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Tree size structure of Tectona grandis (Linn f.) stand in Hilltop and Valley-Bottom of Omo Forest Reserve †

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Abstract: Competition for growth resources contributes to size hierarchy in tree populations. Competition hierarchy of trees is dependent on rate of growth and stages of stand development. However, competition hierarchy may not cause size symmetry in tree populations. Size structure of even-aged stand can identify mechanisms for growth resources competition among trees. The study investigated tree size structure of Teak stand in Valley-Bottom and Hilltop of Omo Forest Reserve. Ten (10) years old Teak plantation was divided into Hilltop and Valley-Bottom stands base on topography. Five (30m x 30m) sample plots were systematically demarcated in each of Hilltop and Valley-Bottom stands. Tree stems were enumerated and stem densities of both stands were estimated. Diameter at -breast height and total height were measured using Girth tape and Spiegel Relaskop, respectively. Stem size inequality, diversity and evenness of both stands were evaluated. Data collected were analyzed using descriptive, correlation, regression analysis and t-test at α0.05. Mean diameter and height of Valley-Bottom (11.42±4.83cm dbh and 3.46±1.35m) were not significantly different from Hilltop stands (10.29±4.59 cm dbh and 3.41±1.55m). Stem density of Hilltop (1431.0 stems/ha) was higher than Valley-Bottom stands (1248.0stems/ha). Coefficient of determination (R2) of Height-Diameter allometry for Valley-Bottom (0.59) was higher than Hilltop stands (0.45). Diameter distribution of Valley-Bottom and Hilltop expressed bimodality and unimodality, respectively. Height distribution of Valley-Bottom and Hilltop expressed positive skewed unimodality. Inequality was higher in Hilltop than Valley-Bottom for height and diameter. Elevation affected the stem form and size hierarchy of Teak stems in Hilltop habitat than Valley-Bottom habitat. Different mechanisms were responsible for stand structure of Hilltop and Valley-Bottom Habitats.

Keywords: Size diversity indices; stem size hierarchy; elevation gradient; inequality measures; stem diameter; H-D allometry

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1. Introduction

There is competition for resources among plant populations. Asymmetric and symmetric models are recognized as two extreme expressions of competition models [1]. There is intrinsic difference between competition symmetry for above-ground and below-ground tree growth resources. Asymmetric and symmetric models are considered for light and plant nutrient, respectively. Therefore, tree size symmetry varies with variation in resources availability [2]. Identification of mechanisms that determine size hierarchy in tree populations is critical because of their ecological and management significance [3]. However, understanding the effect of topographic elevation on competition hierarchy is limited [4]. The estimate of size structure of even-aged *Tectona grandis* plantation in different elevations is required so as to identify competition mechanisms for tree growth resources at different elevation belts. Tree height and stem diameter are components of tree size. The tree height determines light capturing capacity while stem diameter determines mechanical support and water transport efficiency [5]. Allometry and architecture of a tree are regulated by abiotic and biotic factors [5]. Moreover, tree height-diameter relationship reflects the available environmental resources and therefore, can be used to support decisions on silvicultural treatments. However, the effect of elevation on tree height-diameter allometry is yet to be clarified. The hypothesis was to assess the effect of habitat on size inequality within the teak plantation. The aim of the study was to analyse the the spatial difference of the diameter distribution of 10-year-old *Tectona grandis* plantation in Omo Forest Reserve. Therefore, this study investigated tree size structure of Teak stands in Hilltop and Valley-Bottom of Omo Forest Reserve.

2. Materials and Methods

2.1. The Study Area

This study was conducted in 10-year-old *Tectona grandis* plantation in Area J4 of Omo Forest Reserve. Omo Forest Reserve is located between Latitude 6° 35′ to 7° 05′ N and Longitude 4° 19′ to 4° 40′ E at altitude 150 above sea level (asl) in the Ijebu area of Ogun state in Southwestern Nigeria [6]. Omo Forest Reserve covers 130,500 hectares of land area. It is the largest industrial plantation in Nigeria. The *Tectona grandis* plantation used for this study was planted in year 2010 using a spacing of 2.0 m x 3.0 m among tree stems and covers 22 hectares of land area. The plantation is located in Fire Blast area of Area J4 in Omo Forest Reserve.

2.2. Demarcation of Sample Plots and Method of Data Collection

Reconnaissance survey was conducted to access the landscape and stand physiognomy so as to determine the sampling technique to be adopted. It was observed that the Teak plantation was on steepy landscape. Therefore, Teak plantation was divided into two stands base on natural demarcation of its topography so as to achieve the objective and reduce variation. Therefore, the plantation was subjectively divided into two altitudinal levels; Hilltop stand is located between 105 and 112 m and Valley-Bottom stand is located between 85 and 104 m above sea level (asl). The sampling method for plot selection was systematic sampling technique. Five sample (30m x 30m) plots were systematically demarcated in each of Hilltop and Valley-Bottom stands. The height and diameter-at (base, breast-height, middle and top) of Teak stems were measured in each plot using Spiegel relaskop and Girth tape and stem density was estimated.

2.3. Data Analysis

Stem density was computed for Hilltop and Valley-Bottom stands and converted to hectare. The regression analysis of stem H-D allometry of Hlltop and Valley-Bottom stands were evaluated. Also, diameter-at-breast height (dbh) and height measurements of tree stems were divided into 17 equal interval size classes starting from the smallest to the largest and size-density distribution were represented with histogram of stem diameter and height distributions, respectively. Therefore, diameter-density and height-density distribution of Hilltop and Valley-Bottom stands were characterized by their mean, standard deviation and Coefficient of Variation and tested for normality by calculating Skewness coefficient and Kurtosis. Also, Inequality measures (Gini-coefficient, Coefficient of Variation and Skewness coefficient) were calculated for the diameter and height distributions of Hilltop and Valley-Bottom stands. Further analysis was carried out; (i) Significant differences between means were tested using t-test at 0.05 level, (ii) Inequality statistics (Gini-Coefficient, Coefficient of Variation and Skewnes-Coefficient) were correlated with tree size diversity measures (Shannon-Weiner and Simpson-indices) and tree size eveness measures (Eveness and Margalef indices) at 0.05 level. The highly significant correlation values at 0.05 level were extracted from matrices.

3. Results

3.1. The H-D Allometry

The H-D relationship for Hilltop stand was derived from 644 sample tree stems and best described by the equation (Height = 5.73*ln(Dbh) -5.61) which explained 45.5% of variation in tree height while the Valley-Bottom stand was derived from 562 sample tree stems and best described by the equation (Height = 5.34*ln(Dbh) – 5.16) which explained 59.1% of variation in tree height. There was significant difference between tree height for a given diameter of stems in Hilltop and Valley-Bottom stands. The diameter-at-breast-height increased with exponential increase in height in Hilltop and Valley-Bottom stands of *Tectona grandis*. Figure 1 and 2 showed that H-D relationship may be site specific. Therefore, a single equation can not be used for the prediction of H-D relationship of *Gmelina arborea* in Omo Forest Reserve.

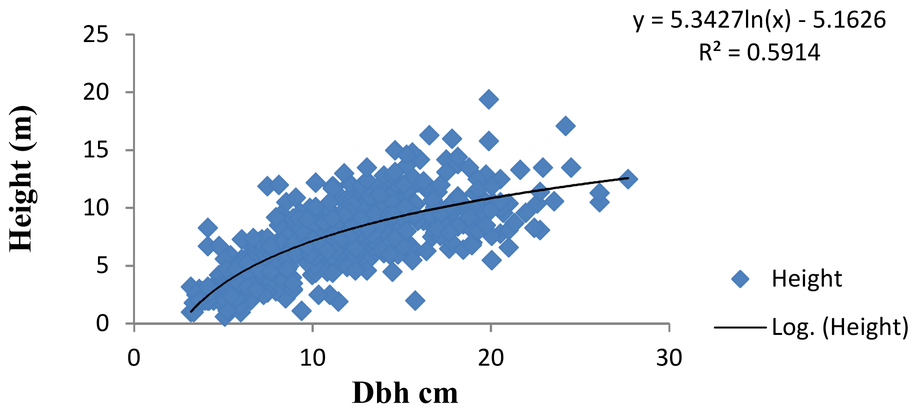

Figure 1a. Height - Diameter Allometry of Teak stands in Valley-Bottom of Omo Forest Reserve

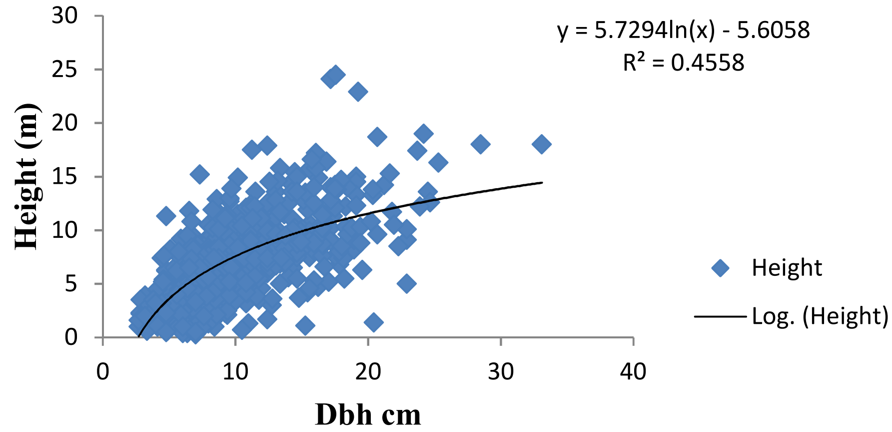

Figure 1b Height - Diameter Allometry of Teak stands in Hilltop of Omo Forest Reserve

3.2. Diameter-density and Height-density Distributions of Hilltop and Valley-Bottom stands

Diameter-density distribution of Valley-Bottom and Hilltop stands were represented by histogram of seventeen (17) classes (Figure 2). Diameter-density distribution of Valley-Bottom stand expressed positively skewed bimodal distribution while diameter-density distribution of Hilltop stand expressed positively skewed reverse J-shaped unimodal distribution. The diameter-density distribution of Hilltop stand ranged from 0.00 to 34.16cm dbh with positive skewness (0.8582) and kurtosis (0.5748). It contained highest stem density in the intermediate tree stem (6.03 -8.03 cm dbh classes). (Figure 2 and Table 1a). Conversely, diameter-density distribution of Valley-Bottom stand had two peaks at 8.04-10.04 and 12.06- 14.06cm dbh classes (Figure 2). The diameter distribution of stems ranged from 0.00 to 26.12cm dbh in Valley-Bottom stand with positive skewness (0.4296) and negative value of kurtosis (-0.1596) (Table 1a)**.** Therefore, skewness and kurtosis of stem height in Hilltop stand were higher than Valley-Bottom stand. (Table 1b).

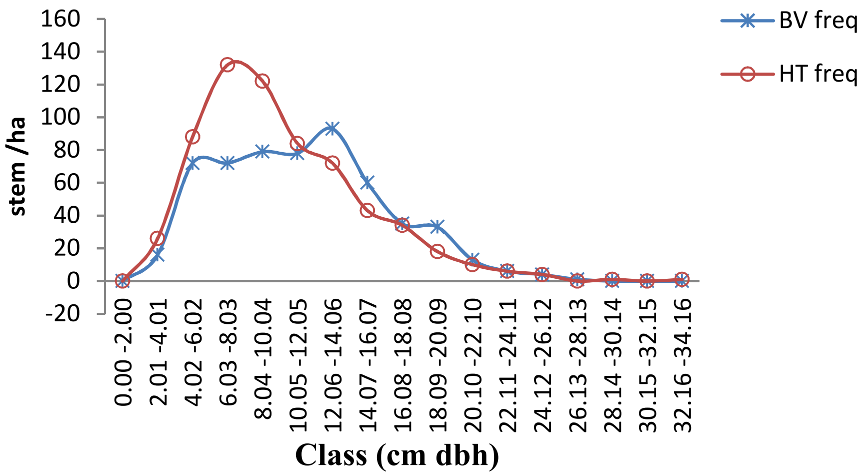

Figure 2. Diameter distribution of Teak stand in Valley-Bottom and Hilltop stands in Omo Forest reserve

Mean of stem diameter in Hilltop stand was not significantly different from mean of stem diameter in Valley-Bottom stand (10.19±4.62 vs. 11.30±4.82 cm dbh; t-test=4.06, p=0.000).

Inequality of stem height and diameter was evaluated by Gini-Coefficient (GC), Coefficient of Variation (CV) and Skewness Coefficient (SC). Therefore, inequality of stem diameter and height distribution of Hilltop stand was higher than inequality of Valley-Bottom stand (Table 1a and 1b). Also, stand density of Hilltop stand (1431.00 stems/ha) was higher than Valley-Bottom stand (1251.00 stems/ha) (Table 1a and 1b).

Table 1. a. Statistics of diameter distributions of *Tectona grandis* stand in Valley-Bottom and Hilltop habitats of Omo Forest Reserve.

Stand	Minimum (cm dbh)	Maximum (cm dbh)	Mean±std (cm dbh)	Gini	CV (%)	Skewness	Kurtosis	SD (stems/ha)
Hilltop	2.71	23.10	10.19±4.62	0.24	45.37	0.97	1.18	1431.00
Valley-Bottom	3.18	24.68	11.30±4.82	0.24	42.68	0.47	0.47	1251.00

Coefficient of Variation; CV., Gini-Coefficient; Gini, Skewness-Coefficient; Skewness.

Also, mean of stem height in Hilltop stand was not significantly different from mean height in Valley-Bottom stand (7.12±3.88 vs. 7.26±3.21 m; t-test=0.67, p= 0.500). The stem height distribution of Hilltop and Valley-Bottom stands expressed positively skewed unimodal distribution. The height-density distribution both Valley-Bottom and Hilltop had peak at 7.38-9.83m class and decreased steadily to 22.14-24.59m. The values of skewness and kurtosis of height-density distribution in Hilltop stand (skewness=0.858 and kurtosis=0.574) were higher than that of Valley-Bottom (skewness=0.429 and kurtosis=-0.1590).

Table 1. b. Statistics of height distributions of Teak stand on Valley-Bottom and Hilltop in Omo Forest Reserve.

Stand	Minimum (m)	Maximum (m)	Mean±std (m)	Gini	CV (%)	Skew-ness	Kurto-sis	SD (stems/ha)
Hilltop	0.30	24.50	7.12±3.88	0.29	54.51	0.77	1.11	1431.00
Valley-Bottom	1.00	19.40	7.26±3.21	0.25	44.30	0.22	-0.21	1251.00

Coefficient of Variation; CV., Gini-Coefficient; Gini, Skewness-coefficient; Skewness.

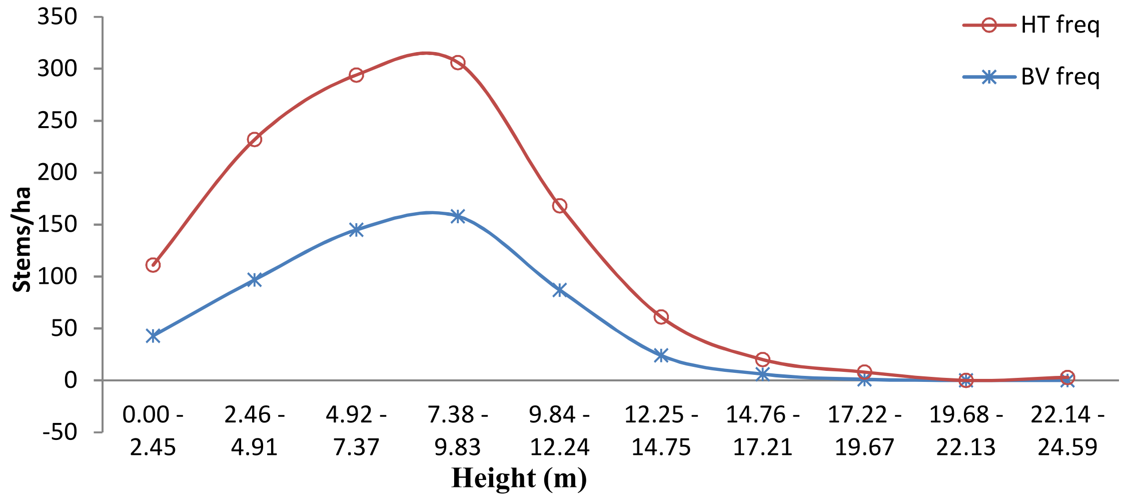

Figure 3. Height distribution of Teak stand on Valley-Bottom and Hilltop in Omo Forest Reserve

3.3. Relationship Between Inequality Measures and Diversity Indices of Stem Diameter

The result of correlation analysis between inequality measures and diversity indices of stem diameter distribution in Hilltop stand (Table 2a). Pearson correlation coefficient indicated significantly positive correlation between Simpson diversity index and Margalef index of stem diameter distribution in Hilltop stand (r=0.956, p=0.011) at 0.05 level. Also, Evenness and Equitability of stem diameter distribution in Hilltop stand was significantly positive correlated (r=-0.955, p=0.011) at 0.05 level, Skewness and Margalef index of diameter distribution was significantly positive correlated in Hilltop stand (r=-0.936, p=0.019) at 0.05 level. Also, there was a significant positive correlation between Skewness and Simpson diversity index of diameter distribution in Hilltop stand (r=-0.932, p=0021) at 0.05 level. Furthermore, there was a significant positive correlation between Skewness and Shannon-Weiner diversity index of diameter distribution in Hilltop stand (r=0.905, p=0.034) at 0.05 level. Eveness and Margalef index of diameter distribution was significantly negatively correlated in Hilltop stand (r= -0.905, p=0.035) at 0.05 level.

Table 2a. Statistics of Pearson correlation of stem diameter distribution in Hilltop stand of Omo Forest Reserve.

Attribute	Attribute	Correlation Value	At 0.05 level
Simpson index	Margalef index	0.956	0.011
Evenness	Equitability	0.955	0.011
Skewness coefficient	Margalef index	0.936	0.019
Skewness coefficient	Simpson index	0.932	0.021
Skewness	Shannon index	0.905	0.034
Evenness	Margalef index	-0.905	0.035

The result of correlation analysis between inequality measures and diversity indices of stem diameter distribution in Valley-Bottom stand (Table 2b). Pearson correlation coefficient was significantly positive between Mean and Simpson diversity index of diameter distribution in Valley-Bottom stand (r=0.915, p=0.029) at 0.05 significant level. There was significant negative correlation between Mean and Stem density of diameter distribution in Valley-Bottom stand (r=-0.913, p=0.030) at 0.05 significant level. Also, stem density and Shannon-Weiner diversity index of diameter distribution was significantly negative correlated in Valley-Bottom (r=-0.917, p=0.029) at 0.05 significant level.

Table 2. b. Statistics of Pearson correlation of stem diameter distribution in Valley-Bottom stand of Omo Forest Reserve.

Attribute	Attribute	Correlation Value	At 0.05 level
Mean_D	Simpson	0.915	0.029
Mean_D	Stem_density	-0.913	0.030
Stem_Density	Shannon	-0.917	0.029

3.4. Relationship Between Inequality Measures and Diversity Indices of Stem Height

The result of correlation analysis between inequality measures and diversity indices of stem height distribution in Hilltop stand (Table 3a). Pearson correlation coefficient was significantly positive between Simpson diversity index and Equitability index of stem height distribution Hilltop stand (r=0.952, p=0.012) at 0.05 probability level. Also, there was significant positive correlation between Simpson diversity index and Eveness index of height distribution in Hilltop stand (r=0.918, p=0.028) at 0.05 level.

Table 3. a. Statistics of Pearson correlation of stem height distribution in Hilltop stand of Omo Forest Reserve.

Attribute	Attribute	Correlation Value	At 0.05 level
Simpson	Equitability	0.953	0.012
Simpson	Eveness	0.918	0.028

The result of correlation analysis between inequality measures and diversity indices of stem height distribution in Valley-Bottom stand (Table 3b). Pearson correlation coefficient was significantly positive between Gini-Coefficient and Shannon diversity index of height distribution in Valley-Bottom stand (r=0.945, p=0.015) at 0.05 probability level (Table 3b). Coefficient of Variation and Margalef index of height distribution were significantly positive correlated in Valley-Bottom stand (r=0.945, p=0.016) at 0.05 probability level, Skewness coefficient had positive correlation with Margalef diversity index of height distribution in Valley-Bottom stand (r=0.944, p=0.016) at 0.05 probability level, Also, Evenness and Equitability indices of height distribution were significantly positive correlated in Valley-Bottom stand (r=0.941, p=0.017) at 0.05 level, There was significant positive correlation between Coefficient of Variation and Simpson diversity index of height distribution in Valley-Bottom stand (r=0.931, p=0.022), Pearson correlation coefficient was significantly positive between Gini-Coefficient and skewness of height distribution in Valley-Bottom stand (r=0.930, p=0.022), Gini-Coefficient and Margalef height index (r=0.915, p=0.029), Simpson diversityand Margalef indices of height distribution (r=0.914, p=0.030). Pearson correlation coefficient indicated positive correlation between Coefficient of Variation and Skewness coefficient of height distribution in Valley-Bottom stand (r=0.901, p=0.037). Pearson correlation coefficient indicated positive correlation between Skewness coefficient and Shannon-Weiner diversity index of height distribution in Valley-Bottom stand (r=0.883, p=0.047), Gini-Coefficient and Simpsom height diversity index in Valley-Bottom stand (r=0.878, p=0.050) at 0.05 level.

Table 3. b. Statistics of Pearson correlation of stem height distribution in Valley-Bottom of Omo Forest Reserve.

Attribute	Attribute	Correlation Values	At 0.05 level
Gini-Coefficient	Shannon index	0.945	0.015
Coefficient of Variation	Margalef index	0.945	0.016
Skewness coefficient	Margalef index	0.944	0.016
Eveness	Equitability	0.941	0.017
Coefficient of Variation	Simpson-index	0.931	0.022
Gini-Coefficient	Skewness Coefficient	0.930	0.022
Gini-Coefficient	Margalef index	0.915	0.029
Simpson index	Margalef index	0.914	0.030
Coefficient of Variation	Skewness	0.901	0.037
Skewness coefficient	Shannon-index	0.883	0.047
Gini-Coefficient	Simpson index	0.878	0.050

4.Discussion

4.1. The H-D Allometry of Hilltop and Valley-Bottom stands

The relationship between tree height and diameter is an indicator of stem form [7] and therefore was examined in Hilltop and Valley-Bottom stands. The relationship of Height-Diameter allometry is useful to identify competitive effect of tree stems on their morphological feature since relationship between height and diameter depends on site conditions [8]. Therefore, a regression analysis of H-D allometry was used to determine the relationship between tree height and diameter-at-breast of Teak in Hilltop and Valley-Bottom habitats. The results showed that variability of H-D allometry in Valley-Bottom stand was higher than variability in Hilltop stand. Stem form of many trees were more than the average (Height-Diameter ratio > 1.0) in Hilltop stand. Therefore, Hilltop stand had trees that allocated more biomass to tree height growth than stem diameter growth. Conversely, stem form of many tree were approximately average in Valley-Bottom stand (Height-Diameter = 1.0). This indicated that relative height growth of most tree stems was almost equal to relative diameter growth. Tree stems in Hilltop stand had increased height growth compared to diameter growth. Hilltop stand displayed higher canopy stature than Valley-Bottom stand. The axial growth is a trait that show strong adaptation where competition for space is very important. This contrary to the report of [9] that tree growth and competition for light declined with elevation. Therefore, effect of stem density is more significant on tree growth than effect of elevation. The height increased with increase in diameter in Valley-Bottom stand. This suggested that stem form differ among trees of different sizes [7] and elevations. [5] stated that allocation of biomass to stem diameter is likely to occur when greater inter tree competition is present or environmental disturbance. Difference in H-D relationship was found in the two stands. Stem density probably caused difference in the allometric equation of the two sites. Initially Hilltop and Valley-Bottom stands were established using 2.0 x 3.0 espacement but a lot of forked stems were observed in the Hilltop stand probably due to water stress at seedling stage. Flooding and water logging were noticed in Valley-Bottom stand. Flooding and water logging during rainy season may reduce rate of plant growth of large tree stems in Valley-Bottom stand. Therefore, size hierarchy is influenced by water availability and duration of water availability. Competition may be primarily symmetric when water availability is low and asymmetric when water availability is high [10] and [4]. The difference in stem form between Valley-Bottom and Hilltop stands may be caused by water logging as a consequence of difference in elevation.

4.2. Diameter-density and Height-density distribution of Hilltop and Valley-Bottom stands

Histogram of frequency distribution allows a visual estimate of the shape of distribution to be made [11]. Diameter-density distribution of Valley-Bottom stand expressed positively skewed bimodal distribution while Hilltop stand expressed positively skewed reverse J-shaped unimodal distribution. Therefore, Valley-Bottom stand had a second maximum in the middle size class in addition to positive skewness. Histogram of Valley-Bottom stand indicated unequal decline in relative growth rates across plant size classes with decreasing stem density. [12] suggested that bimodality distribution was the consequence of a disjunct distribution of relative growth rates in the population where individuals share limited resources disproportionately in relation to their relative sizes. Diameter classes of Hilltop stand contained higher stem density (stems/ha) than Valley-Bottom stand except at class 12.06-14.06 and 14.07-16.07 cm dbh. Therefore, forest structure of Hilltop stand was higher than Valley-Bottom stand. Two peaks in diameter distribution of Valley-Bottom stand suggest development of a two tiered canopy of large and small tree stems. Therefore, Valley-Bottom produced bimodal frequency distribution of plant size. This described a segregation of *Tectona grandis* tree stems into suppressed and dominant trees. The segregation occurs before the occurrence of substantial mortality in monoculture stands [13]. The large diameter trees had higher relative growth rates than small diameter trees. Moreover, [13] reported that segregation occurs when large plants intercept a disproportionately large portion of available light as their canopies overlap those of the smaller trees. The difference between dbh classes of Hilltop and Valley-Bottom stands was the number of stems in the mid-classes of diameter distribution. The major difference between the Hilltop and Valley-Bottom was stem density of the saplings (4.02-14.02 cm dbh). This partialy support the report of [14] that vigorous mid-class growth may produce a sigmoid distribution.

Positive skewness showed that few large trees suppressed growth of numerous small stems [15]. High coefficient of variation indicates that a higher relative growth rate of stem diameter [16] in Hilltop than Valley Bottom stands. Although there was no significant difference in the stem diameter of both Hilltop and Valley-Bottom stands but tree stems of relatively small diameter occupied Valley-Bottom habitat because selective logging was noticed in the area. The value of skewness of Hilltop stand was higher than Valley-Bottom. According to [17] skewness indicates interference among tree stems. Therefore, more interference occurred among tree stems of Hilltop stand.

Stem diameter inequality of Hilltop stand was higher than Valley-Bottom stand. Therefore, stem diameter inequality was greater at higher tree density [18]. Size asymmetric competition is more applicable in Hilltop stand than size symmetric competition. It was proposed that skewness can be used as a measure of interference [17]. Also, size asymmetry refers to skewness within the size-frequency distribution while size inequality refers to the uneven allocation of mass among individuals in a population [19]. The difference in inequality of diameter distribution of Hilltop and Valley Bottom stands could be a consequence of elevation gradient. The presence of resource depletion increase the skewness and variance of distributions of plant size [20]. Size inequality in plant communities arises when a few large individual suppress the growth of the other tree stems [15]. The two stands differ in height-density distribution and size inequality. This suggested that competition intensity of Hilltop was greater than Valley Bottom stands because competition for resources increases size inequality in tree populations.

The height-density distribution of Hilltop and Valley-Bottom stands had a single peak shape. The number of trees decreased rapidly with the increase in diameter of trees. Tree of small stem height dominated the Valley-Bottom stand because selective logging was noticed in the area. Hilltop stand contained slightly greater proportion of stems of intermediate height which decreased with increase in stem height.

4.3. Stem diameter and height inequality and diversity measures

The Gini coefficient obtained from the stem diameter distribution of Hilltop and Valley Bottom stands were higher than the Gini obtained from stem height of Hilltop and Valley Bottom stands. Therefore inequality was significantly greater in diameter than in height in the Hilltop stand but not in the Valley. The Gini values were significantly higher in the Hilltop than in the Valley Bottom for both stem diameter and height. This resulted in greater size variability at increased density. Size variability increases with stem density [19]. Size inequality was measured for stem size by Gini-Coefficient, Coefficient of Variation and Skewness Coefficient [21] and [22]. Size diversity was measure by Shannon-Weiner and Simpson indices and stem size eveness was measure by Margalef index and Eveness. Size asymmetry refers to skewness within the size frequency distribution while size inequality refers to the uneven relative growth rate among individuals in a population [19]. Environmental constrain may reduce the evenness of plant stems and communities [23]. All diversity and evenness indices showed considerable relationship with skewness of stem diameter [24] in Hilltop stand. The value of Gini-Coefficient of height distribution was closely related to Shannon-Weiner diversity index of height and Margalef index of height. Therefore, inequality measures were closely related to size diversity measures and evenness for stem height distribution. The two main factors taken into consideration when measuring diversity are richness and evenness. Richness is a measure of the number of different size classes in a population while evenness compares the similarity of different size classes in a population and is related to other attributes of the population such as competition, structure and stability [24].

5. Conclusion

The variation in height-diameter allometry between Hilltop and Valley-Bottom stands may be caused by difference in elevation. Therefore, stem form differ among trees of different sizes and elevations. The frequency distribution of plant diameter in Valley-Bottom was bimodal. High elevation promotes tree size inequality while low elevation promotes homogeneity in tree size classes. Valley-Bottom stand had approximately homogeneity tree size classes. The relationship between proportion of different height classes (inequality) and height variation (diversity) was greater than that of diameter in Valley-Bottom stand. Stem height distribution indicated asymmetric competition among tree stem than diameter distribution in Valley-Bottom stand of 10-year-old *Tectona grandis* plantation. Therefore, height distribution of Valley-Bottom stand was more applicable for description of size asymmetric competition in 10-year-old *Tectona grandis* plantation.

Conflicts of Interest: The authors declare no conflict of interest.

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