Tree slenderness coefficient at Bali Botanic Garden

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Abstract. Standing trees has a higher risk regarding structural damage that can cause trees or parts of trees to fail. Meanwhile, Bali Botanic Garden is located in a highland area that periodically gets natural disasters such as heavy wind. However, the information on tree stability is little known. Therefore, tree stability at Bali Botanic Garden was assessed using tree slenderness coefficient (SC) as an indicator. Purposive sampling technique was adopted for locations which highly visited. A total of 624 trees with dbh>40 cm were examined as samples. Trees were classified based on their SC as high (>80), moderate (SC:70-80), low (SC<70). Data were analyzed using descriptive and correlation analysis. Tree slenderness coefficient at Bali Botanic Garden classified as low (609 specimens), medium (11 specimens), and high (4 specimens). Trees with the high category were three individuals of Bischofia javanica Blume (SC=82.76, 83.69, and 89.63) and a Syzygium polyanthum (Wight) Walp. (SC=116.13). Trees with high SC had a higher susceptibility to wind-induced damage. There was a negative correlation between SC and other tree parameters except for tree height (r=0.44). Hence appropriate silvicultural treatment like thinning is recommended to enhance better tree development and minimize tree risk.

1. Introduction
The botanic garden is an ex-situ plant conservation area; many plants from various habitus are grown at a botanic garden. Standing trees has a higher risk regarding structural damage that can cause trees or parts of trees to fail. This damage can result in material and non-material losses. A low-risk tree can lose its branches in locations where there are no physical damage and human injury. In contrast, a high-risk tree is located in areas with high human activity and valuable properties [1]. Therefore, the examination of tree stability has the advantage of minimizing the risk of a fallen tree.

Meanwhile, Bali Botanic Garden is in a highland area that periodically gets natural disasters such as heavy wind. This heavy wind sometimes results in uprooting trees, especially collection trees such as Cupressus guadalupensis S. Watson and Pavetta sp on 2021 or broken branch/ twig

Tree slenderness coefficient is total height divided by diameter at breast height [2, 3, 4]. The tree slenderness coefficient is used for the tree and stand stability evaluation. A large value of tree slenderness coefficient indicates either tree grown on open space without competition or tree grown in
a crowded stand with mutual supporting neighboring trees. While, a smaller value of tree slenderness coefficient indicates the longer crown length, higher crown projection area, better-developed root system, lower position of the center of gravity, and higher stability of the trees [3].

The tree slenderness coefficient is also used as a good indicator of the wind-throw stability of trees [5, 6, 7]. Several studies use tree slenderness coefficient for tree and stand stability and vulnerability to natural disasters [8, 9]. Meanwhile, the tree slenderness coefficient is also used for assessing tree vigor and health. Tree with higher SC may have a lower vigor in general [3]. By understanding the tree slenderness coefficient, the manager of the botanic garden is able to assess tree stability and may better design silviculture prescriptions based on the range of SC. The objective of this research was to assess the tree slenderness coefficient as an indicator of tree stability at Bali Botanic Garden and give tree management recommendations at Bali Botanic Garden.

2. Materials and methods
This research was conducted at Bali Botanic Garden from May to August 2016. This garden is located at Tabanan district Bali province on 1.250 m above sea level. The sample location was selected by purposive sampling based on the level of group visitors who rent a location in the botanic garden.

The equipment used in this research were diameter tape, roll meter (30 m), Nikon Forestry Pro (Laser Rangefinder), and Microsoft Excel 2010. Samples were observed as many as 624 trees with a diameter at breast height (DBH) > 40 cm. The sample consists of the collection and non-collection trees. The tree’s height (H) was measured with Nikon Range finder Forestry Pro and diameter at breast height was measured with diameter tape at 1.3 m height from the ground.

Data then were analyzed used the following formula:

\[
SC = \frac{H}{DBH} \tag{1}
\]

where:
SC = tree slenderness coefficient
H = tree height (m)
DBH = diameter at breast height (m)

\[
BA = \frac{\pi}{4} \times DBH^2 \tag{2}
\]

where:
BA = Basal area per tree (m²)
DBH = Diameter at breast height (m)

The linear associations among measured tree growth variables were evaluated using Karl Pearson’s correlation.

3. Result and discussion
Stand stability is affected by two factors consist of biological factors and physical factors. Physical factors consist of the wind component (direction, speed, and duration), the topography, and the site properties (soil depth, structure, and drainage). In contrast, biological factors comprise the species characteristics (root anchorage, crown architecture form, mechanical properties of wood), tree dimensions (height, diameter, crown ratio, and slenderness coefficient), tree vigor and health and stand density [9].
3.1. Tree slenderness coefficient

Tree slenderness coefficient classes as high (with SC > 80), moderate (with SC: 70-80), and low (with SC < 70) [2]. The result from the sample examination at Bali Botanic Garden (figure 1) showed trees with slenderness coefficient as low (609 specimens), medium (11 specimens), and high (4 specimens).

That means 97.60% of high-risk trees in Bali Botanic Garden were in excellent stand stability, 1.76% in moderate stand stability, and only 0.64% standing unstable. Trees with the high SC category were three individuals of *Bischofia javanica* Blume (SC=82.76, 83.69, and 89.63) and a *Syzygium polyanthum* (Wight) Walp. (SC=116.13). They had a higher susceptibility to wind-induced damage and might be prone to fall. Therefore, they were dangerous for humans and/or properties around them.

A straight relationship exists between the slenderness coefficient of the stands and the risk of stem breakage or tree fall due to abiotic factors such as the wind [10]. The occurrence of trees with a high slenderness coefficient may result from inadequate silvicultural treatments like thinning or selective logging [2].

![Figure 1. Tree slenderness coefficient from Bali Botanic Garden tree.](image)

3.2. Correlation matrix for tree growth variable

Tree slenderness coefficient has a positive correlation with tree height (H) but has a negative correlation with a diameter at breast height (DBH) and basal area (BA) (table 1.)

| Tree variables       | Slenderness coefficient (SC) values (Significant (P<0.05)) |
|----------------------|----------------------------------------------------------|
| Diameter at breast height (cm) | -0.48*                                                   |
| Tree height (m)      | 0.44*                                                    |
| Basal Area (m²)      | -0.41*                                                   |

Tree slenderness coefficient has a negative correlation with a diameter at breast height (1.3 m) above ground level. This agrees with the finding of [2], who reported a similar result. [5] also reported tree slenderness coefficients decreased with increasing tree DBH, height, age, and crown length.

The tree slenderness coefficient has a positive correlation with tree height. This agrees with the finding of [2] in Oban group forest, [11] for *Pinus caribaea* in Omo Forest Reserve, Nigeria. This result is different from the result of [5], who reported tree slenderness coefficients decreased with increasing tree height in boreal mixed-wood of Canada. This difference may be due to different locations. [5] mention the most promising approaches in determining tree and stand stability to windthrow are the integration of tree stability characteristics such as slenderness coefficient with local stand condition, site, topography, and windiness feature.

The tree slenderness coefficient has a negative correlation with the basal area. This indicates that the proportion of trees susceptible to wind-throw or damage in the areas decrease with the increase of
tree basal area per ha. This agrees with the finding of [2], who reported that stand with high SC expected since the least number of trees per ha and basal area per ha.

3.3. Species characteristic
Species characteristic is another biological factor to determine the stand stability [9]. There are two kinds of trees with a high tree slenderness coefficient at Bali Botanic Garden consisting of *Bischofia javanica* and *Syzygium polyanthum*. Both are tree species that were used for reforestation in the Bali Botanic Garden location a long time ago [12].

 *B. javanica* is a rapidly growing evergreen or semi-evergreen, the height reach between 30-50 m and trunk diameter between 80-140 cm [13, 14]. This tree is native to Indonesia (Java, Lesser Sunda Island, Maluku, New Guinea, Sulawesi, and Sumatra) [15]. This species was reported as an invasive alien tree in Japan [16, 17]. Although this study showed that *B. javanica* had a high slenderness ratio, [16] mentioned that *B. javanica* had lower mortality than native tree species when Typhoon 0614 YAGI occurred in 2006. *B. javanica* also showed a better growth rate than native tree species. Furthermore, *B. javanica* has a dense rounded crown, and the thick trunk was often planted as a shade tree, but this tree is susceptible to breakage. The aggressive roots can lift sidewalks if they are planting near pedestrians [13,18]. On the other hand, this tree species was reported fallen in Indonesia, such as West Jakarta [19].

 *S. polyanthum* is also native to Indonesia (Java, Lesser Sunda Island, and Sumatra) [15]. The height of this tree is able to reach 30 m with trunk diameter until 60 cm [20]. This tree species was reported fallen in many cities in Indonesia, such as Bogor [21], Bekasi [22], and Karanganyar [23]. This phenomenon was caused by the old age of the tree and the heavy wind. Meanwhile, based on an internal report of plant collection staff at Bali Botanic Garden, *B. javanica* and *S. polyanthum* have tree breakage. *B. javanica* has frequency more often to has broken branch or twig because loads many epiphytic plants, while *S. polyanthum* has a problem more often caused by stem borer attack. However, [24] reported that a high slenderness coefficient is the best accurate predictor of high growth stress in mature Beech, although the slenderness coefficient explained only 10% of the growth stress variability.

3.4. The effect of tree age and growth characteristics on tree slenderness coefficient
Since the tree age of the sample is not all known because the samples consist of collection and non-collection trees, we cannot measure the exact effect of tree age and growth characteristics (i.e., fast-growing species) on tree slenderness coefficient. However, the tree slenderness coefficient of Chinese fir (*Cunninghamia lanceolata* (Lam.) Hook.) plantation, a native and fast-growing species in southern China, reported increasing with increasing of tree age and basal area and decreasing with increasing of relative diameter and tree density index [4]. Furthermore, fast-growing species definition is a tree that has an annual mean increment of more than 1 cm per year [25].

3.5. Recommendation to maintain the tree stability at Bali Botanic Garden
Silvicultural operations must be done to avoid the fast increase of SC and move the risk to the lower risk (SC< 70) by applying to thin. This solution accordance with [9,5,2]. Appropriate silvicultural treatments like thinning are recommended to enhance better tree development. Since stand stability depends on physical and biological factors, pest and disease management should be handle as soon as possible to reduce the risk of standing trees.

4. Conclusion
Tree slenderness coefficient at Bali Botanic Garden classified as low (609 specimens), medium (11 specimens), and high (4 specimens). Trees with the high category are *Bischofia javanica* Blume and a *Syzygium polyanthum* (Wight) Walp. Trees with high SC had a higher susceptibility to wind-induced damage. Silvicultural treatment must be done to avoid the fast increase of SC and move the risk to the lower risk (SC< 70) by applying to thin.
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**Authors contribution**

We declare that S.F.H, M.B.A, and G.A.E.O are the main contributors whereas I D.P.D, H.M., and A.F. are member contributors of this paper. All member participate in collect data. S.F.H. designed the research, wrote down in almost all section of the paper. M.B.A. and G.A.E.O. analyses the data and added in the discussion. I D.P.D, H. M. and A.F. added in the discussion.