

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

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**Abstract:** Tree size diversity is an indicator of biodiversity values of a forest. Microsite conditions of a forest determine the survival and growth of trees. 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, the size distribution and spatial pattern of trees can identify the process governing resource utilisation in the forest. The objective of the study was to investigate the tree stem structural diversity in the Elephant Camp natural forest in the Omo Forest Reserve. Three and four 0.09 ha sample plots were established in Riparian (RF) and Old-growth forests (OF) in the Elephant Camp natural forest, respectively. The tree stems (Dbh  $\geq$  5cm) were identified to the species level and enumerated within each plot, and the 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 the Gini coefficient (GC), coefficient of variation (CV),  $H'$  and  $1-D'$ . The performance of single two- and three-parameter Weibull models was evaluated using Kolmogorov–Smirnov (K-S) chi-square ( $\chi^2$ ), root-mean-square error (RMSE), bias and the 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. The stem density of RF was significantly higher than that of OF. The values of species diversity ( $H'$ ,  $1-D'$ ) and evenness ( $E'$ ) were higher in OF than in RF, while richness (Margalef and number of species) was higher in RF than in OF. The Dbh was  $38.30 \pm 21.4$  and  $42.87 \pm 19.2$  cm in Riparian and Old-growth forests, respectively. Size-density distributions of both forests were positively skewed and expressed exponential pattern. The forest types of the Elephant Camp natural forest comprise the same size-density frequency shape but a different proportion of tree sizes and structural diversities.

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## 1. Introduction

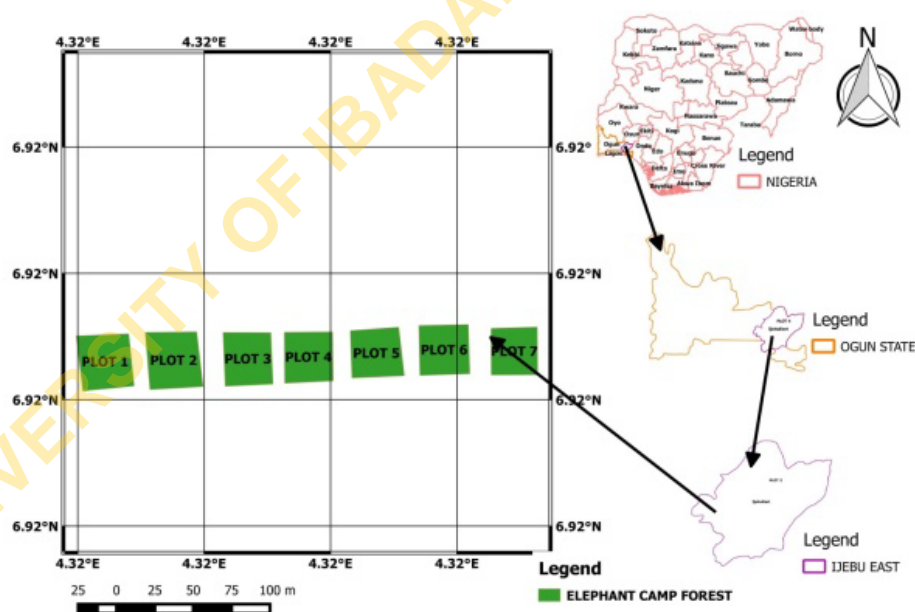
The structure of plant populations in a forest can be described by ages, sizes and forms of individual plants [1]. However, it is better to classify a plant by size because the fecundity and survival of plants are often related to plant size than age [1]. The diameter and height indicate the stem size. Therefore, diameter and height distributions are effective tools to describe the forest structure. The diameter is easy to measure and closely related to the height [2] and other tree attributes [3] of forest trees. Conversely, the structural diversity of a forest indicates the degree of variation in stem diameter and height and the spatial distribution [4]. Attributes of stem diameters provide detailed information about the stand [3,5] and suggest underlying mechanisms controlling re-

generation 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 the effect of a variable habitat is critical for understanding the factors controlling the forest structure. Tree size variation in a population is caused by different mechanisms. Moreover, understanding of competition among plant stems for periodic supplied resource is limited. The size distribution and spatial pattern of trees can identify the process governing resource utilisation in the forest. Therefore, the 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 stem structural diversity of Riparian and Old-growth forests in the Elephant Camp natural forest.

## 2. Materials and Methods

### 2.1. The Study Area

The study was conducted in the elephant forest reserve in the Omo Forest Reserve. The Omo Forest Reserve is located between latitude  $06^{\circ}51'00''$  N and  $06^{\circ}91'00''$  N and longitude  $04^{\circ}22'48''$  E and  $04^{\circ}32'48''$  E at an altitude of 150 m above sea level (asl) in the Ijebu area of Ogun State in Southwest Nigeria [8]. It is one of the remaining protected forests in Southwest Nigeria. The Elephant Camp national forest covers approximately 55,000 ha (Figure 1).



**Figure 1.** Map of the Elephant Camp natural forest in the Omo Forest Reserve.

A preliminary survey was conducted to observe the general physiognomy of the forest reserve, and it was observed that the forest was heterogenous based on its water regime. Therefore, the Elephant Camp natural forest 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 the other part that 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 ( $30\text{ m} \times 30\text{ m}$ ) sample plots were established in the Riparian and Old-growth forests, respectively, using a hand compass and cloth tape. The corners of each sample plot were marked with a wooden peg and the boundary with red twine. Tree stems with  $\geq 5\text{ cm}$  diameter at breast height (dbh) were identified at the species level

and enumerated in sample plots. Flora of west tropical African [9] and woody plants of West Africa forests [10] were used for the identification of the plant species composition on the field with the assistance of taxonomists and authenticated with the collection of reference samples available in the herbarium of the Forestry Research Institute of Nigeria.

The forest structure of riparian and old-growth forests was estimated using tree species and size diversity indices and the tree diameter distribution. The species diversity indices were Shannon–Weiner and Simpson and Margalef indices [11].

The Shannon–Wiener species diversity index is expressed as Equation (1):

$$H = -\sum_{i=1}^n P_i \ln P_i \tag{1}$$

where  $\ln$  is the natural logarithm and  $P_i$  is the percentage of individual trees represented by species  $i$  and is estimated by:

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

where  $n_i$  is the number of individuals of the  $i$ th species and  $N_i$  is the total number of individuals.

The Simpson species diversity index is expressed as Equation (2):

$$D = 1 - \left[ \frac{\sum_{i=1}^n n_i(n_i-1)}{N(N-1)} \right] \tag{2}$$

where  $n_i$  is the number of individuals of the  $i$ th species and  $N$  is the total number of individuals.

The Margalef index of species richness ( $Ma$ ) is expressed as Equation (3):

$$Ma = \frac{(S - 1)}{\ln N} \tag{3}$$

where  $S$  is the total number of species in the community,  $N$  is the total number individual trees, and  $\ln$  is the natural logarithm.

### 2.3. Stem Diameter Distribution

The stem diameter of trees in Riparian and Old-growth forests was categorised into size classes of 3 cm dbh width, starting from the smallest to the largest. A 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 Equations (4) and (5), respectively:

$$f(x) = \frac{c}{b} \left(\frac{x}{b}\right)^{c-1} \exp\left(-\left(\frac{x}{b}\right)^c\right) \tag{4}$$

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

where  $x$  is the tree diameter and  $a$ ,  $b$  and  $c$  are the location, scale and shape parameters of the distribution, respectively. In addition,  $a = 0$  in the two-parameter Weibull function.



<i>Irvingia gabonensis</i>	28.0	22.03	<i>Baphia nitida</i>	29.0	20.35
<i>Albizia glaberima</i>	28.0	25.03	<i>Khaya ivorensis</i>	26.0	30.19
<i>Dracaena fragrans</i>	33.0	25.19	<i>Irvingia garbonesis</i>	37.0	36.73
<i>Cordia millenii</i>	28.0	26.93			
<i>Terminalia superba</i>	33.0	27.86			
<i>Milicia excelsa</i>	28.0	41.07			

IVI: important value index.

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

The Riparian forest contained more tree stems per hectare ( $338.89 \pm 9.80$  stems/ha) compared to the Old-growth forest ( $296.30 \pm 8.92$  stems/ha). The Shannon–Weiner and Simpson indices were higher in the Old-growth forest than in the Riparian forest (Table 2). However, evenness and equitability indices of tree species were higher in the Riparian forest than in the Old-growth forest (Table 2). A comparison of Riparian and Old-growth forests at the species level using the Sorensen similarity index showed high (74.50%) similarity with nine tree species shared by the two forests.

**Table 2.** Indices of tree species diversity in riparian and old-growth forests in the Elephant Camp natural forest.

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
Evenness index (H/S)	0.717	0.82
Equitability index	0.899	0.937
Sorensen similarity index		75.0%
Stem density (stem/ha)	$338.89 \pm 9.80$	$296.30 \pm 8.92$

### 3.2. Diameter Distribution of the Tree Stems

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

**Table 3.** Descriptive statistics of stem diameter of riparian and old-growth forests in the Elephant Camp national forest.

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

Std: standard deviation; stand density (N/ha).

The Gini coefficient (GC) ([15]), 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 the Riparian forest were relatively higher compared to the Old-growth forest, and the dissimilarity coefficient followed the same pattern (Table 4). However, the value of the Gini coefficient of the diameter distribution of the Old-growth forest (0.91) was higher compared to the Riparian forest (0.82) (Table 4). The values of size diversity (Shannon–Weiner,  $H'$ ; Simpson,  $1-D'$ ; and evenness,  $E'$ ) were higher in the Riparian forest compared to the Old-growth forest, while richness (Margalef and tree richness) was higher in the Riparian forest than in the Old-growth forest (Table 4).

**Table 4.** Indices of diameter diversity in riparian and old-growth forests in the Elephant Camp national forest.

Diversity Indices	Riparian Forest	Old-Growth Forest
Shannon–Weiner ( $H'$ )	3.038	3.007
Simpson ( $1-D'$ )	0.942	0.940
Margalef index	5.204	5.705
Evenness ( $e^{H'/S}$ )	0.802	0.778
Equitability <sub>J</sub>	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 the goodness of fit showed no significant difference between the single three-parameter Weibull function and the size–density distribution of Riparian and Old-growth forests (Figures 2 and 3). Therefore, the single three-parameter Weibull distribution provided a good approximation than the single two-parameter Weibull distribution for the diameter distribution of Riparian and Old-growth forests. In addition, the values of model selection criteria (root-mean-square error (RMSE), bias and coefficient of determination ( $R^2$ )) of the single three-parameter Weibull model that fit the size–density distribution of the Old-growth forest were much less than those of the Riparian forest. The three-parameter Weibull model provided a better approximation of the diameter distribution of the Old-growth forest than the Riparian forest. Therefore, data properties and forest type affect the fit of the diameter distribution. The two size–density distributions were not significantly different from the 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 ( $R^2$ ) tests (Table 5).

**Table 5.** Statistics of diameter distributions of riparian and old-growth forests in the Elephant Camp national forest.

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

K-S: Kolmogorov–Smirnov; A-D: Anderson–Darling; RMSE: root-mean-square error;  $R^2$  coefficient of determination.

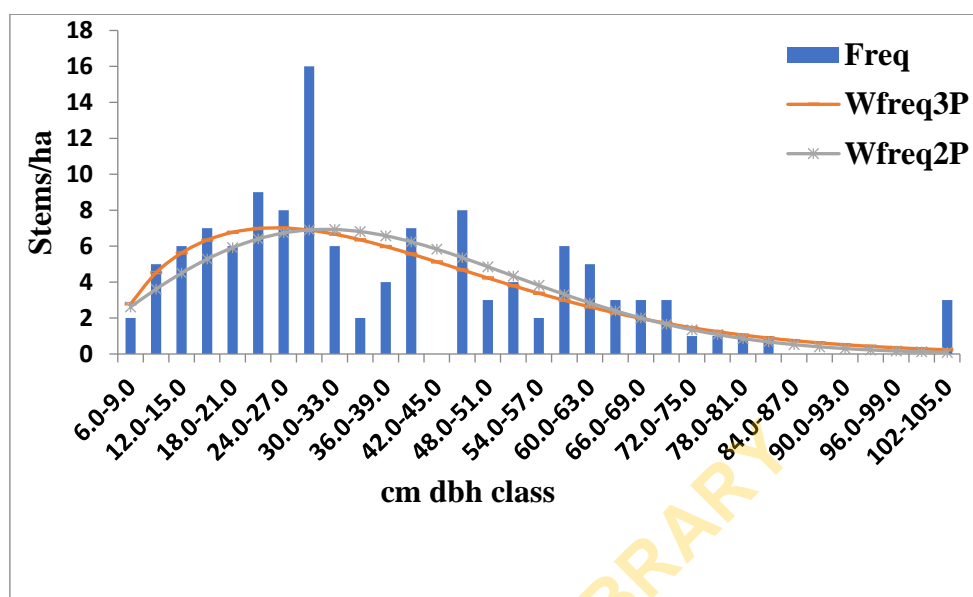


Figure 2. Observed and expected diameter distributions of the Riparian forest in the Elephant Camp natural forest in the Omo Forest Reserve.

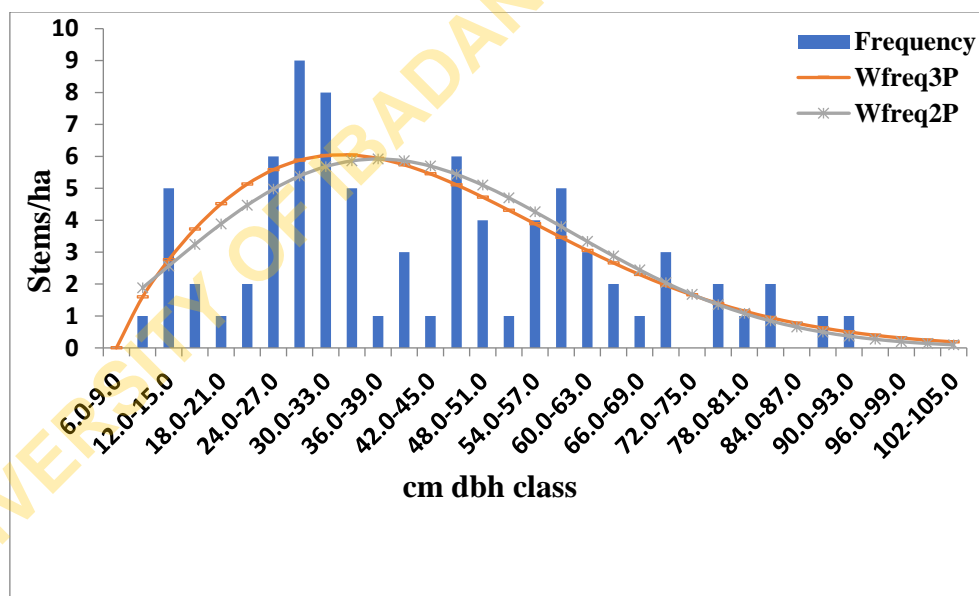


Figure 3. Observed and expected dbh distributions of the old-growth forest in the Elephant Camp natural forest in the Omo Forest Reserve.

#### 4. Discussion

##### 4.1. Tree Species Diversity and Richness

A total of 42 tree species were identified in the Riparian forest (27 tree species) and the Old-growth forest (24 tree species) in the Elephant Camp natural forest. However, both forests had nine tree species in common. The present study showed that the Riparian forest contained more tree species than the Old-growth forest, and the Riparian forest also had higher tree species diversity indices than the Old-growth forest. Most diversity indices combine measurements of evenness and richness. Therefore, tree species in the Old-growth forest had almost an equal proportion of stems than the Riparian forest. The availability of water at most times of the year probably created conducive micro-sites for the growth and survival of most tree species in the Riparian forest, while induced disturbance in the Old-growth forest probably created an enormous space for the growth of

individual stems [17]. The similarity index was used to measure the similarity of tree species in the two forests. Applying the benchmark threshold given in [18], the two forests can be considered to be of the same vegetation type due to the high degree of similarity ( $\geq 50\%$ ) by the Sorensen index. Of the 42 tree species identified in the Elephant Camp natural forest in the Omo Forest Reserve, *Milicia excelsa*, *Terminalia superba*, *Khaya ivorensis*, *Cordia millenii*, *Iroigia 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 the Riparian forest was significantly higher than the Old-growth forest. The Gini coefficient (GC) [15] and coefficient of variation (CV) can be used to measure tree size diversity [5]. A high Gini coefficient (GC) in the Old-growth forest indicated higher structural diversity and stability in the Old-growth forest. The result showed that the Riparian forest and the 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 indicate a capacity to endure difficult environmental and biologically stressful conditions [19]. The CV increases with an increase in stem density [20]. Conversely, the presence of large stems was a distinctive feature that was noticeably lacking in the Old-growth forest. This implied that the Old-growth forest has experienced exogenous or endogenous disturbances. Tree size diversity is an indicator of the biodiversity values of a forest.

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

The best result of approximation for the positively skewed exponential distribution of Riparian and Old-growth forests was obtained with the single three-parameter Weibull distribution based 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, the single three-parameter Weibull model provided a better approximation of the size–density distribution of the Old-growth forest compared to the Riparian forest. Therefore, data properties and forest type affected the fit of the size–density distribution. An exponential pattern is expected when individual mortality

and growth are independent of tree size [23]. It shows that tree growth and mortality are related to random events in both forest types. The Riparian forest contained a high density of small-size stems ( $6.0 \leq \text{dbh} \leq 39.0$  cm dbh), while the Old-growth forest contained a high density of mid-size stems ( $39.0 \leq \text{dbh} \leq 60.0$  cm dbh). Therefore, the Riparian forest represents reproductive success and survival of the tree stems, while the Old-growth forest represents a rapidly growing population with high reproductive capacity.

## 5. Conclusions

The Riparian forest and the Old-growth forest exhibited stem size inequality and structural diversity and stability, respectively. The size–density distribution of trees in the two forests was hypothetically similar but may be shaped by water gradients. The Riparian forest had a sufficient density of small-size trees to replace mid-size trees, while the Old-growth forest had sufficient mid-size trees to replace adult trees. The Riparian forest represents reproductive success and survival of tree stems, while the Old-growth forest represents a rapidly growing population with high reproductive capacity. The single three-parameter Weibull function proved to be suitable for effective conservation and management of plant resources in the Elephant Camp natural forest. The Elephant Camp natural forest shows good growth and adequate self-replacement of adult tree species. Data properties and forest type affect the fit of the size–density 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.

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