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Tree Slenderness Coefficient and Percent Canopy Cover in Oban Group Forest, Nigeria

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Abstract

Oban Forest health was assessed using tree slenderness coefficient (SC) and percent canopy cover as indicators. Systematic sampling technique was adopted for plot locations in *Aking*, *Ekang*, *Erokut* and *Ekuri* sites within the forest. Four transects of 2 km-long situated 600 m apart were established in each site. Five 0.25ha-plot were then alternately laid along each transect at 400 m intervals. A total of 20 plots per site, and 80 plots in all were used. Tree heights, Dbh and crown diameter were measured on trees with Dbh≥10cm to compute SC and percent canopy cover (%CC). Trees were classified based on their SC as high (SC>80), moderate (SC: 70-80 and low (SC<70). Data were analyzed using descriptive statistics and correlation analysis. There were 36, 49 and 67 trees/ha with high, moderate and low SC, respectively for the pooled data with 56.5% CC. On site basis, *Aking* had 145 trees/ha, and of these, 44, 45 and 56 trees/ha had high, moderate and low SC, respectively. *Ekang* had 147 trees/ha, and of these, there were 45, 50 and 52 trees/ha with high, moderate and low SC, respectively. *Erokut* had the least 143 trees/ha, and of these, 37, 50 and 56 trees/ha were with high, moderate and low SC, respectively with 49.95% CC. *Ekuri* had the highest 173 trees/ha, and of these, 62, 43 and 68 trees/ha had high, moderate and low SC, respectively with 59.8% CC. There were negative correlations between SC and other tree growth parameters except tree height (r = 0.07). About 24% of the trees had high SC, which implies high susceptibility to wind-induced damage, with highest trees/ha in this category found in *Ekuri* site due to high stand density. This may cause competitions among trees, thereby limiting trees development. Hence, appropriate silvicultural treatment such as low-impact logging is recommended.

Keywords: Stand stability, slenderness ratio, crown dimension, susceptibility, wind-throw

1. Introduction

Tree slenderness coefficient has been variously described as a dimensionless value based on the ratio of tree diameter at breast height (Dbh) and total height, and computed as the tree total height divided by the Dbh (Moravčík, 2007; Harja *et al*., 2012; Magruder *et al*., 2012; Budeanu and Sofletea, 2013). Greater values indicate taller and narrower trees, and trees with values over a threshold of 80 are prone to wind-throw as well as wind-induced breakage (Rudnicki *et al*., 2004). It has been observed that slenderness ratio of trees is an excellent indicator of their long-term exposure to wind before harvesting (e.g. Mattheck and Breloer, 1994; Harris *et al*., 1999; Rudnicki *et al*., 2001). A very tall, slender, plantation-grown tree would respond dynamically like a pole or chimney, which is the approximation used by Kerzenmacher and Gardiner (1998) when modelling tree behaviour with slenderness ratio of 75.

James (2010) and Šebeň *et al*. (2013) noted that slenderness coefficients above 100 generally indicate low stability and the affected tree is likely to buckle under its own weight. For forest trees, slenderness coefficient below 80 indicates excellent stability (Smudla, 2004; Slodicak and Novak, 2006; Kontogianni *et al*., 2011). For trees in urban areas, lower slenderness ratios of 50:1 have been proposed by Mattheck *et al*. (2003).

According to Dubravac *et al*. (2009), one of the most important elements of tree structure is the crown, where essential living processes like photosynthesis take place. The crown projection area, together with crown volume, also determines the amount of intercepted precipitation, and regulates the amount of precipitation that reaches the forest floor (Vrbek *et al*., 2008).With the knowledge of crown projection area, it is possible to calculate the percentage canopy cover and canopy closure (Jennings *et al*., 1999; Pekin and Macfarlane, 2009; Pretzsch, 2014).

The crown structure of a forest stand is defined through the size, shape, growth and development of tree crowns, their distribution in time and space, and the proportions of the crown compared to other parts of the tree. The crown size and shape of a particular tree is the result of an intricate interplay of its internal genetic composition and the influence of the surrounding biotic and abiotic factors. According to Dubravac (1998), the range of variations in crown size and shape depends on tree species, site quality, age, position of the tree in the canopy and management interventions throughout the life of the forest stand.

Many ecological and economic problems in forestry are approached using crown dimensional measures (Grote, 2003). For example, individual tree competition indices are derived from crown area estimates (Bella, 1971). This is because crown dimension is a result of past competition as well as an indicator of the current growth potential (Iwasa *et al*., 1984). Thus, crown dimensional measures are used in more sophisticated single-tree models, particularly when forest growth in uneven-aged or mixed species stands is being considered

(Pretzsch, 1992). Furthermore, crown size and canopy cover determine the probability of successful natural regeneration because of its influence on the pattern of shade, light, and rainfall on the ground (Utschig, 1995). In general, many approaches for modelling light distribution (e.g. Stadt and Lieffers, 2000), water balance (e.g. Oltchev *et al.*, 1996), tree growth (e.g. Biging and Dobbertin, 1995; Pretzsch *et al.*, 2002), and tree physiology (e.g. Wang and Jarvis, 1990) depend on information about crown dimensions of individual trees. Crown projection area can be estimated from stem dimensions (Dubrasich *et al.*, 1997), but has to be thoroughly parameterised for specific stand conditions (Gilmore, 2001), which in most cases involves a large number of direct measurements. Nevertheless, canopy cover cannot be assumed to be the sum of tree crown projection areas, because overlapping is a common phenomenon, particularly in dense, uneven-aged and mixed stands (Crookston and Stage, 1999; Grote, 2003). The difficult measurements and the sensitivity of crown dimension on management makes it desirable to develop estimation procedures based on variables that are easier to measure than crown extension itself. Thus, maximum crown radius or diameters, which can be derived from stem diameter, has been used to estimate crown projection area (Goelz, 1996).

The structure of the canopy and crowns is crucial for the feedback between structure-environment-growth, which drives population dynamics (Pretzsch, 2014). Furthermore, canopy cover percentage has been identified as an indicator of wildlife habitat. As noted by Crookston and Stage (1999), percent canopy cover is the percentage of the ground area that is directly covered with tree crowns. For a particular forest, information on slenderness coefficient and canopy cover is vital for forest health evaluation, and they provide valuable information about the stability of that forest for continued existence, while giving insight into the susceptibility of same to wind-related damages. Therefore, this study assessed slenderness coefficients of trees within the Oban Group Forest as well as providing baseline information on canopy cover with a view to ascertaining the stand health and percentage canopy cover in the stand.

2. Methodology

2.1 The study area

The study was carried out in Oban Group Forest, which occupies an area of about 251,345 ha in southern Nigeria (Oates *et al*., 2007, NFIS, 2011). The area lies north-east of Calabar, the Cross River State capital, within longitudes 8^{o}02' and 8^{o}55'E and latitudes 5^{o}00' and 6^{o}00'N in Akamkpa and Etung Local Government Areas of Cross River State. It is bounded in the east by the Korup National Park and Ejagham Forest Reserve of Cameroon (Figure 1).

Annual rainfall is generally high throughout the area and decreases from about 3,000 mm in the south to 2,500 mm in the north of the area. This general trend is affected locally by altitude resulting in higher rainfall in the hilly and mountainous areas. The central parts of the forest are estimated to receive about 4,000 mm (Oates *et al*., 2007). Rain falls in one season from March to November with peaks in June/July and September. There is a marked dry season between December and February with very few days of rains. The mean annual temperature is 27^{o}C. According to Oates *et al*. (2007), mean monthly relative humidity varies between 78% and 91% with an average of 85%. The prevailing wind is southerly, but during the dry season, the north-east trade winds carry dust-laden air from the Sahara (the Harmattan), as far as Calabar. Most of the area is characterized by hilly terrain ranging from 100 to over 1,000 m altitude (WWF, 1989). The topography in the southern part of the area ranges from gently undulating to rolling plains with occasional isolated hills. Greater elevation is accompanied by increased dissection and structural control of drainage (WWF, 1989).

The Oban Group Forest houses Oban Hills, which are one of the five granite massifs, which dominate the Eastern Highlands of Nigeria and part of the basement complex of southern Nigeria. The dominant rock types are ancient metamorphic rocks of the basement complex, which cover 50% of Nigeria (UNICEM, 2008). Derived from sedimentary rocks and Precambrian in age, these rocks are interspersed with smaller areas of intrusive igneous rocks. The metamorphic rocks are mainly gneisses (biotite-hornblende, granite and migmatitic gneiss and to a lesser extent amphibolite (schist). The intrusive granodiorite form the headwaters of the Kwa River (UNICEM, 2008).

Oban Group Forest is the most extensive area of relatively undisturbed tropical rain forests remaining in Nigeria. It contains approximately 21% of the remaining 1,187,488 ha tropical rainforest in the country (Ojonigu *et al*., 2010). According to National Forestry Information System, NFIS (2011), the area contains 251, 345 (52.34%) of the standing tropical rainforest (480, 216 ha) in Cross River State. It lies within the Lower Guinea region, and contains a large number of plant species.

Meanwhile, Cross River State (CRS), in south-south Nigeria, contains much of Nigeria's remaining standing tropical forest (40.44%). In 2008, 26% of the state remained forested. The loss of forests is expected to have declined as a result of the recent moratorium on commercial logging, raising the prospect that Cross River State has reached the bottom of its forest transition curve. The Oban Hills are part of the Guineo-Congolian regional centre of endemism, which comprises about 8,000 to 12,000 plant and animal species of which more than 80% are endemic (USAID, 2008). The area was designated as a "Centre of Plant Diversity" by WWF and

IUCN in 1994 (UNICEM, 2008).

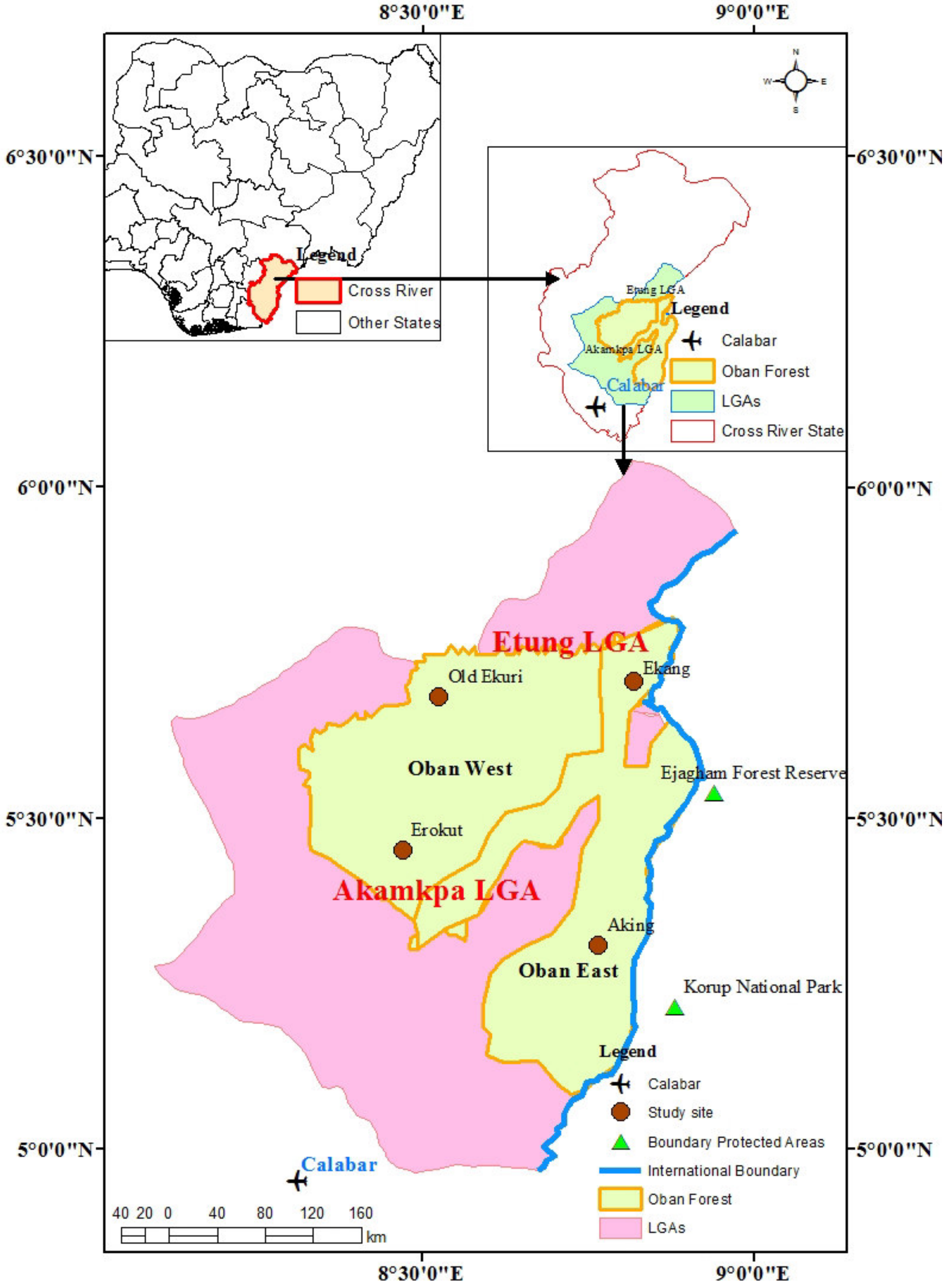

Figure 1. Map of the study area

2.2. Sampling Procedures and Data Collection

The data for this study were collected from four study locations (*Aking*, *Ekang*, *Erokut* and *Ekuri*) within the Oban Group Forest. Systematic (line transect) sampling technique was adopted for plot locations in each of the four study sites. A distance of 100 m from the forest boundary was measured to locate the first transect. The starting point of each transect was determined with the aid of prismatic compass and global positioning systems (GPS) receiver (Husch *et al*., 2003). Four transects of 2 km long situated 600 m apart were established in each of the locations. Five 0.25 ha (i.e. 50 m × 50 m) plots were then alternately laid along each transect at 400 m intervals resulting to 20 plots per location. Hence, eighty (80) sample plots were used for the study.

Tree heights and diameter at breast height (Dbh) were measured on all trees with Dbh $\geq$ 10cm. Crown diameter measurement was achieved using field technique by projecting the perimeter of each crown vertically to the ground, and making diameter measurement on this projection (Figure 2). The average of diameter of the crown's widest point was taken, and a second measurement was made at right angle as described by Tallent-Halsell (1994). The average of the two measurements gives the crown diameter.

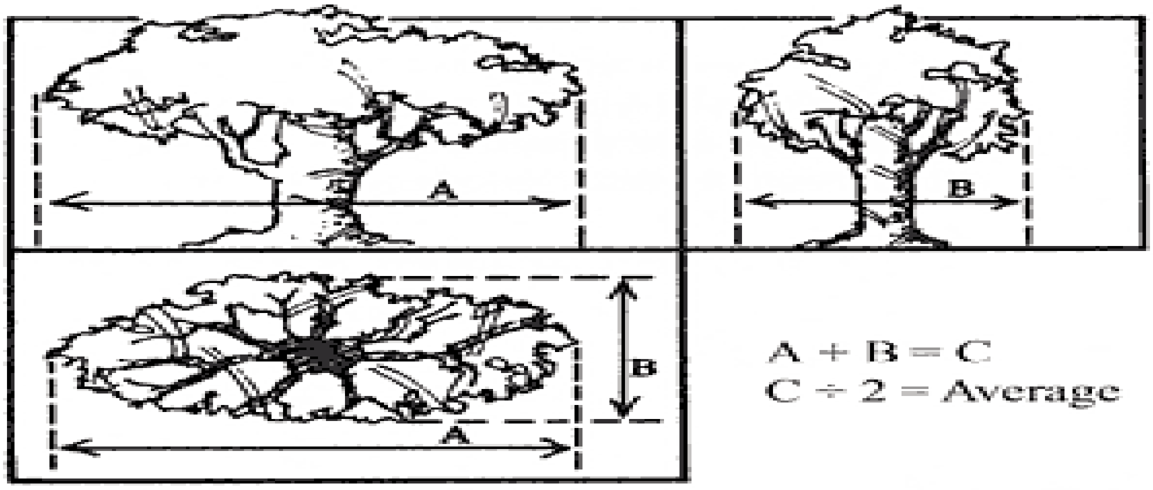

Figure 2. Tree crown diameter measurement procedure

2.3 Data Analysis

2.3.1Computations Derived Variables

2.3.1.1Tree Slenderness Coefficient

The individual tree slenderness coefficient was computed using:

$$SC_i = \frac{THT_i}{Dbh_i} \quad (1)$$

Where: SC_i = slenderness coefficient of ith tree; THT_i = total height of the tree (m); Dbh_i = corresponding tree diameter at breast height (m).

The individual trees were grouped into slenderness coefficient classes as high (with SC > 80); moderate (with SC: 70-80) and low (with SC < 70) slenderness coefficients. The frequencies of trees per hectare in each of the slenderness coefficient categories were computed by averaging the trees/plot in each category and then multiply the mean values by 4 (4 being the number of 0.25ha-plot in a hectare).

2.3.1.2 Crown Projection Area

The crown projection area was computed for individual trees using:

$$CPA = \frac{\pi\, CD^2}{4} \quad (2)$$

Where: CPA = crown projection area (m^2); CD = crown diameter (m).

2.3.1.3 Percent Canopy Cover

The percentage canopy cover was computed as follows:

$$C' = 100\left(\sum_{i=1}^{n} p_i CPA_i\right)A^{-1} \quad (3)$$

To correct for crown overlap, equation 4 was used as suggested by Satterlund in Moeur (1986).

$$C = 100\left[1 - \exp(-0.01C')\right] \quad (4)$$

Where: C' = percent canopy cover without accounting for overlap; P_i = trees/ha for the *ith* sample plot; CPA_i = crown projection area/ha for the *ith* tree; A = total area (m^2/ha); C = percent canopy cover that accounts for overlap.

2.4 Descriptive Statistics and Correlation Analysis

Descriptive statistics such as frequency, percentage, graph, mean; standard deviation and coefficient of variation (CV) were used to summarize the derived (computed) tree variable information. The linear association among measured tree growth variables were evaluated using Karl Pearson's product correlation coefficient at $\alpha = 0.05$.

3. Results

The result of the tree slenderness coefficients (SC) categorization for the pooled data in the study area revealed that 36 trees/ha had high slenderness coefficients (SC > 80) on the whole. About 49 trees/ha were moderately slender (SC: 70 - 80). Sixty-seven (67) trees/ha had low slenderness coefficients (SC < 70) as shown in Figure 3.

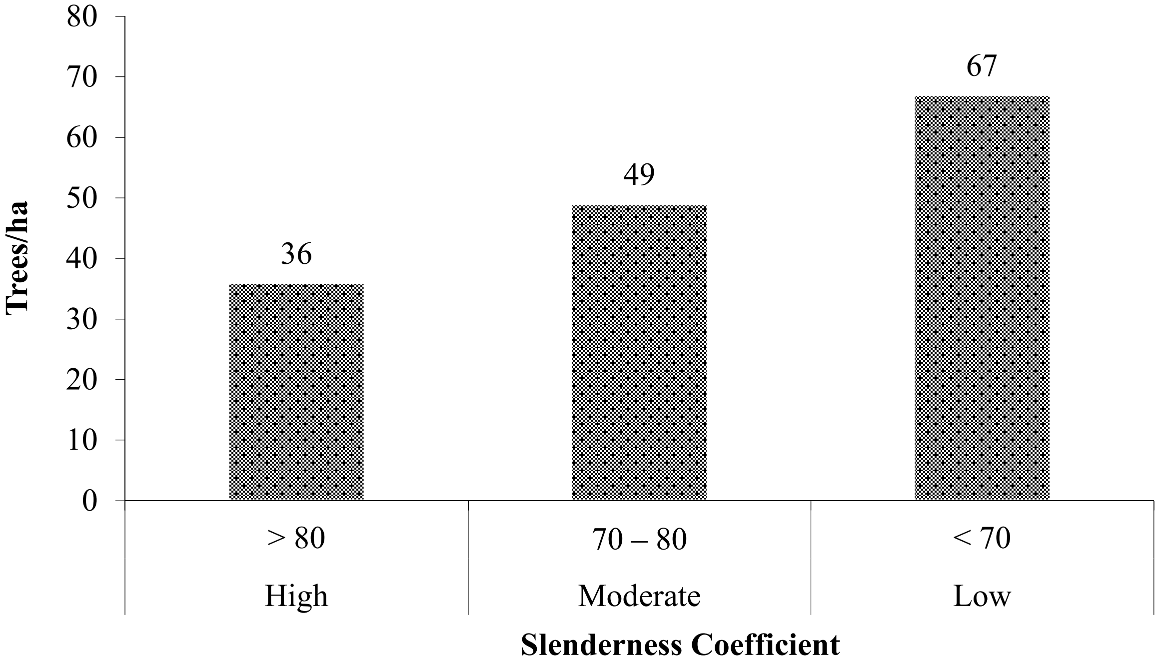

Figure 3. Slenderness coefficient categorization for the pooled data

The results of slenderness coefficients on site basis showed that for *Aking* site, 44 trees/ha (i.e. 30.34%) had high slenderness coefficients (SC > 80). About 45 trees/ha had moderate slenderness coefficients (SC: 70 - 80). In this site, 56 trees/ha were in the low slenderness coefficient (SC < 70) category. With respect to *Ekang* site, trees with high slenderness coefficients were 45 trees/ha (i.e. 30.61% of the trees/ha). About 50 trees/ha had moderate slenderness coefficients with 52 trees/ha having low slenderness coefficients in the location (Figure 3). The result for the *Erokut* site revealed that 37 trees/ha (i.e. 25.87%) were in the high SC category. About 50 trees/ha had moderate SC with 56 trees/ha in the low SC category. With respect to the *Ekuri* site, 62 trees/ha (i.e. 35.84%) were in the high SC category. About 43 trees/ha had moderate SC. Sixty-eight (68) trees/ha fell in the low SC category (Figure 4).

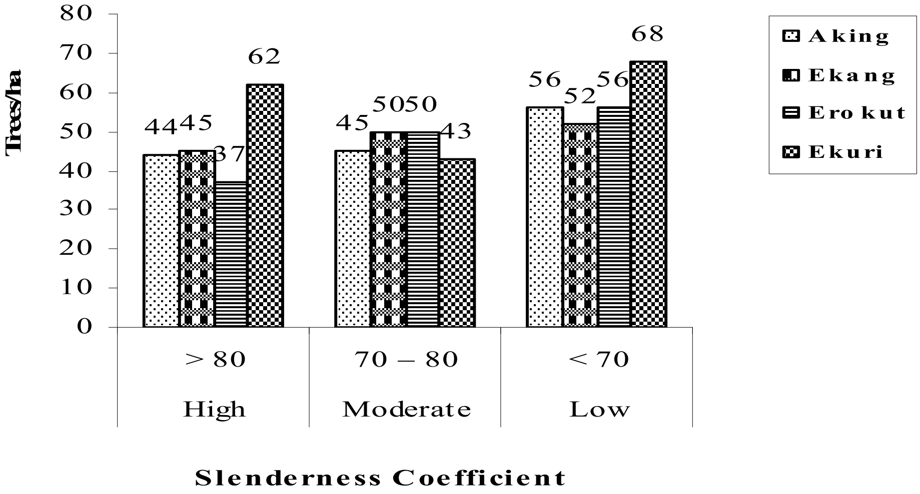

Figure 4. Slenderness coefficient categorization for the four sites in the study area

Table 1 presents crown projection area/ha as well as the percentage canopy cover for pooled data and on site basis. The mean crown projection area (CPA) for the area was 8322 ± 4137 m^2/ha with CV of 0.50. About 57% of a hectare is covered by tree canopy on the whole. On site basis, *Ekuri* stand had the highest mean CPA of 9120.52 ± 3942 m^2/ha and CV of 0.43 with 59.8% canopy cover/ha. This was followed by *Aking* stand with a mean CPA of 8516.68 ± 4519 m^2/ha and CV of 0.53 with 57.3% canopy cover/ha. The least mean CPA of

6920.52 ± 4448 m^2/ha and CV of 0.64 was recorded in *Erokut* with about 49.95% canopy cover/ha. Details of the CPA and the percentage canopy cover for the study area are shown in Table 1.

Table 1. Crown projection area/ha and percentage canopy cover in the study area

Site	**Statistics**	**Trees/ha**	**CPA/ha (m^2)**	**% canopy cover**
Pooled	Mean	152	8322	56.5
	SD	37.84	4137	
	CV	0.25	0.50	
Aking	Mean	145	8516.68	57.3
	SD	16	4519	
	CV	0.11	0.53	
Ekang	Mean	147	7430.39	52.4
	SD	30	2798	
	CV	0.20	0.38	
Erokut	Mean	143	6920.52	49.95
	SD	39	4448	
	CV	0.27	0.64	
Ekuri	Mean	173	9120.98	59.8
	SD	51	3942	
	CV	0.29	0.43	

N.B.: *SD - standard deviation; CV - coefficient of variation; CPA - crown projection area*

Most of the growth variables had significantly positive correlations with each other with fewer variables having weak and negative correlations. There were significant and positive correlation between tree total height (THT) and diameter at breast height (Dbh), slenderness coefficient (SC), crown diameter (CD), basal area (BA), crown projection area (CPA) as well as stem volume (SV) with correlation coefficients (r - values) of 0.47, 0.07, 0.44, 0.32, 0.34 and 0.43, respectively (Table 2). However, most of the correlations were weak. Diameter at breast height (Dbh) had strong, significant and positive correlations with most of the measured tree growth variable except SC (r = -0.55). Slenderness coefficient (SC) negatively and significantly correlated with all other tree growth variables apart from tree height (Table 2). Crown projection area (CPA) had strong and positive correlation with CD (r = 0.93). Basal area (BA) had positive and significant correlation with other measured variables and negatively correlated with SC (r = - 0.42).

Table 2: Correlation matrix for the tree growth variables

	THT	Dbh	SC	CD	BA	CPA
THT	1					
Dbh	0.47*	1				
SC	0.07*	-0.55*	1			
CD	0.44*	0.75*	-0.37*	1		
BA	0.32*	0.92*	-0.42*	0.65*	1	
CPA	0.34*	0.67*	-0.33*	0.93*	0.65*	1

** Significant ($P < 0.05$); THT - tree total height; Dbh - diameter at breast height; SC - slenderness coefficient; CD - crown diameter; BA - basal area; CPA - crown projection area*

4. Discussion

The results of tree slenderness coefficient classification showed that 23.7% (i.e. 36 in 152 trees/ha) of the measured trees in the area had high slenderness coefficient, which implies high susceptibility to wind-throw and damage. Rudnicki *et al.* (2004) noted that trees with values over a threshold of 80 are prone to wind-induced breakage. For forest trees, slenderness coefficient below 80 indicate excellent stability (Smudla, 2004; Slodicak and Novak, 2006; Kontogianni *et al.*, 2011). The high occurrence of trees with high slenderness coefficients may be a result of inadequate silvicutural treatments like thinning or selective logging. For example if a forest stand remains un-thinned for several decades, the vertical (height) growth may become disproportional in relation to the horizontal development (diameter growth) of tree stems (Liu *et al.*, 2003). It has been noted that the more the number of stems per hectare, the higher the rate of competition for light among trees, which results in high slenderness coefficients, thereby increasing the risk of stem damage as that may limits individual trees horizontal developments.

As noted by Liu *et al.* (2003), when tree slenderness coefficient becomes very high, there is possibility of exposure of such trees to bending stress, leading to reaction wood, which may affect wood properties as well as the ultimate usage to which the wood can be put. Jullien *et al.* (2013) observed that high slenderness coefficient is the best accurate predictor of tree growth stress. Hence, it can be said that more that one-fifth of the trees in every hectare of the study area may have being experiencing growth stress, a situation unpleasant to sustainable forestry. This observation is supported by Peltola (2006); Teste and Lieffers (2011). Trees with high slenderness coefficient are more susceptible to breakage than those with low slenderness coefficients. On site basis, *Ekuri* had more trees per hectare in this category than the other three sites.

The least number of trees per hectare in the high SC category recorded in *Erokut* stand is expected since the stand had lesser stand density (i.e. trees/ha and Basal area/ha) than the other three sites. This corroborates the finding of Penner *et al*. (2001) and Harja *et al*. (2012), who reported that trees in denser stand tend to be more slender compared to the less-dense ones because competition for light among trees is more in denser. This view was also buttressed by Magruder *et al*. (2012), who noted that height growth is favoured than the horizontal development in trees grown in denser stands as a result of restrictions in growing spaces. Therefore, it is equally possible that tree vertical growth in the study area is sensitive to changes in stand density. This finding is contrary to the submission by Nyland (2007), who observed that tree height is not overly sensitive to changes in stand density. However, Chin and Wang (2007) reported that at a later developmental stage, shade may contribute towards limiting diameter growth.

The correlation between tree basal area and slenderness coefficient was negative. This implies that the proportion of trees prone to wind-throw or damage in the area decreases with increase in tree basal area per hectare. This agrees with the finding of Martín-Alcón *et al*. (2012), that the proportion of wind-throw and damaged trees in a stand decreases strongly at higher stand basal area for a given slenderness ratio.

The percent canopy cover in the Oban Group Forest was about 57% per hectare on the whole. This means that in a hectare (10,000 m^2), only 5,700 m^2 of the land area were under canopy cover. On site basis, CPA and percentage canopy cover were higher in *Ekuri* than the other three sites. This may have resulted from higher stand density and stocking (trees/ha and BA/ha). Canopy cover has been identified as an indicator of wildlife habitat, and they are a good descriptor of forest stand structure (Crookston and Stage, 1999). Consequently, in the absence of other limiting factors such as human, ecological or natural disturbance, *Ekuri* site has the potential to support more wildlife population than the other sites. The canopy structure exhibited may be due to more anthropogenic disturbance in the other parts of the forest than this site, especially the *Erokut* axis with least percentage canopy cover, and various signs of anthropogenic activities. According to Franklin *et al*. (2007), disturbance leaves great negative impacts on the forest canopy structure, which in turn affects the overall productivity and health of the forest per unit area.

5. Conclusion

The study has shown that up to 23% of the trees per hectare in the study area had high slenderness coefficient, which implies high susceptibility to wind-throw and damage. Trees in this category were more at *Ekuri* site compared to the other three sites. This situation is usually caused by high stand density, which may have resulted in competition for growth requirements among the growing trees, especially light with consequent limited development diameter growth. High slenderness ratio in trees may also occur when a stand remains un-thinned for decades. Therefore, appropriate silvicultural treatments like thinning or low-impact logging, as the case may be, is recommended in to enhance better tree development in the area, and to ensure moderate to excellent stand stability. This has potential to positively impact on the forest stand health.

The study further revealed that percent canopy cover in the study area, as a whole, was about 57%. On stand basis, the mean percent canopy cover was higher in *Ekuri* than the other study sites. This is an indication of a better forest structure, and it may imply a better faunal diversity in the absence of other disturbances in the forest ecosystem. Going by the findings of this study, it can be concluded that *Erokut* had the least-suitable results in terms of stand stability, forest structure as well as the percent canopy cover. Hence, it is the most-unhealthy stand in comparisons to others within the Oban Group Forest. In that stand, there were signs of encroachments, lesser structural diversities and consequently, a reduced tree density compared to other sites. Therefore, a stricter protection measures should be adopted to ensure a better stand condition, health and stability.

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