies across the four forest reserves was significantly different ($F=4.425$, $P=0.014$)(Table 1c). *K. ivorensis* recorded the highest average number (42.24±7.50) of individuals in each cluster of diameter in all the four forest reserves. The next highest performance was observed in *E. angolense* (24.83±6.51).Whereas *E. cylindricum* registered the least number of individuals (16.13±3.84) in each diameter class amongst the three species of African mahoganies at the all the four forest reserves (Table 1c). This suggests relatively low frequency of occurrence or commonness in these forest reserves.

DISCUSSION

4.1 Population structure of the species

The results highlight one of the fundamental difficulties in assessing the status and population structure of tropical tree species. For many tropical tree species, information on the trend of population structure and status is inadequate or entirely lacking. The three species of mahogany studied show various size distribution. All the species failed to describe typical inverse J-shaped curve found in many tropical rain forest tree species [43, 42].This may be due to the cutoff point of inventory data at dbh size class of 30cm. There is possibility of low diameter classes below this cutoff point will not

be captured in the inventory data. Hence, high proportion of larger diameter class in the analyses. Nevertheless, high proportion of larger diameter class sizes in the distribution is not uncommon in population structure of tropical tree species [6, 22]. However, the low numbers of trees generally recorded in the smaller size classes suggests a relatively high mortality of smaller trees and saplings. This may be associated with the irradiant requirements for recruitment and establishment of seedlings or saplings [5]. The so called functional group or guild characteristic of tropical tree species [27, 45]. The population structures or size distributions were consistent with light-demanding tropical species such as mahogany [35]. Light attributes such as quality and quantity are strong factors which determine or shape population structure in plant communities [15]. The results support the classification of *K. ivorensis E. angolense* and *E. cylindricum* as non-pioneer light demander [27]. Non-pioneer light demander is species which establish as seedlings in deep shade but require gaps to develop [25]. Generally light-demanding tropical tree species such as mahoganies have populations structure which are positively skewed. This is an indication of population with relatively high proportion of larger diameter size class individuals. Wright et al., (2003) [49] indicated that gap-depending tree species are usually characterized by size distribution with many large individuals and long tail with small individuals. However, size distribution with relatively small number of young individuals can also be seen as population on the decline [7].

4.2 Population Status

Although, irregularity in the distribution of the population structures were observed from one forest reserve to another, the most notable is Tinte Bepo forest reserve. *E. angolense* was virtually absent in Tinte Bepo forest reserve, with the few observed recorded in the lowest dbh class size. The disruptive nature of the distribution of both *Khaya* and *Entandrophragma* species is of great concern. This may be reflection of past history of both natural and anthropogenic disturbances in the Tinte Bepo forest reserve. The population structure of a particular tree species is profoundly affected by past history of both direct and indirect anthropogenic and natural disturbances [30, 7].The particular case of Tinte Bepo forest reserve may be due to activities of selective and illegal logging [1]. Anthropogenic disturbances in Tinte forest reserve have been going on since 1980s [1]; this might have influenced the distribution and population structure of African mahoganies in the reserve. The fact that *E. angolense* and *E. cylindricum* are very slow-growing species for management and conservation purposes, care should be taken not to lose the population base for natural regeneration. Moreover, natural regeneration of *Khaya* species is generally poor after disturbances (i.e. selective logging) [28]. The reason being that *Khaya* species are light demanding and they have low survival ability relative to extraction rate [28]. However, Hawthorne (1995) [27] reported high levels overexploitation of *Entandrophragma* species in some Ghanaian forest reserves. The population structures and status of African mahoganies in Bowiye range, Bobiri and Draw River forests are well defined reflecting pristine nature of these forest reserves. Moreover, some selective logging was done in Bobiri and Draw forest in the past, but this was done within the framework of laid down management and conservation practices [44]. As a result, this seems to have little or no impact on the population structures and status of African mahoganies in these three forest reserves.

4.2Variation in diameter distribution

Variations in the diameter distribution were observed at all hierarchical levels of forest reserves, population and species. Bowiye range forest reserve recorded highest values of average numbers of individuals in each dbh size class at forest reserve and population levels amongst the four forest reserves. This is indicative of the intact nature of this forest type. Bowiye range forest reserve is subjected to virtually no or limited anthropogenic disturbances because of its location, coupled with difficult terrain and limited accessibility. Moreover, this is reinforced by cultural and religious belief system associated with Bowiye range forest reserve by the community living close to the forest reserve. Nevertheless, there is also likelihood that environmental and climatic conditions of the location may play unique role in bringing about observed variability in population structure of Bowiye forest reserve [9, 37]. However, in Ghana forest reserves on mountainous range by law cannot be subjected to logging activities. This is because of serious environmental consequences such as soil erosion. In contrast, Tinte Bepo forest reserve where anthropogenic disturbances [1] are in their highest performed poorly at all hierarchical levels considered in the analyses of variance. This supports the general opinion of many authors that disturbances from both natural and anthropogenic influence population structure of tree plants communities. [17, 30, 33, 32, 37]

The size distribution varied with species and forest reserve type. *K. ivorensis* recorded highest number of individual per each dbh class size in the four forest reserves. On comparative terms, the mean number of individual in *K. ivorensis* per each size class was lowest in Tinte Bepo forest reserve. Two factors might have accounted for observed variation. First, *K. ivorensis* is more or less restricted to wetter part of the country [11]. It is not surprising that Bowiye and Draw forest reserves recorded highest mean number of individuals in each dbh size class as compared to Tinte Bepo forest. Bowiye and Draw forest reserves are located in Moist and Wet Evergreen ecological zones respectively. These ecological zones record highest rainfall amounts in the country. However, Tinte Bepo is located moist semi-deciduous ecological zone which records relatively low amount of rainfall. Secondly, Tinte Bepo forest reserve has been impacted upon through illegal logging and other forms of natural disturbances. Thus, variation in the relative proportion of individuals in

size class is expected to occur depending on forest disturbance regime. Historical factors such as recovery time since abandonment or logging are also expected to influence population size distribution [31, 33].*E. cylindricum occurs at a relatively small numbers as compared to E. angolense* across all the four forest reserves in Ghana. This result supports IUCN assessment that *E. cylindricum is threatened [25*]. However, some studies have reported relative low density of *Entandrophragma* species in unlogged mahogany rich tropical rainforest [20].Moreover, edaphic factors have been implicated to influence the spatial distribution pattern of adult *E. angolense* and *E cylindricum* at meso-scale [21].The distribution of the adults also depends on growth performance of seedlings in relation to soil fertility [21].The general assessment of the mahoganies population and status in the four forest reserves is such that only *K. ivorensis* is qualified for some level of selective logging. This is because the minimum annual allowable felling limit of mahoganies is set at dbh of 110cm and above, by Forestry Commission of Ghana. In line with this felling limit small numbers of *K. ivorensis* can be selectively extracted from Draw and Bowiye forest reserves.

5.0 Conclusions

Based on the results of this study, we conclude that within forest type the population structure of African mahoganies depend on past history of disturbances. The size distributions and population structures of African mahoganies vary within species and across different forests type. The size distribution of African mahoganies in the four forest reserves described classical non-pioneer light demander species. The population structures consist of relatively high proportion of larger dbh classes. It is evident that maintaining the population of *E cylindricum* will require intensive management to prevent its extinction. *For conservation and management purposes, K. ivorensis is only mahogany species which can be selectively extracted from Bowiye and Draw forest reserves.*

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