Environmental Sciences Proceedings

Proceedings

Structural Diversity of Tree Stems of Elephant Camp Natural Forest in Omo Forest Reserve

Oladele Fisayo Falade *,[1] and Janet Ugochukwu Iheke [2]

Department of Forest Production and Products, University of Ibadan, Ibadan 200284, Nigeria; ihekejanet27@gmail.com

* Correspondence: faladedele@yahoo.com

† Presented at the 1st International Electronic Conference on Forests, 15–30 November 2020; Available online: https://sciforum.net/conference/IECF2020

Published: 15 November 2020

Abstract: Tree size diversity is an indicator for biodiversity values of a forest. Microsite conditions of forest determine the survival and growth of tree. However, the contribution of variable habitats to tree size hierarchy and segregation is poorly understood. Tree size variation in a population is caused by different competition mechanisms. Therefore, size distribution and spatial pattern of trees can identify the process governing resources utilization in the forest. The objective of the study was to investigate tree stems structural diversity of Elephant Camp natural forest in Omo Forest Reserve. Three and four 0.09ha sample plots were established in Riparian (RF) and Old-growth forests (OF) of Elephant camp, respectively. The tree stems (Dbh≥5cm) were identified to species level and enumerated within each plot and stem density was computed. The diameter-at-breast height (Dbh) was measured with diameter tape. Species diversity was assessed using Shannon-Weiner (H′) and Simpson indices (1-D′) while size inequality was assessed using Gini coefficient (GC), Coefficient of Variation (CV), H′ and I-D′. The performance of single two- and three-parameter Weibull models were evaluated; Kolmogorov-Smirnov (K-S) Chi-Square (χ^2), Root Mean Square Error (RMSE), Bias and Coefficient of determination (R^2). Data were analysed using descriptive statistics. A total of 27 and 24 tree species were identified in RF and OF, respectively. Stem density of RF was significantly higher than OF. The value of species diversity (H′, 1-D) and Evenness (E′) were higher in OF than RF while richness (Margalef and number of species) was higher in RF than OF. The Dbh were 38.30±21.4 and 42.87±19.2 cm in Riparian and Old-growth forests, respectively. Diameter distributions of both forests were positively skewed and expressed exponential pattern. The forest types of Elephant Camp natural forest comprise the same size frequency shape but different proportion of tree sizes and structural diversities.

Keywords: Forest structural diversity; Tree stem hierarchy; Natural forest; Diameter distribution; Tree stem diversity and Tree species diversity

---

1. Introduction

The structure of plant populations in the forest can be described by ages, sizes and forms of individual plants [1]. However, it is better to classify the plant by size because fecundity and survival of plants are often related to plant size than age [1]. The diameter and height indicate the stem size. Therefore, diameter and height distributions are effective tools to describe forest structure. Diameter is easy to measure and closely related to height [2] and other tree attributes [3] of forest trees. Conversely, structural diversity of forest indicates the degree of variation of stem diameter and height and the spatial distribution [4]. Attributes of stem diameters provide detail information about the stand [5] and [3]) and suggest the underlying mechanisms controlling regeneration and mortality [6]. Hence, tree size diversity can be used as an indicator for commercial [7] and biodiversity values [1]. However, the contribution of water gradients to tree size and segregation is limited. Knowledge of effect of variable habitat is critical for understanding the factors controlling forest structure. Tree size variation in a population is caused by different mechanisms. Size distribution and spatial pattern of trees can identify the process governing resources utilization in the forest. Therefore, tree species and size diversity of two adjacent forest areas with different water regimes were investigated. The objective of the study was to investigate tree stems structural diversity of Riparian and Old-growth forests in Elephant camp natural forest.

2. Materials and Methods

2.1. The Study Area

The study was conducted in Elephant Forest Reserve of Omo Forest Reserve. Omo Forest Reserve is located between Latitude 06°51′00″N and 06°91′00″N; and Longitude 04°22′48″E and 04°32′48″E at altitude 150 above sea level (asl) in the Ijebu area of Ogun State in Southwestern Nigeria [8]. It is one of the remaining protected forests in Southwestern Nigeria. Elephant Camp forest covers approximately 55,000 ha (Figure 1).

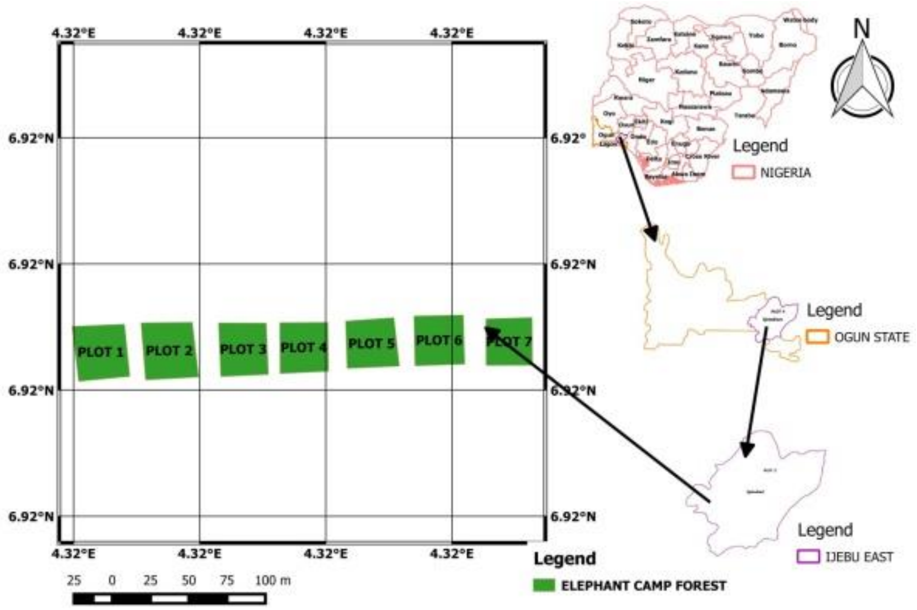

FIG. 1: MAP OF ELEPHANT CAMP NATURAL FOREST OF OMO FOREST RESERVE

A preliminary survey was conducted to observe general physiognomy of the forest reserve and it was observed that the forest was heterogenous based on its water regime. Therefore, Elephant Camp was divided into two parts based on its water regime. A part of the forest with close proximity to the river course was referred to as Riparian forest and other part which was relatively far from the river course was referred to as Old-growth forest.

2.2. Demarcation of Sample Plots and Method of Data Collection

Four and three (30m×30m^2) sample plots were established in the Riparian and Old-growth forests, respectively, using a hand compass and cloth tape. The corners of each sample plots were marked with wooden peg and the boundary with red twine. Tree stems with ≥5cm diameter-at-breast height (dbh) were identified to species level and enumerated in sample plots. Flora of West Tropical African [9] and Woody plants of Western African forests [10] were used for the identification of plants species composition on the field with the assistant of taxonomists and authenticated with collection of reference samples available in the Herbarium of the Forestry Research Institute of Nigeria.

Forest structure of Riparian and Old-growth were estimated using tree species and size diversity indices and tree diameter distribution. The species diversity indices were Shannon-Weiner and Simpson and Margalef indices [11].

Shannon-Wiener species diversity index is expressed as:

$$H = -\sum_{i=1}^{n} P_i lnP_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1) \tag{1}$$

Where, $\ln is\ natural\ logarithm$; P_i is the percentage of individual trees represented by species i and is estimated by;

$$P_i = \frac{n_i}{N_i} \tag{2}$$

Where, n_i = number of individuals of the ith species and N_i = total number of individuals.
The Simpson species diversity index is expressed as:

$$D = 1 - \left[\frac{\sum_{i=1}^{n} n_i(n_i-1)}{N(N-1)}\right] \tag{3}$$

Where, n_i = number of individuals of the ith species and N= total number of individuals
The Margalef index of species richness (Ma) is expressed as:

$$Ma = \frac{(S-1)}{\ln N} \tag{4}$$

Where
S = total number of species in the community
N = total number individual trees
*l*n = natural logarithm

2.3. Stem Diameter Distribution

The stem diameter of trees in Riparian and Old-growth forests were categorized into size classes of 3cm dbh width, starting from the smallest to the largest. Histogram of the dbh classes was produced and single two- and three-parameter Weibull distributions [12] were used for fitting size-density distributions of Riparian and Old-growth forests. The two- and three-parameter Weibull functions are expressed as:

$$f(x) = \frac{c}{b}\left(\frac{x}{b}\right)^{c-1} \exp\left(-\left(\frac{x}{b}\right)^{c}\right) \tag{5}$$

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left(-\left(\frac{x-a}{b}\right)^{c}\right) \tag{6}$$

Where: x = tree diameter, a, b and c are the location, scale and shape parameters of the distribution, respectively. Also, a = 0 in two-parameter Weibull function.

2.4. Data Analysis

Tree species diversity was calculated using Shannon-Weiner and Simpson indices. The number of tree species present and Margalef index represented tree species richness. Important value index (IVI) was calculated for the tree species following standard method [13] and [14]. The degree of size inequality of the diameter distribution of Riparian and Old-growth forests was characterized using Gini Coefficient (GC) [15], Coefficient of variation (CV), dissimilarity coefficient, Shannon-Weiner

(H′), Simpson diversity and Margalef indices [5]. The size-density distribution of Riparian and Old-growth forests were fitted with single two- and three-parameter Weibull models and parameter estimation of Weibull models was performed using maximum likelihood estimate (MLE) techniques because studies have shown that MLE is superior to other parameter estimation methods [16]. Also, the performance of single two- and three-parameters Weibull models were evaluated using Goodness-of-fit tests such as Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), Root Mean Square Error (RMSE), Bias and Coefficient of determination (R^2). The Gini coefficient (G) is expressed as:

$$G = \sum_{i=1}^{n} \sum_{j=1}^{n} \left| x_i - x_j \right| / 2xn^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where i= 1, n and j=1, n and χi, χj are the sizes of ith and jth plant, respectively.
G ranges from 0 (all individuals equal) to a theoretical maximum of 1.

3. Results

3.1. Tree Species Diversity Attributes of Riparian and Old-Growth Forests

A total of 27 and 24 tree species were identified in the Riparian and Old-growth forests, respectively (Table 1).

Milicia excelsa had the highest important value index (41.0%), followed by *Terminali superba* (27.0%), *Cordia millenii* (26.0%).in the Riparian Forest. Also, *Irvigia garbonensis* had the highest important value index (36.0%), followed by *Khaya ivorensis* (30.0%), *Baphia nitida* (23.0%) in the Old-growth forest. Therefore, these six tree species were ecologically important and most widely distributed tree species in Elephant Camp of Omo Forest Reserve. *Milicia excelsa, Terminali superba* and *Khaya ivorensis* are pioneer and belong to the upper canopy while *Cordia millenii* belong to the lower canopy (Table 1).

Table 1. Tree species distribution in Riaparian and Old-growth forests.

Riparian Forest			**Old-growth Forest**		
Species	**Stems/ha**	**IVI**	**Species**	Stems/ha	IVI
Funtumia elastica	3.0	1.97	*Cynnometra megalophylla*	4.0	1.24
Baphia nitida	3.0	2.00	*Entandrophragma utile*	4.0	2.80
Ficus thonningii	3.0	2.04	*Antiaris africana*	4.0	3.22
Detarium macrocarpum	3.0	2.17	*Musanga cecropioides*	4.0	3.37
Celtis integrifolia	3.0	2.63	*Hunteria umbellata*	7.0	5.87
Macaranga barteri	3.0	2.63	*Dracaena fragrans*	7.0	6.59
Musanga cacropioides	3.0	2.76	*Uapaca guinensis*	7.0	7.74
Hunteria umbellata	6.0	3.36	*Albizia glaberima*	7.0	8.22
Pterigota macrocarpa	5.0	3.46	*Pterigota macrocarpa*	11.0	8.31
Okoubaka aubrevillei	6.0	3.59	*Ceiba petandra*	7.0	8.76
Ficus exaspirata	6.0	4.75	*Milicia excelsa*	7.0	9.40
Nauclea diderrichii	6.0	5.01	*Ficus exasprata*	15.0	9.76
Stylochiton hypogaeus	8.0	5.08	*Strombosia pustulata*	11.0	10.52
Khaya ivorensis	6.0	5.16	*Nauclea diderrichii*	11.0	10.72
Pycnanthus angolensis	11.0	6.98	*Cordia Millenii*	11.0	11.66
Entandrophragma utile	11.0	7.14	*Funtumia elastica*	15.0	11.85
Antiaris africa	8.0	7.42	*Sida acuta*	15.0	12.09
Sida acuta	11.0	8.31	*Alstonia boonei*	11.0	16.34
Pausinystalia johimbe	17.0	12.95	*Terminalia superba*	15.0	17.04
Ceiba petandra	17.0	20.71	*Ficus thonningii*	19.0	20.43
Ficu capensis	25.0	21.67	*Gossypium arboreu*	19.0	20.94
Irvingia gabonensis	28.0	22.03	*Baphia nitida*	29.0	20.35
Albizia glaberima	28.0	25.03	*Khaya ivorensis*	26.0	30.19
Dracaena fragrans	33.0	25.19	*Irvingia garbonesis*	37.0	36.73
Cordia millenii	28.0	26.93			
Terminalia superba	33.0	27.86			
Milicia excelsa	28.0	41.07			

Important value index; IVI.

Riparian Forest contained more tree stems per ha (338.89±9.80 stems/ha) compared to Old-growth forests (296.30±8.92 stems/ha). The values of Shannon-Weiner and Simpson indices were higher in Old-growth forest than Riparian Forest (Table 2). However, values of Evennes and Equitability indices of tree species were higher in Riparian Forest than Old-growth Forest (Table 2). A comparison of Riparian and Old-growth forests at species level using Sorensen similarity index showed high (74.50%) similarity with 9 tree species shared by two forests.

Table 2. Indices of tree species diversity in Riparian and Old-growth forest of Elephant camp.

Diversity indices	Riparian forest	Old-growth forest
Tree species richness	27	24
Shannon-weiner diversity index	2.963	2.98
Simpson diversity index	0.937	0.939
Margalef index	5.412	5.249
Evennes (H/S)	0.717	0.82
Equitability index	0.899	0.937
Sorensen similarity index	75.0%	
Stem density (stem/ha)	338.89±9.80	296.30±8.92

3.2. Diameter Distribution of the Tree Stems

The mean diameter of Old-growth forest (42.87±18.90cm dbh) was significantly higher than Riparian forest (38.30±21.35cm dbh) (Table 3). The size-density distribution of Old-growth forest ranged from 9.65 to 90.63cm dbh while Riparian forest had extended distribution ranged from 6.43 to 104.96 cm dbh. The diameter distribution of Riparian and Old-growth forests are positively skewed. The values of skewness and kurtosis of Riparian forest (skewness=0.90, kurtosis= 0.65) were higher than Old-growth forest (skewness= 0.49, kurtosis= 0.53), respectively. However, both had the highest peak in size class 27.9-30.0cm dbh.

Table 3. Descriptive statistics of stem diameter of Riparian and Old-growth forests of Elephant Camp forest.

Forest	N/ha	Mean±Std (cm)	Minimum (cm)	Maximum (cm)	Skewness	Kurtosis
Riparian	338.0	38.30±21.35	6.42	104.96	0.895	0.646
Old-growth	296.0	42.87±18.90	9.65	90.63	0.485	0.527

Standard deviation (Std), Stand density (N/ha).

Gini-coefficient (GC) ([15] Weiner and Thomas, 1986) and Coefficient of Variation (CV) and dissimilarity coefficient (DC) measure plant size inequality in a population [5]. The Coefficient of variation (CV) and Dissimilarity Coefficient of Riparian forest was relatively higher compared to Old-growth forest and dissimilarity coefficient follow the same pattern (Table 4). However, the value of Gini coefficient of diameter distribution of Old-growth forest (0.91) was higher compared to Riparian forest (0.82) (Table 4). The values of size diversity (Shannon-Weiner; H′, Simpson; 1-D and Evenness; E′) were higher in Riparian forest compared to Old-growth forest while richness (Margalef and tree richness) was higher in Riparian forest than Old-growth forest (Table 4).

Table 4. Indices of diameter diversity in Riaprian and Old-growth forest of Elephant camp.

Diversity indices	Riparian forest	Old-growth forest
Shannon-Weiner (H′)	3.038	3.007
Simpson (!-D)	0.942	0.940
Margalef index	5.204	5.705
Evennes (e^H′/S)	0.802	0.778
Equitability_J	0.932	0.923
Gini-coefficient	0.825	0.915
Coefficient of Variation (CV)	0.557	0.44
Dissimilarity Coefficient	0.557	0.466

The values of Kolmogorov-Smirnov (K-S) and Anderson-Darling (A-D) test criteria for goodness of fit showed no significant difference between single three-parameter Weibull function and size-density distribution of Riparian and Old-growth forests. Therefore. single three-parameter Weibull distribution provided a good approximation than single two-parameter Weibull distribution, for the diameter distribution of Riparian and Old-growth forests. Also, the values of model selection criteria (Root mean square error (RMSE), Bias and Coefficient of determination (R^2)) of single three-parameter Weibuill model that fit size-density distribution of Old-growth forest is much less than the Riparian forest. Three-parameter Weibull model provided better approximation to diameter distribution of Old-growth forest than Riparian forest. Therefore, data properties and forest type affected the fit of diameter distribution. The two size-density distributions were not significantly different from single three-parameter Weibull distribution as shown by Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), Root Mean Square Error (RMSE), Bias and Coefficient of determination (R^2) test (Table 5).

Table 5. Statistics of diameter distributions of Riparian and Old-growth forests of Elephant Camp forest.

Forest	Distributions	A	β	γ	K-S	A-D	RMSE	Bias	R^2
Riparian	2-p Weibull	-	2.037	42.434	0.099	0.991	2.474	1.610	0.5064
	3-p Weibull	5.508	1.565	36.472	0.073	0.463	2.359	1.551	0.4603
Old-growth	2-p Weibull	-	2.324	47.777	0.089	0.615	1.936	1.414	0.6651
	3-p Weibull	7.452	1.831	39.813	0.075	0.511	1.910	1.386	0.6474

Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), Root Mean Square Error (RMSE) and Coefficient of determination (R^2).

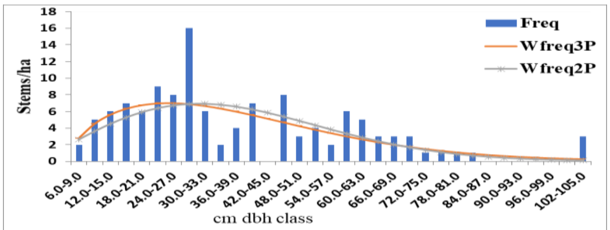

Figure 2. Observed and expected diameter distribution of Riparian forest of Elephant Camp forest in Omo Forest Reserve

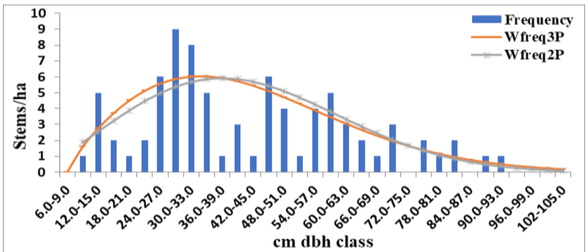

Figure 3. Observed and expected Dbh distribution of Old-growth forest of Elephant Camp in Omo Forest Reserve

4. Discussion

4.1. Tree Species Diversity and Richness

A total of forty two (42) tree species was identified in Riparian forest (27 tree species) and Old-growth forest (24 tree species) of Elephant camp natural forest. However, both forests had nine (9) tree species in common. The present study showed that Riparian forest contained more tree species than Old-growth forest and also, Riparian forest had higher values of tree species diversity indices than Old-growth. Most diversity indices combine measurement of eveness and richness. Therefore, tree species in Old-growth forest had almost equal proportion of stems than Riparian forest. The availability of water in most times of the year probably created conducive micro-sites for growth and survival of most tree species in Riparian forest while induced disturbance in Old-growth forest probably created enormous space for growth of individual stems [17]. Similarity index was used to measure similarity of tree species in the two forests. Applying the benchmark threshold of [18], the two forests can be considered to be of the same vegetation type due to high degree of similarity (≥50%) by Sorensen index. However, both forests have nine tree species in common. Out of forty-two (42) tree species identified in Elephant camp natural forest of Omo Forest reserve, *Milicia excelsa, Terminali superba, Khaya ivorensis, Cordia millenii*, *Irvigia garbonensis* and *Baphia nitida* are widely distributed and ecologically important for biodiversity conservation while the infrequent and sparse species require proper protection and regeneration.

4.2. Size-Density Distribution of the Elephant Camp Natural Forest

The mean tree density of Riparian forest was significantly higher than Old-growth forest. Gini coefficient (GC) [15] and Coefficient of variation (CV) can be used to measure tree size diversity [5]. High value of Gini coefficient (GC) in Old-growth forest indicated a higher structural diversity and stability in Old-growth forest. The result showed that Riparian forest and Old-growth forest exhibited stem size inequality and structural diversity and stability, respectively. Therefore, stem size diversity may not indicate structural diversity and stability. Structural diversity and stability indicates capacity to endure difficult environmental and biologically stressful conditions [19]. The CV increases with increase in stem density (20Liu and Burkhart, 1993). Conversely, the presence of large stems was a distinctive feature that was noticeable lacking in Old-growth forest. This implied that Old-growth forest had experience exogenous or endogenous disturbances. Tree size diversity is an indicator for biodiversity values of a forest.

The mean stem diameter of Old-growth forest (42.87±18.90 cm) was significantly higher than Riparian forest (38.30±21.35 cm). Therefore, high mean diameter of Old-growth forest resulted from few mid-size stems (38≤dbh≤81cm) because Riparian forest had extended diameter distribution with few largest trees. The size-density distribution of two forest types expressed irregular exponential distribution. The shape of the two diameter distributions is not different from each other as shown by Goodness-of-fit tests but with different value of skewness and kurtosis. This is probably because both forest types experienced the same environmental conditions except different water regime. However, [21] stated that similar size-density distribution could be shaped by different mechanisms. Therefore, size-density distribution of trees of two forests was hypothetical similar but may be shaped by different processes. The Riparian forest expressed extended irregular exponential distribution to ≤104.96 cm dbh with high density of small size trees (5.0-39 cm dbh) while size-density distribution of Old-growth forest is truncated at ≤90.63 cm dbh with high density of mid-size trees (39≤dbh≤ 60 cm dbh). The result of high value of skewness and kurtosis of size distribution in Riparian forest may be caused by high density of small size trees (5.0-40 cm dbh). Therefore, Riparian forest had sufficient density of small size trees (5.0-40 cm dbh) to replace the mid-size trees while Old-growth forest has sufficient mid-size trees (39≤dbh≤ 60 cm dbh) to replace the adult trees. Therefore, Elephant camp natural forest is showing good growth and adequate self-replacement of adult tree species. High stem density of mid-size trees (39≤dbh≤ 60 cm dbh) may cause low density of small size trees (5.0-40 cm dbh) in Old-growth forest because high tree diversity decreased light interception through structural complexity of the canopy [22].

The best result of approximation for positively skewed exponential distribution of Riparian and Old-growth forests was obtained with the single three-parameter Weibull distribution base on the result of goodness-of-fit tests (Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), Root Mean Square Error (RMSE), Bias and Coefficient of determination (R^2). Moreover, single three-parameter Weibull model provide better approximation to diameter distribution of Old-growth forest compared to Riparian forest. Therefore, data properties and forest type affected the fit of diameter distribution. Exponential pattern is expected when individual mortality and growth are independent of tree size [23]. It showed that tree growth and mortality are related to random events in both forest types. Riparian forest contained high density of small-size stems (6.0≤dbh≤39.0cm) while Old-growth forest contained high density of mid-size stems (39.0≤dbh≤60.0cm). Therefore, Riparian forest represented reproductive success and survival of the tree stems while Old-growth forest represented rapidly growing population with high reproductive capacity

1. Conclusion

Riparian forest and Old-growth forest exhibited stem size inequality and structural diversity and stability, respectively. Size-density distribution of trees of two forests was hypothetical similar but may be shaped by water gradients. Riparian forest had sufficient density of small size trees to replace the mid-size trees while Old-growth forest has sufficient mid-size trees to replace the adult trees. Riparian forest represented reproductive success and survival of the tree stems while Old-growth forest represented rapidly growing population with high reproductive capacity. Single three-parameter Weibull function proved to be suitable for effective conservation and management of plant resources in Elephant Camp natural forest reserve. The Elephant Camp natural forest is showing good growth and adequate self-replacement of adult tree species. Data properties and forest type affected the fit of diameter distribution. The protection of the study area is required for conservation of its plant resources and biodiversity components.

Conflicts of Interest: There is no conflict of interest on this article

References

1. Shaltout, K. H., Sheded, M. G. and Salem, A. H. 2009. Population structure of common shrubs and trees in Wadi Aliaqi Biosphere Reserve, South-East Egypt. *Feddes Repertorium* **120**: 343-354. Doi: 10.1002/fedr.200911114
2. Loetsch, F., Zohrer, F., Haller, K. E. 1973. Forest Inventory 2. Munique, BLV-verlagsgesellschaft
3. Podoga, P., Ochai, W. and Orzel, S. 2020. Performance of karnel estimator and Johnson SB function for modeling diameter distribution of Black Alder (Alnus glutinosa (L.). Gaertn.) stands. *Forests* **11**: 634; doi:10.3390/f11060634
4. Pach, M. and Podlaski, R. 2014. Tree diameter structural diversity in Central European forests with Abies alba and Fagus sylvatica: managed versus unmanaged forest stands. *Ecological Research* **30**(2): 367-384
5. Weiner, J. and Solbrig, O. T. 1984. The meaning and measurement of size hierarchies in plant populations. *Oecologia* **61**: 334=336.
6. Alessandrini, A., Biondi, F., Di Filippo, A., Zianco, E. and Piovesan, G. 2011. Tree size distribution at increasing spatial scales converges to the rotated sigmoid curve in two old-growth beech stands of the Italin Apennines. *Forest Ecology and Management* **262**: 1950-1962
7. Mendez-Alonzo, R., Hernandez-Trejo, H. and Lopez-portillo, J. 2012. Salinity constrains size inequality and allometry in two contrasting Mangrove habitats in the Gulf of Mexico. J. Tropical Ecology. 28:171-179 doi: 10.1017/s0266467412000016
8. Ojo, L. O. 2004. The fate of a tropical rainforest in Nigeria: Abeku sector of Omo Forest Reserve (PDF). *Global Nest: the International Journal* **6**(2): 116-130
9. Hutchinson, J., Datziel, J. M., Keay, RWJ and Hepper, F. N. 2014. Folora of West Tropical Africa. Volume1 Part 2. Royal Botanical Gardens, Kew, London. UK 330pp
10. Hawthorne, W. and Jongkind, C. 2006. Woody lants of western African forests. Kew Publishing, Royal Botanical Gardens, Kew, London.1023pp
11. Peet, R. K. 1975. Relative diversity indices. *Ecology* **56**: 496-498

12. Bailey, R. L. and Dell, T. T. 1973. Quantifying diameter distributions with the weibull function. *Forest Science* 19: 97-104
13. Gilliam, F. S., Turrill, N. L. and Adams, M. B. 1995. Herbaceous layer and overstory species in clear-cut and mature Central Appalachian Hardwood Forests. *Ecological Applications* **5**(4): 947-955
14. Houchanou, T. D., Assogbadjo, A. E., KaKau, R. G., Kyndt, T. and Houinato, M. and Sinsin, B. 2013. How far a protected area contributes to conserve habitat species composition and population structure of endangered African tree species (Benin, West Africa). *Ecological Complexity* **13**: 60-68
15. Weiner, J. and Thomas, S. C. 1986. Size variability and competition in plant monocultures. *Oikos* 47:211-222
16. Zhang, I., Packard, K. C. and Liu, C. 2003. A comparisons of estimation methods for fitting Weibull and Johnson's SB distriutions to mixed spruce-fir stands in northeastern North Americ. *Canadian Journal of Forest Research* **33**: 1340-1347
17. Sharma, K. P., Bhatta, S. P. and Lamsal, S. K. 2020. Species diversity and regeneration status of community-managed hill sal (*Shorea robusta*) forest in central Nepal. *Current Science* **119**(1): 83-92
18. Bradley, A. F. and Crow, G. F. 2010. The flora and vegetation of Timber Island, Lake Winnipesaukee, New Hampshire, U. S. A. *RHODORA* 112.950: 156-190
19. Chivulescu, S., Ciceu, A., Leca, S., Apostol, B., Popescu, O. and Badea, O. 2020. Development phases and structural characterististics of the Penteleu-Viforata virgin forest in the Curvature Carpathians. iForest 13: 389-395
20. Liu, J. and Burkhart, H. E. 1993. Dynamics of size-variable distribution parameters in juvenile loblolly pine (Pinus taeda L.) stands. *Forest Ecology and Management* **58**: 321-347
21. Toledo, J. J., Magnusson, W. E. and Castilho, C. V. 2012. Competition, exogenous disturbance and senescence shape tree size distribution in tropical evidence from tree mode of death in Central Amazonia. Journal of Vegetation Science.
22. Rissanen, K., Martin-Gay, M., Riopel-Bouvier, A. and Paquette, A. 2019. Light interception in experimental forests affected by tree diversity and structural complexity of dominant canopy. Agricultural and Forest Meterology 278:107655. doi.10.1016/j.agrformet.2019.107655
23. Muller-Landau, H. C., Condit, R., Harms, K. E., Marks, C. O., Thomas, S. C., Bunyavejchewin, S., Chuyong, G. et. Al. 2006. Comparing tropical forest tree size distributions with the predictions of metabolic ecology and equilibrium models. Ecological Letter 9: 589-602