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Tree Risk Assessment with Sonic Tomograph Method at Bali Botanical Garden

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Abstract

Safety perception is the most important part of people's choice in determining tourist sites. Standing trees that are prone to falling are very dangerous for both visitors and employees. Standing tree with decay wood inside is often the cause of tree failure. Therefore, there is a need for research examining the risk of collection and non-collection trees in Bali Botanical Garden. Tree risk checks were carried out using the Tree Risk Assessment method from the International Society of Arboriculture (ISA), which has been modified. The result of this research gives valuable information for the manager to determine tree handling to minimize tree risk.

Keywords: Acoustic Tomograph, tree risk assessment, public space, ArborSonic 3D Tomograph, decay level

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Introduction

Botanical Gardens are ex-situ plant conservation areas with a plant collection of data arranged according to taxonomic classification, bioregion, thematic, and a combination of these patterns with the aim of conservation activities, research, education, tourism and environmental services (PP RI Number 93/2011). Bali "Eka Karya" Botanical Garden (BBG) is an institution that carried out ex-situ conservation of dry highland plants. BBG carries out the functions of carrying out plant exploration, managing plant collections, researching and developing plant collections, and carrying out services and information (Perka LIPI Number 5/2016). In his vision, BBG mentioned providing services in aspects of botany, environmental education, horticulture, landscaping, and tourism (Darma & Hanum, 2007). BBG is one of the tourist attractions with the highest visits, reaching more than 500,000 visitors in 2015 (Muntadliroh, 2016). Hence, urban communities also prefer to relax and pay more in public places with many trees (Dwyer et al., 1989).

The existence of trees provides advantages and disadvantages. Trees have economic value and ecological benefits. As the tree's growth, the benefits of economic value and ecological are increasing. Benefits from the presence of trees include providing shade from sunlight and wind barrier, managing rainwater into surface water, reducing air pollution through the uptake of pollutants by leaves, increasing property values, providing a positive effect on human psychological health, providing shade and food for wildlife and increasing the use of shaded asphalt roads (Hauer & Johnson, 2003). However, the existence of trees can also be dangerous. The accident of fallen trees is unpredictable, although many measurements have been carried out (Lazim & Misni, 2016). Failure trees or parts of trees can break and cause material damage or physical injury (Hauer & Johnson, 2003). Tree risk is defined as a tree with structural damage that can cause trees or parts of trees to fall. This damage can result in material and non-material losses. The risk of a tree can vary from low to high. This risk is determined by the damage that will be occurred. A low-risk tree is a tree that can lose its branches in locations where there are no physical damage and human injury. While a high-risk tree is a tree located in areas with high human activity and valuable properties (Hauer & Johnson, 2003)

As a conservation institution, BBG has more than 20,000 plant specimens (Registration, 2020). The plant collections in BBG consists of trees, shrubs, herbs, and climbing plants. BBG has been established since 15 July 1959 (Muntadliroh, 2016), so it has many old collections. Tree collections over 50 years old have a higher risk of falling traits such as weathering, broken branches, cracks and hollow stems (Raihandhany & Kurniawati, 2016)

Several years ago, tree species in Bogor Botanical Garden had structural damage caused by termites that injured several visitors (Zuhri et al., 2018). This case proves that trees are prone to falling are very dangerous for both visitors and employees. Therefore, perceptions about safety are the most important part of people's choices in determining tourist locations (Schroeder, 1990). To provide safety locations, trees conditions must be checked regularly, from

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outside and inside of the tree. Visual tree assessment was used to examine the tree's condition from outside, slenderness ratio used to examine tree resistance from wind blow. In contrast, sonic tomography is used to examine inside tree conditions.

ArborSonic acoustic 3D Tomograph is one example of non-destructive commercial equipment (Li et al., 2016). This equipment uses stress waves, which produce manually from hammer tapping on one pin to each other pin to detect wood decay inside the tree (Loon et al., 2018). Stress wave velocity measured in trees has also been found effective to detect moderate to severe decay in Cibodas and Bogor Botanical Garden (Helmanto et al., 2018; Rachmadiyanto et al., 2019; Zuhri et al., 2018). The objective of this research was to assess tree risk in the public area at Bali Botanical Garden. The result of this research will help the BBG manager to arrange tree priority handling.

Methods

Location and time The study was conducted at BBG from May to August 2016. The research location was selected by purposive sampling based on the level of visits of group visitors who rented locations in the botanical garden (Figure 1).

Tools and materials The equipment used is a set of ArborSonic 3D Acoustic Tomograph equipment (sensors, hammers, and computers connected to arbosonic), diameter tape, roll meter (30 m), digital cameras, Nikon Forestry Pro (Laser Rangefinder) and Microsoft Excel 2010.

Visual observation of tree conditions Tree risk checks were carried out using the modified Tree Risk Assessment Form from the International Society of Arboriculture (ISA) (Figure 2). Samples were observed as many as 497 trees with

Figure 1 The map of research location (brown color) at Bali Botanical Garden.

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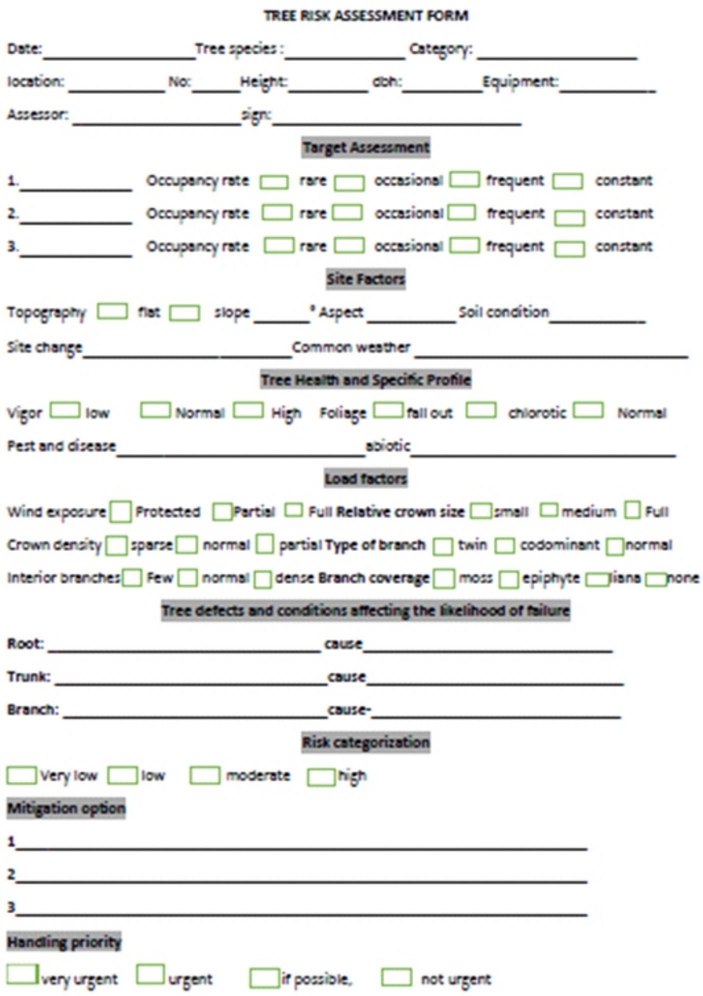
diameter breast height > 40 cm. This sample consists of the collection and non-collection trees. A collection tree is a tree with data information, while a non-collection tree is an existing tree in the garden without data information. Tree morphological characters observed were tree height measured by Nikon Forestry Pro (Laser Rangefinder); tree canopy width measured by roll meter and diameter at breast high (DBH) measured by diameter tape. Visual observation of tree trunks' condition was also done by looking at the outermost trunk of the sample tree, especially to see whether there were any symptoms or signs of deterioration. Observation of the tree's visual condition will support the results of the examination using ArborSonic. The results of visual observations are recorded on the observation sheet. We use the scoring number from 13 for each parameter, then calculate the score from each parameter (Table 1). A tree with the highest scoring number will be analyzed by further check using ArborSonic 3D Acoustic Tomograph.


TREE RISK ASSESSMENT FORM

Date:________ Tree species:________ Category:________

location:______ No:____ Height:______ dbh:______ Equipment:______

Assessor:________ sign:________

Target Assessment

1.______ Occupancy rate ☐ rare ☐ occasional ☐ frequent ☐ constant

2.______ Occupancy rate ☐ rare ☐ occasional ☐ frequent ☐ constant

3.______ Occupancy rate ☐ rare ☐ occasional ☐ frequent ☐ constant

Site Factors

Topography ☐ flat ☐ slope ____° Aspect ______ Soil condition______

Site change________ Common weather ________

Tree Health and Specific Profile

Vigor ☐ low ☐ Normal ☐ High Foliage ☐ fall out ☐ chlorotic ☐ Normal

Pest and disease________ abiotic________

Load factors

Wind exposure ☐ Protected ☐ Partial ☐ Full Relative crown size ☐ small ☐ medium ☐ Full

Crown density ☐ sparse ☐ normal ☐ partial Type of branch ☐ twin ☐ codominant ☐ normal

Interior branches ☐ Few ☐ normal ☐ dense Branch coverage ☐ moss ☐ epiphyte ☐ liana ☐ none

Tree defects and conditions affecting the likelihood of failure

Root:________ cause________

Trunk:________ cause________

Branch:________ cause-________

Risk categorization

☐ Very low ☐ low ☐ moderate ☐ high

Mitigation option

1________

2________

3________

Handling priority

☐ very urgent ☐ urgent ☐ if possible, ☐ not urgent

Figure 2 Modified ISA risk assessment form.

Table 1 Tree risk scoring from Tree Risk Assessment Form

Parameter	Score = 1	Score =2	Score =3
Occupancy rate	Occasional	Frequent	Constant
Topography	Flat	Slope < 45°	Slope > 45°
Soil condition	Soil	Partial pavement	Full pavement
Wind exposure	Protected	Partial	Full
Crown density	Sparse: 1–33%	Normal: 34–66%	Dense: 67–100%
Type of branch	Normal	Codominant	Twin
Branch coverage	None/only moss/ epiphyte/liana	Moss+epiphyt/moss+ liana/epipyht+liana	Moss+epiphyt+liana

Note: Tree risk scoring: low = 7–11; middle = 12–16; high = 17–21

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Selection of sample trees for arbosonic measurements The selection of tree samples was carried out by purposive sampling with criteria for tree trunk diameters > 40 cm, having epiphyte load or branching off, or there were signs of damage due to pests and diseases, located in an area that was visited by tourists. Thus, a total of 44 trees were sampled in this study.

Evaluate wood decay inside the tree using ArborSonic Checking the internal condition of each sample tree trunk is done using the ArborSonic 3D Acoustic Tomograph tool. The step to use ArborSonic 3D were: (1) drive eight sensors perpendicular to the trunk with the equal distance in counterclockwise order (Figure 3A); (2) connect the sensors to the amplifier boxes then connect the amplifiers in a line. Connect the battery box on any end of the line then connect to PC; (3) each sensor was tapped with a steel hammer to generate sound waves; (4) the software was calculated and displayed the internal sound-velocity distribution of the tree (Figure 3B). To get accurate information about the internal trunk condition, it is important to assess the tree in several layers (Figure 3C). The level of tree risk is obtained from the maximum percentage of decay level. The observations are grouped into three groups: low-risk trees with characteristic parts of the tree appearing intact (Figure 4), medium tree risk with characteristic features of trees appearing to decay (Figure 5) and high tree risk, trees with hollow or hollow insides (Figure 6). ArborSonic measurement results determine the type of tree handling. Trees with a high priority will get immediate treatment and special treatment (regular monitoring) compared to trees with low priority. Trees with high priority are trees located in densely populated areas, have large trunk diameters, are aged, or are seen to be attacked by pests and diseases (Helmanto et al., 2018).

Determination of tree-level damage using ArborSonic is done based on Helmanto et al., (2018) which classifies high risk if the percentage of wood decay is above 60%, moderate risk if the percentage of wood decay is between 30–60% and low risk if the percentage of wood decay is below 30%.

Slenderness ratio Tree slenderness is an important characteristic of shade tree resistance to wind and rainstorm

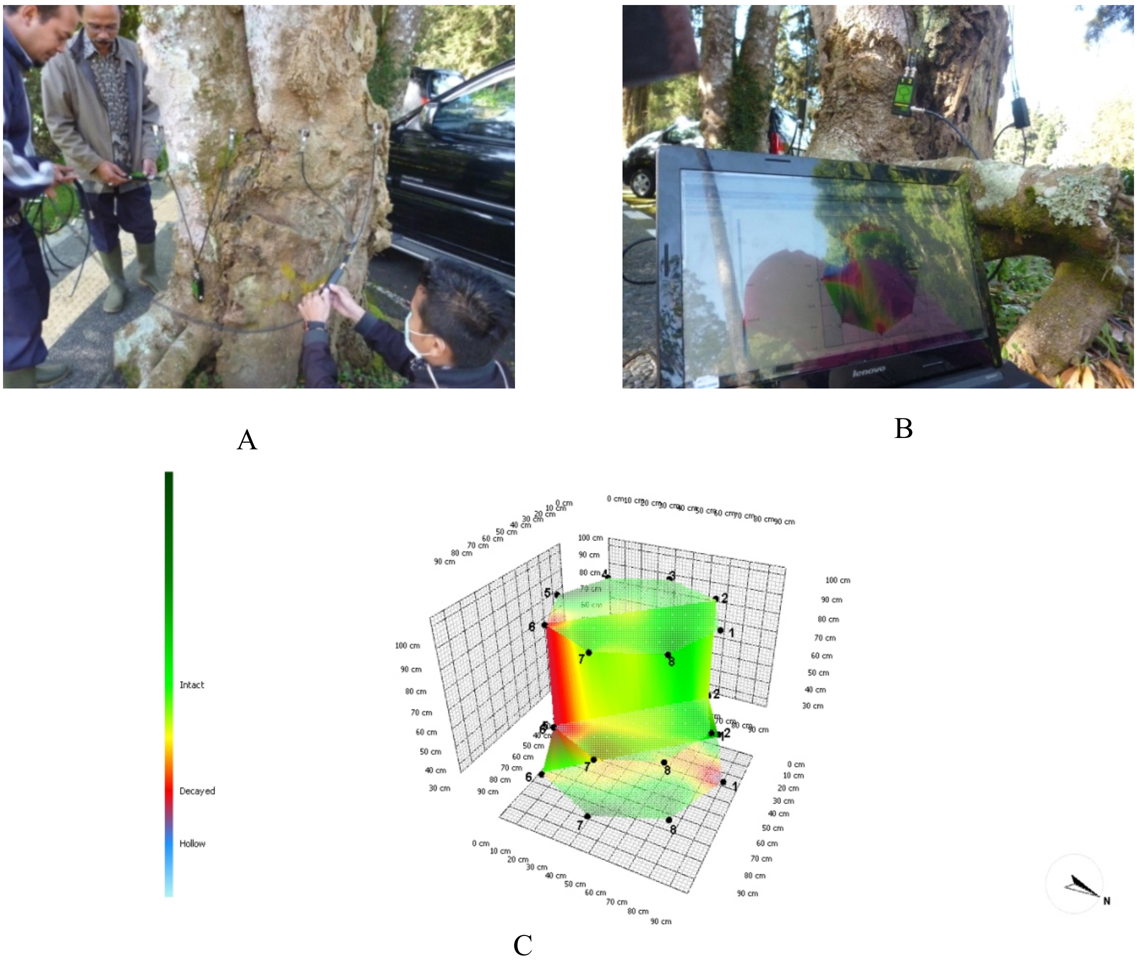

Figure 3 Arbosonic equipment installation around tree trunks (A), The result will be shown in the computer (B), The three-dimensional appearance of the trunk examined, the x-axis indicates the height of the pinned metal mounted (C).

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(Puspitasari, 2014). Tree slenderness is obtained from a ratio between height (h) and the diameter of the tree at breast height (Dbh) (Adeyemi & Adesoye, 2016). This ratio is a good indicator describing the optimization of biomechanical systems in plants (Jelonek et al., 2012). The optimum value for the slenderness ratio is between 25–50; trees with a slenderness ratio of more than 50 have a greater risk of fallen trees (Mattheck & Bethge, 2011). While Adeyemi & Adesoye, (2016) have different criteria in determine slenderness ratio as high > 80; moderate; 70–80 and low: < 70.

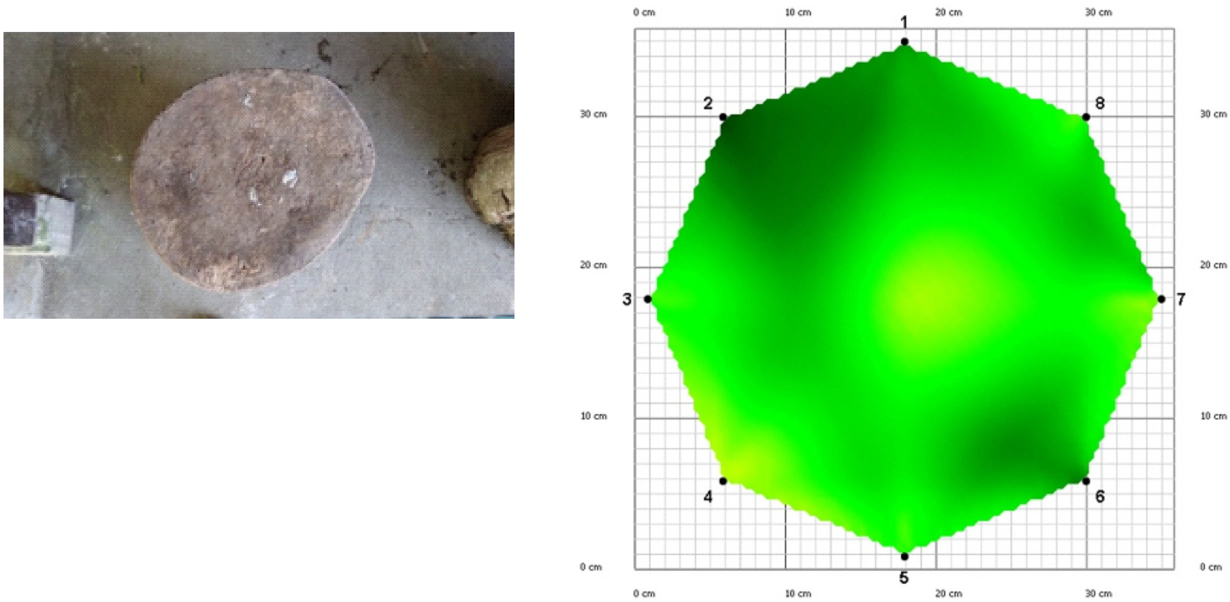

Figure 4 Inside tree trunk show good condition with green color.

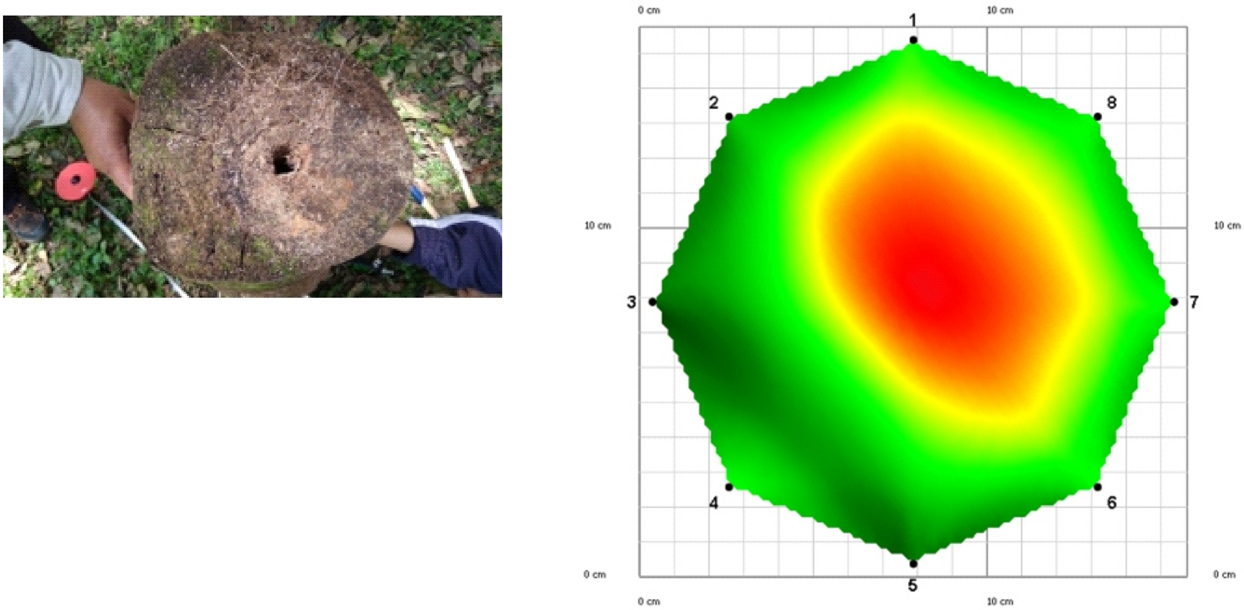

Figure 5 Inside tree trunk show decayed condition which represented with yellow and red color.

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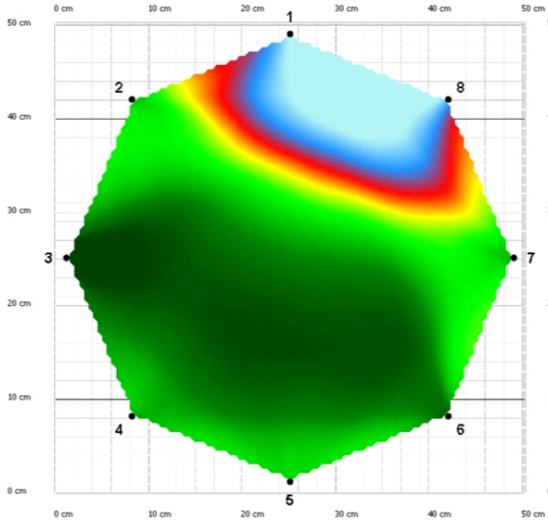

Figure 6 Inside tree trunk show hollow represented with blue color.

Results and Discussion

Tree risk assessment From 497 trees observed, there were 170 trees with low risk and 327 trees with moderate risk (Figure 7). High-risk trees were not found in this observation. This is because the assessment only focusses on visual observation, which cannot detect high-risk damage to the tree.

Since visual observation results are not enough, a further check with ArborSonic acoustic 3D tomography is done for selected trees. The results showed that seven trees were classified as high-risk trees comprise of *Casuarina junghuhniana*, *Enterolobium timbouva* (two trees), *Toona sureni*, *Cinnamomum burmanni*, *Cupressus arizonica,* and *Ehretia javanica*., seven moderate risk trees comprise of *Cupressus lusitanica* (two trees), *Enterolobium timbouva*, *Cinnamomum camphora*, *Araucaria* sp., *Prunus puddum,* and *Cinnamomum camphora*, and 24 low-risk trees comprises of the remain sample tree (Table 2). Determination of tree-level damage using ArborSonic is done based on Helmanto et al., (2018) which classifies high risk if the percentage of tree damage is above 60%, moderate risk if the percentage is between 30–60% and low risk if the percentage of hollow trees is below 30%. Mostly the highest percentage of wood decay occurred on ground level or at the base of the trunk (Table 2). This result similar to Makys et al. (2018), who mention that wooden poles fixed in and covered up with soil are the most damage after checked with sonic Tomograph.

Height and diameter tree able to determine the slenderness ratio. According to slenderness ratio classification by Mattheck & Bethge, (2011), *Syzygium polyanthum*, *Causarina junghuhniana*, *Araucaria cunninghamii* and *Araucaria heterophylla* has a higher risk of fallen trees than other trees because it has a ratio more than 50 (Table 2). This result is higher compare with *Pterocarpus indica*, which has a ratio below 50 (Puspitasari, 2014). Besides the slenderness ratio, the type of tree also determines

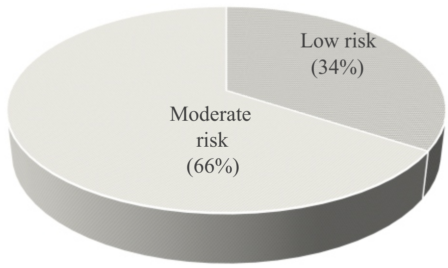

Figure 7 Proportion of tree risk based on visual observation.

the resistance to the winds. Jelonek et al. (2012) stated that the type of needle leaf (scots pine) that grows in northern Poland forests is still considered stable despite having a slim value of 66–81. This means *Casuarina junghuhniana*, *Araucaria cunninghamii*, and *Araucaria heterophylla* in Bali Botanical Garden still considered stable compare with *Syzygium polyanthum. Casuarina* and *Araucaria* have a needle leaf type, while *Syzygium polyanthum* has a broadleaf.

Furthermore, tree morphological character such as tree slenderness and canopy diameter have a weak relation with ArborSonic inspection results. Trees with a high risk based on ArborSonic do not have a high tree slenderness ratio, whereas trees with low risk based on ArborSonic have a high tree slenderness ratio (Table 2). The correlation between the slenderness ratio and the level of risk is weak because R^2 = 0.28, p < 0,1. However, when correlating between tree canopy diameter and ArborSonic result checked, there is also a week correlation because $R^2 = 0.02, p < 0.1$. This is because ArborSonic only detects the percentage of wood decay inside the trunk based on species character. This result also in line with Zuhri et al. (2018), who said even the tree visually shows the poor condition, not always correlate with ArborSonic result.

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Table 2 The result of tree health assessment with ArborSonic

No	Species name	Notes	Morphological character				Arbosonic result					
			Canopy diameter (m)	DBH (cm)	High (m)	Slenderness ratio	1st height from ground level (cm)	Decay (%)	2nd height from ground level (cm)	Decay (%)	Max decay	Level of destructive
1	*Casuarina junghuhniana* Miq. (Casuarinaceae)	XIII.E.30	19.2	116.6	41.8	35.85	0	58	100	64	64	1
2	*Enterolobium timbouva* Mart. (Leguminosae)	XIII.E.31	15.5	102.3	35.8	35.00	30	55	60	62	62	1
3	*Toona sureni* (Meliaceae)	Non-collection	14	76	21	27.63	0	62	50	64	64	1
4	*Cinnamomum burmanni* (Nees & T.Nees) Blume (Lauraceae)	XIII.E.34	12.5	71.4	14.6	20.45	0	62	50	63	63	1
5	*Cupressus arizonica* Greene (Cupressaceae)	XIII.E.45	12.3	94	15.2	16.17	25	66	75	50	66	1
6	*Enterolobium timbouva* Mart. (Leguminosae)	XIII.E.31	12	145.5	33.6	23.09	30	49	90	63	63	1
7	*Ehretia javanica* (Boraginaceae)	Non- collection	10	72	22.5	31.25	0	63	50	56	63	1
8	*Cupressus lusitanica* Mill (Cupressaceae)	XIII.E.47	15	89	13.8	15.51	0	55	50	49	55	2
9	*Cupressus lusitanica* var. *benthamii* (Endl.) Carrière (Cupressaceae)	XIII.E.37	11.7	190	24	12.63	0	55	50	51	55	2
10	*Enterolobium timbouva* Mart. (Leguminosae)	XIII.E.31	16	119.4	35.4	29.65	0	48	50	10	48	2
11	*Cinnamomum camphora* (L.) J.Presl (Lauraceae)	XIII.E.33	16.5	169	30.6	18.11	0	60	60	58	60	2
12	*Araucaria* sp. (Araucariaceae)	Non-collection	11	86.2	31.2	36.19	25	1	100	43	43	2
13	*Prunus puddum* (Rosaceae)	Non-collection	13.5	80	13.5	16.88	0	50	80	42	42	2
14	*Cinnamomum camphora* (L.) J.Presl (Lauraceae)	XIII.E.33	19.5	152	34.8	22.89	0	47	50	6	47	2
15	*Casuarina junghuhniana* Miq. (Casuarinaceae)	XIII.E.30	17	92.5	46.8	50.59	0	6	100	13	13	3
16	*Araucaria cunninghamii* Mudie (Araucariaceae)	XIII.E.19	9.8	78	36	46.15	25	20	50	5	20	3
17	*Ehretia javanica* (Boraginaceae)	Non-collection	10	97.8	33	33.74	0	26	100	11	26	3
18	*Agathis borneensis* Warb. (Araucariaceae)	XIII.E.38	7	110.1	36.8	33.42	0	6	50	0	6	3
19	*Agathis borneensis* Warb. (Araucariaceae)	XIII.E.38	7	89.5	36.8	41.12	0	0	100	5	5	3
20	*Araucaria cunninghamii* Mudie (Araucariaceae)	XIII.E.19a	13.25	60	29.6	49.33	25	0	50	3	3	3
21	*Araucaria cunninghamii* Mudie (Araucariaceae)	XIII.E.8	14	76	25.4	33.42	0	0	100	0	0	3
22	*Araucaria cunninghamii* Mudie (Araucariaceae)	XIII.E.8	14	59	26.2	44.41	0	0	100	0	0	3

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Table 2 The result of tree health assessment with ArborSonic (continued)

No	Species name	Notes	Morphological character				Arbosonic result					
			Canopy diameter (m)	DBH (cm)	High (m)	Slenderness ratio	1st height from ground level (cm)	Decay (%)	2nd height from ground level (cm)	Decay (%)	Max decay	Level of destructive
23	*Araucaria cunninghamii* Mudie (Araucariaceae)	XIII.E.10/19	8	58.6	33.6	57.34	0	1	100	4	4	3
24	*Araucaria heterophylla* (Salisb.) Franco (Araucariaceae)	XIII.E.28	8	84.4	43.2	51.18	30	12	100	1	12	3
25	*Casuarina junghuhniana* Miq. (Casuarinaceae)	Non-collection	12	77.2	40	51.81	0	8	100	3	8	3
26	*Pinus massoniana* Lamb. (Pinaceae)	XIII.E.7	12.5	80.47	35.2	43.74	0	0	100	0	0	3
27	*Taxodium huegelii* C. Lawson (Cupressaceae)	XIII.E.32	17	129.2	32.8	25.39	0	13	50	2	13	3
28	*Ficus benjamina* L. (Moraceae)	Non-collection	23.5	136	26	19.12	0	6	100	11	11	3
29	*Sloanea sigun* (Elaeocarpaceae)	Non-collection	16.5	78.3	21	26.82	0	4	100	10	10	3
30	*Syzygium polyanthum* (Myrtaceae)	Non-collection	15.4	60.3	23.2	38.47	0	4	100	2	4	3
31	*Syzygium polyanthum* (Myrtaceae)	Non-collection	7.25	66.5	26	39.10	0	8	100	0	8	3
32	*Syzygium polyanthum* (Myrtaceae)	Non-collection	16.5	62.3	33	52.97	0	4	100	0	4	3
33	*Syzygium polyanthum* (Myrtaceae)	Non-collection	11.5	71	32	45.07	0	6	100	4	6	3
34	*Syzygium polyanthum* (Myrtaceae)	Non-collection	12.5	65	26	40.00	0	8	100	5	8	3
35	*Syzygium polyanthum* (Myrtaceae)	Non-collection	11.5	69	23.4	33.91	0	0	100	3	3	3
36	*Syzygium polyanthum* (Myrtaceae)	Non-collection	13.3	51.7	34	65.76	0	1	100	7	7	3
37	*Syzygium polyanthum* (Myrtaceae)	Non-collection	13.5	64	46	71.88	0	8	100	6	8	3
38	*Syzygium polyanthum* (Myrtaceae)	Non-collection	14.1	73.5	24	32.65	0	4	100	1	4	3
39	*Syzygium polyanthum* (Myrtaceae)	Non-collection	17	77	27	35.06	0	9	100	5	9	3
40	*Syzygium polyanthum* (Myrtaceae)	Non-collection	14	59.5	30	50.42	0	3	100	0	3	3
41	*Toona sureni* (Meliaceae)	Non-collection	15.6	77	22.2	28.83	0	4	100	3	4	3
42	*Dacrycarpus imbricatus* (Podocarpaceae)	Non-collection	12	61	20.5	33.61	0	1	100	6	6	3
43	*Dacrycarpus imbricatus* (Podocarpaceae)	Non-collection	12	50.75	19	37.44	0	20	na	na	20	3
44	*Dacrycarpus imbricatus* (Podocarpaceae)	Non-collection	9	49.5	22	44.44	0	3	100	1	3	3

Note: na = not available

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Trees with visual assessment from high-risk tree exhibit symptoms of deterioration such as the weathered trunk, moist trunk, codominant and have a litter in tree branches and have hollow in the base of the tree trunk (Table 3) Only one high-risk tree shows a healthy trunk, that is *Toona sureni* from Meliaceae family. Since we cannot find damage on the trunk, we suggest wood termite and borer attack cause the hollow inside trunk. This pest is common to attack *Toona sureni* (Lemmens, 1995). However, ArborSonic measurement will support visual assessment results.

Cause of tree failure There are many ways for trees to fail. According to Albers et al. (2003), a fail tree occurs when the load (weight and canopy motion) exceeds the mechanical strength of a branch, trunk, or root system. Some fail tree incidents lead to fallen trees or broken tree branches in BBG due to root problems and branch problem (Figure 8). This is following Albers et al. (2003), who mention that a fail tree can be predicted because the sign of damage indicates that the part of the tree will fail. There are seven signs of damage to trees, namely: rotted wood, crack, root problems, cancer (areas where the bark or cambium dies), poor tree architecture, weak branch unions, dead trees/branches.

Plant collection in BBG is mostly obtained from the forest in seedling, then acclimatize in the nursery at BBG. During acclimatization, the seedlings are planted in polybags. This practice may cause root growth disrupted, especially in taproots. Therefore, plant collection which grows in the field will have shallow root. Then when strong winds come, this will lift the shallow root tree (Figure 8B). Pokorny (2003) states that 84% of trees' damage caused by windstorms already had signs of previous damage to trees and branches. One effort to avoid the catastrophic effect of strong winds is by planting trees in groups rather than individuals.

Furthermore, the cause of fallen trees in BBG is weak branch unions' support with termite attack. A tree with more than two branches has the potency to fail one of these branches. Figure 8A shows that a branch of *Joannesia princeps* has falled. This incident was alleged because of weak branch unions' support due to termite attack. We suggest it from the symptom, such as a presence of tunnels inside the base of the trunk.

Moreover, some tree also has an epiphyte plant on a limb and cause weathering. This limb susceptible to fall when the strong wind. This result is in line with Puspitasari (2014),

Table 3 Visual assessment of high-risk tree with ArborSonic

Name of species	Visual Assessment
Casuarina junghuhniana	Weathered trunk
Enterolobium timbouva Mart.	Codominant, and has litter in tree branches
Toona sureni	Healthy trunk
Cinnamomum burmanni (Nees & T.Nees) Blume	Hollow in the base of tree trunk
Enterolobium timbouva Mart	Codominant
Cupressus arizonica	Dry limb
Ehre tia javanica	Hollow in the base of the tree trunk

(A)

(B)

Figure 8 Fail branch of *Joannesia princeps* (A) and uproot tree (B).

which mention weathering also found as the most visual deterioration in *Pterocarpus indicus* at Surabaya street. Ephyphite plant on the tree will cause weathering in the tree surface for a long period.

Tree risk management A failure tree is unpredictable. Therefore regular tree risk management is mandatory. Tree risk management consists of tree risk inspection and tree risk assessment. This is an activity that started with visual tree assessment and continues with ArborSonic measurement. For high-risk locations, inspections are carried out more often than low-risk locations. Strategies to reduce high-risk trees in the public area are moving targets such as benches and installing dangerous tree signs. Pokorny (2003) states that tree risk management should be integrated with planting, pruning, tree maintenance, and rapid response activities. Several things that can be done to avoid losses due to failure trees started from choosing the quality of the plant, correct planting technique, proper pruning technique, and protect trees from damage to construction (Johnson et al., 1999).

Conclusion

Modern technology can be used to minimize the risk of tree failure to individual injury and property. Visual assessment is not enough to detect a failure tree. Therefore, ArborSonic measurement will support visual assessment. Tree risk assessment initiated with tree inspection and continue with ArborSonic measurement is suggested to be done regularly, especially in the public area. The result of tree assessment classified location into high-risk, moderate-risk, and low-risk. Strategies to reduce high-risk trees in public areas are by moving targets such as benches and installing high-risk tree signs.

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