The detection of wood decay of trees collection Agathis borneensis and Castanopsis argentea at the public area in Cibodas Botanical Garden

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Abstract. Due to tree hazard risk, the collection of living plant species in the public area of Cibodas Botanical Garden should be detected. The objective of this research was to assess the existence of wood decay in the stand of Agathis borneensis and Castanopsis argentea tree using visual investigation and Arborsonic measurement technology. Six A. borneensis (20 to 36 m tall) and three C. argentea (16 to 26 m tall) trees were evaluated visually and measured for percentage of decay area. Visual report of A. borneensis indicated that 17% of the root, root collar and crown collar were in damaged and decayed condition; 33% trunk was in damaged and cracked condition; and 83% crown was in dry to damaged limb condition. Visual evaluation of C. argentea showed that the trunk, crown collar and crown were in poor condition. The ArborSonic 3D® measurement indicated a decayed area ranging from 0-10% and 39-71% for A. borneensis and C. argentea respectively. Only one C. argentea tree indicated a high risk from tree fallen. The others showed a low risk although visually were reported in poor condition. It was caused by Arborsonic risk rating resulted from the percentage decayed area and the safety factor not including the health condition of the tree. Moreover, more attention is required to prevent tree’s falling hazard from living plant species of Cibodas Botanical Garden.

1. Introduction
Due to maintaining the structural safety, standing trees must be evaluated [1,2]. One method to assess potential hazard of stress is measuring the internal decay [3]. The visual tree assessment is required to find external symptoms of internal decay and if there are any symptoms detected, the related decay has to be confirmed and measured by further inspection, e.g. measuring sound waves traveling through tomography, drilling methods and using a fractometer to measure the strength of the remaining healthy wood [4].

ArborSonic® is a non-destructive evaluation tool for trees. It works based on estimation of sound velocity between sensors around the trunk. Furthermore, the ArborSonic® decay detector is supporting the ultrasound moves in firm substances, in sound of wood, the signal moves at a speed of approximately 2,000 m/sec through the cell walls. Because the sound velocity decreases in the internal decayed areas, the internal holes can be identified and the steadiness of the tree can be assessed [5].

This research observed two tree species, i.e. Agathis borneensis and Castanopsis argentea which were planted on the road side and areas usually have many visitors. A. borneensis distributed naturally in the Malaysian Peninsular, Sumatra, Borneo and Kalimantan. Based on the IUCN red list, it conservation status is endangered A4cd ver 3.1 [6]. A. borneensis occurs in lowland to mountain tropical rainforest as emergent trees. C. argentea is a large tree up to 35-40 m with tasty edible seeds.
which belongs to the Fagaceae family. It is distributed naturally in India, China, Korea, Japan, Thailand, Indonesia and Malaysia. *C. argentea* is dominant in the primary forest in Java at 150-1750 m asl.

Due to both public safety and tree protection, detection of wood decay in the plant living collection in Cibodas Botanic Garden is needed for detecting damage and defect in living trees. The purpose of this study was to assess wood decay in *A. borneensis* and *C. argentea* of plant living species in the public area of Cibodas Botanic Garden using visual investigation and acoustic tomograph of ArborSonic 3D®.

2. Materials and methods

This study was conducted in 2015 as a response to the potential hazard of the large *Agathis borneensis* and *Castanopsis argentea* trees at the Cibodas Botanic Garden, Indonesia. Several years ago for the same tree species in Bogor Botanic Garden, there were found structural damage to the trees due to termite attack which injured several visitors. Nine trees located in the crowded areas, i.e. garden areas (vak) III, VI, VII, IX, XII and XIV were selected in this study for the detection and evaluation of tree decay which consisted of six *A. borneensis* (19.6 to 36.2 m tall) and three *C. argentea* (16.2 to 25.6 m tall) as displayed in Table 1.

| Tree species   | Location | Crown area* (m²) | Tree height (m) | Dbh (cm) | Degree of lean** (°) |
|---------------|----------|------------------|----------------|---------|---------------------|
| *A. borneensis* | III.A.4a | 243.8            | 34.6           | 143.7   | 85                  |
| *A. borneensis* | III.A.4b | 203.6            | 36.2           | 157     | 90                  |
| *A. borneensis* | III.A.4c | 9.5              | 35.8           | 153.5   | 90                  |
| *A. borneensis* | XI.A.1   | 55.9             | 24             | 250     | 90                  |
| *A. borneensis* | XII.B.2  | 64.4             | 19.6           | 107     | 90                  |
| *A. borneensis* | XIV.A.7b | 108.1            | 19.6           | 250     | 90                  |
| *C. argentea*   | VI.E.18  | 370              | 25.6           | 110     | 75                  |
| *C. argentea*   | VI.E.18b | 55               | 16.2           | 420     | 60                  |
| *C. argentea*   | VII.B.28 | 62.8             | 21.8           | 142.5   | 90                  |

* the area of crown cross-section facing the wind
** the angle between the horizontal and the trunk, 90° mean the trunk is vertical

The structural stability of two tree species was evaluated based on visual investigation and acoustic tomograph of ArborSonic 3D®. Visual inspection was to detect root and trunk decay, crown conditions and as well as anomalies which appear as signals and symptoms such as fungal presence, cavities, bulges and root collar problems. A rubber hammer was knocked to the trunk to help detect trunk decayed which can not be seen visually. Decay on the interior part of the trunk was caused by an empty sound which is different from the solid stem. Usually, visual inspection was done by a minimum of 4 persons to obtain accurate evaluation of tree’s health condition.

Further assessment of internal trunk defects using a tomograph was conducted with ArborSonic 3D®. The step to use ArborSonic 3D® were: (1) eight transducers were driven through the bark using a mallet with equal distance around the trunk; (2) distance between the transducers were measured with a caliper and recorded in the computer; (3) each transducer was tapped with a small steel mallet to generate sound waves; and (4) the program was calculated and displayed the internal sound-velocity distribution of the tree. To get accurate, it is important to assess the tree in several layers. Tomogram results were showed in graphics with green color showed intact, red color showed decayed and blue color showed hollow trees. The results of the ArborSonic® to a decayed area of more than 50% and safety factor less than 100% is categorized as high risk rating. A decayed area is the percentage of an area of decay compared to the total area of the selected layer. Meanwhile, the safety factor is the ratio of maximum stress in the trunk in the selected layer and in the yield strength [5].
3. Results and discussion

Table 2 displays a visual inspection which pointed out the wood decay evaluation on *A. borneensis* and *C. argentea*. The average visual report of *A. borneensis* in this study indicated that 17% of the root and root collar, as well as the crown collar was in damaged and decayed condition; 33% of the trunk in was in damaged and cracked condition; and 83% of the crown was in dry to damaged limbs condition. Generally, the *A. borneensis* was in good condition except for one in XII.B.2 with its root damaged, trunk cracked, pruned crown, dry and hollow limbs. Dry and damaged limbs conditions may be caused by difficulty to prune since *A. borneensis* tree can reached 36.2 m in height.

*A. borneensis* revealed several decays especially in the crown as displayed in table 2 and figure 1 i.e. dry limbs, one-sided canopy, damaged limbs, hollow limbs and pruned. *A. borneensis* III.A.4a indicated a one-sided crown, damaged main trunk and damaged limb. *A. borneensis* III.A.4b indicated a one-sided crown and damage to the main trunk. *A. borneensis* III.A.4c showed a one-sided canopy and a decayed root collar caused by a slash from a sharp object. *A. borneensis* XIX.1 showed that the main trunk was forked, aone-sided canopy, root blocked by a wall of water and dryed limbs. *A. borneensis* XII.B.2 showed a tree located inside the large wall cement pot on the road side which can limit the roots absorption to water and nutrients. Moreover, *A. borneensis* XII.B.2 showed a one-sided canopy, a collar root exposed and a released clear sap, a cracked bark and a released sap and mouldy on pruned limb. *A. borneensis* XIV.A.7b showed a one-sided canopy, a root collar blocked by the wall and road, a tree tilted to the north and any parasitic plant at its trunk.

Table 2. The results of the visual inspection is the detection of wood decay of *A. borneensis* and *C. argentea*.

| Tree speies     | Location  | Root     | Root collar | Trunk     | Crown collar | Crown                  |
|-----------------|-----------|----------|-------------|-----------|--------------|------------------------|
| *A. borneensis* | III.A.4a  | Intact   | Intact      | Intact    | Intact       | Dry limbs, One-sided   |
| *A. borneensis* | III.A.4b  | Intact   | Intact      | Damaged   | Intact       | Damaged limbs          |
| *A. borneensis* | III.A.4c  | Intact   | Decayed     | Intact    | Intact       | Dry limbs, Damaged     |
| *A. borneensis* | XIX.1     | Intact   | Intact      | Cracked   | Damaged      | Pruned, Dry limbs, One-sided |
| *A. borneensis* | XII.B.2   | Damaged  | Intact      | Cracked   | Intact       | Pruned, Dry limbs, Hollow limbs |
| *A. borneensis* | XIV.A.7b  | Intact   | Decayed     | Dense     | Hollow       | Pruned, Dry limbs, Damaged limbs, One-sided |
| *C. argentea*   | V.XE.18   | Intact   | Decayed, Slanting | Decayed, Hollow | Decayed, Hollow, Hollow |
| *C. argentea*   | V.XE.18b  | Intact   | Decayed, Hollow, Slanting | Decayed, Hollow |
| *C. argentea*   | VII.B.28  | Intact   | Decayed, Hollow | Damaged, Hollow | Damaged, Decayed, Hollow |

Visual evaluation of the *C. argentea* showed that the trunk, crown collar and crown was in poor condition i.e. damaged, decayed, slanting, hollow, pruned, dry limbs, decayed limbs, damaged limbs and a one-sided canopy as displayed on figure 2 and noted in table 2. *C. argentea* X.IE.18 showed a decay in the stem bark (bark exposed from the root collar to a height of 2.5 m), hollow in the stem base, termite infestation at the root collar, damaged and decayed limbs. *C. argentea* V.XE.18b showed hollowness from the root collar to the trunk height of 1.2 m, mouldly inside the hollow trunk, the bark exposed, the decayed and damaged crown collar, attached by a parasitic plant, decayed limbs, decayed and damaged main trunk. Moreover, *C. argentea* V.XE.18b is located in a sloping area. *C. argentea* VII.B.28 indicated hollowness in the stem base with a height of 50 cm from the ground, a decayed trunk, the bark exposed, mouldy in the main trunk, a damaged and decayed crown collar and decayed limbs.
Figure 1. 1.a one-sided crown A. borneensis III.A.4a; 1.b damaged limb A. borneensis III.A.4a; 1.c damaged trunk A. borneensis III.A.4b; 1.d decayed root collar A. borneensis III.A.4c; 1.e one-sided crown A. borneensis XI.A.1; 1.f dry limbs A. borneensis XI.A.1; 1.g a one-sided crown and a tree inside the large cement pot of A. borneensis XII.B.2; 1.h crack bark A. borneensis XII.B.2; 1.i decayed limb A. borneensis XII.B.2; 1.j tilted tree A. borneensis XIV.A.7b; 1.k root A. borneensis XIV.A.7b blocked by the road and trash bin.

ArborSonic 3D® is used for advanced detection in order to indicate the decayed area in a range of 0-10% and 39-71% for A. borneensis and C. Argentea, respectively (table 3). Only one tree of the C. argentea showed a high risk from the fallen tree i.e. VI.E.18. The others showed a low risk although visually reported their poor condition. It was caused by Arborsonic risk rating which had resulted from the percentage of the decayed area and the safety factor which does not include tree’s healthy condition. Although ArborSonic measurement showed that there was a low risk for the majority of a large tree with poor condition in the public area, more attention is required to prevent the hazard of falling from the tree from living plant species of the Cibodas Botanic Garden.

Figures 3 to 8 display tomograms and corresponds to the decayed area (%) and the safety factor (%). Figures 3, 4 and 5 displays the tomograms of A. borneensis and figure 6, 7 and 8 displays the tomograms of C. argentea with two height layers. Green indicated that the trunk was intact/undamaged, red indicated the decayed trunk and blue indicated the hollow trunk. A. borneensis trees dominated by a green area which displays the intact trunk and the risk rating for all A. borneensis in this research was low risk. Center part tomograms of A. borneensis III.A.4a, III.A.4b and XI.A.1 showed a yellow and orange side which displayed a trunk almost decayed with a decayed area of 0-
5%, 3-7% and 2-6% respectively and a low risk rate. Tomograms of *A. borneensis* XII.B.2 and XIV.A.7b were slightly hollow and decayed at two points in the periphery of the stem. Tomogram of *A. borneensis* III.A.4c showed slightly a hole and spread to the center of the stem.

![Images of trees with various defects](image)

**Figure 2.** 2.a hollow trunk *C. argentea* VI.E.18; 2.b decayed trunk *C. argentea* VI.E.18; 2.c *C. argentea* VI.E.18 bark peeled; 2.d hollow and decayed trunk *C. argentea* VI.E.18b; 2.e slanting trunk *C. argentea* VI.E.18b; 2.f brown root rot *C. argentea* VI.E.18b; 2.g hollow crown collar *C. argentea* VI.E.18b; 2.h hollow trunk *C. argentea* VII.B.28; 2.i decayed trunk *C. argentea* VII.B.28; 2.j damaged limbs *C. argentea* VII.B.28.

Three trees of *C. argentea* tomograms displayed decayed areas ranging from 39% to 71% and safety factors ranging from 94% to 2392%. Because the safety factor is the ratio of the maximum stress in the trunk and the yield strength and depends on the tree species and wind load calculation, therefore, the range is very wide. Two of the *C. argentea* resulted a low risk rating and one of the *C. argentea*, i.e. VI.E.18, resulted a high risk. High risk means it is supposed to be slashed to prevent hazard of falling trees and for the reason of public safety. It is located near the main attactive place in Cibodas BG, i.e. pond with Mt. Gede Pangrango background view so the main attention from the manager is required to protect visitor safety. Prevention through the installation of dangerous tree hazard signs in the area around the tree was done as a notification for visitors.
Although two of the *C. argentea* resulted low risk of the ArborSonic measurement report, it should receive full attention, because their tomograms showed most of the trunk area under the height of 100 cm was blue which indicated that it was hollow (figure 7 and 8). It also showed the decayed area trend decreased with increasing layer height, e.g. 71% (at 60 cm height) to 56% (at 130 cm height). It also informed the infection begins from the root system spreading upwards.

*C. argentea* decay might be caused by: (1) termite infestation which found termite flakes on the root collar; (2) brown root rot found inside the hollow trunk; (3) tree age of almost fifty years; and (4) tree location and surrounding condition which does not fully support the healthy tree structure. Field observation showed that a tree infected by a brown root rot which was discovered in the base of trunk.

The existing fungal fruiting bodies indicated advanced decay [7].

### Table 3. ArborSonic 3D® measurement report.

| Tree species | Location     | Layer | Layer height (cm) | Decayed area (%) | Safety factor (%) | Risk rating |
|--------------|--------------|-------|------------------|------------------|------------------|-------------|
| *A. borneensis* | III.A.4a     | #1    | 80               | 5                | 702              | Low risk    |
|               |              | #2    | 120              | 0                | 709              | Low risk    |
| *A. borneensis* | III.A.4b     | #1    | 80               | 3                | 613              | Low risk    |
|               |              | #2    | 120              | 7                | 569              | Low risk    |
| *A. borneensis* | III.A.4c     | #1    | 80               | 10               | 11976             | Low risk    |
|               |              | #2    | 120              | 0                | 12313             | Low risk    |
| *A. borneensis* | XI.A.1       | #1    | 60               | 2                | 884              | Low risk    |
|               |              | #2    | 160              | 6                | 1008              | Low risk    |
| *A. borneensis* | XII.B.2      | #1    | 60               | 6                | 3223             | Low risk    |
|               |              | #2    | 120              | 1                | 2672             | Low risk    |
| *A. borneensis* | XIV.A.7b     | #1    | 60               | 3                | 723              | Low risk    |
|               |              | #2    | 120              | 2                | 633              | Low risk    |
| *C. argentea*  | VI.E.18      | #1    | 80               | 67               | 210              | Low risk    |
|               |              | #2    | 180              | 54               | 94               | High risk   |
| *C. argentea*  | VI.E.18b     | #1    | 60               | 71               | 353              | Low risk    |
|               |              | #2    | 130              | 56               | 311              | Low risk    |
| *C. argentea*  | VII.B.28     | #1    | 100              | 59               | 1518             | Low risk    |
|               |              | #2    | 180              | 39               | 2392             | Low risk    |

The result of the tomography was used to support visual evaluation. More decayed areas in visual investigation, usually also were denoted by lower safety factors in a tree. Lin *et al.* [2] reported tomography underestimates the inner rot and overestimates that in the edge of the stem. Therefore, to make better estimation of internal decay, more effective methods should be adopted in order to enhance the accuracy of the data. Moreover, Xu *et al.* [5] also reported ArborSonic cannot be used to detect the decay of the wetwood in oak trees with enough certainty.

![Figure 3. Tomograms of *A. borneensis* III.A.4a (left); III.A.4b (right).](image-url)
Figure 4. Tomograms of *A. borneensis* III.A.4c (left); XI.A.1 (right).

Figure 5. Tomograms of *A. borneensis* XII.B.2 (left); XIV.A.7b (right).

Figure 6. Tomograms of *C. argentea* VI.E.18 layer 1 (left); layer 2 (right).
4. Conclusion
Both visual assessment and acoustic tomograph of the ArborSonic 3D® indicated that generally A. borneensis has a minor decay with a low risk and percentage of the decayed area ranging 0-10%. C. argentea have serious decay in the trunk from low to high risk. It shows by the majority of the tomograms in the trunk area under the height of 100 cm was blue which indicated that it was hollow.

Acknowledgment
We would like to thank the Head of the Cibodas Botanic Garden who allowed this research and funded this research through institution internally fundation. We also thank to Abdurrahman, ST and Bapak Ade from forest products research and development center, Ministry of Environment and Forestry Republic of Indonesia whose fully assisted during field research.

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