The assessment of canary trees in the Bogor Botanic Gardens using forest health monitoring and sonic tomography methods

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Abstract. Canary trees (*Canarium indicum* L.) at the Bogor Botanic Garden are some of the old trees that need to be assessed in term of tree health due to its impact to public safety. The study aims to determine the healthy condition of canary trees using two methods: Forest Health Monitoring (FHM) from USDA and the sonic tomography method, and also to develop a correlation between the assessments by those two methods. The FHM focuses on visual assessment using one parameter through dividing the tree in some locations from roots to bole, while sonic tomography were carried out using technology based on sonic characteristic. Statistical analysis were conducted through developing regression models between two methods. The assessment were conducted in three locations (root, stump, and bole) of 35 samples of canary trees. The result showed that based on FHM method, the Tree Damage Level Index had an average value of 4.3 (±1.2), while the damage to the wood found from using the sonic tomography method had an average value of 19.1% (±25.5). There was a correlation between FHM and sonic tomography at a damage location 1 (r=0.5), location 2 (r=0.7) and location 3 (r=0.8). This study proved the acceptability of the FHM method as well as sonic tomography to assess the tree condition.

1. Introduction

Human needs of the green areas are increasing every year. It is known from the increasingly crowded people visiting city parks, urban forests or natural touristic areas. Bogor Botanical Gardens as an ex situ plant conservation area became a popular tourist spot. In 2008, the visitors are 796,714 tourists, then increased to become 1,104,813 tourists in 2014. The collections of large trees make this area very cool and attractive for tourists. However, many of these trees are old and have damage problems. The damages such as open roots, decay of stems and broken branches. They (the damage) may cause the trees to fall which is very dangerous for people around them. Recently, many natural disasters caused by fallen trees can cause death. Therefore, early attempts are required to prevent the occurrence of these similar disasters.

The first step in the prevention of fallen trees is the assessment of the condition of the tree. Assessment of the damage is done thoroughly to the condition of the tree from roots, stem, branching to the overall canopy [1]. This should be done because every part of the tree could potentially be damaged. Collaborative experts have created various methods for assessing the condition of the trees. Forest Health Monitoring (FHM) is one of the methods applied in various international forest conditions [2]. This method allows researchers, communities, or countries to develop their own systems in monitoring the health of the forest [3].

The canary trees (*Canarium indicum* L.) were planted on both sides of the main gate when entering the Bogor Botanical Garden. Some of them are over 100 years old and have been damaged. Such conditions may be dangerous for visitors passing underneath. To make comfortable conditions and ensure the safety of visitors, there is a need for sustainable tree health monitoring activities. Mitigation

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is done by studying one of the indicators (tree vitality) with one parameter that is the damage of the tree (the location of damage and its cause). The FHM that studies more in-depth only one indicator or parameter is called Research on Monitoring Technique (RoMT). This technique is done to obtain a deeper picture of one indicator. Therefore, it is necessary to conduct a study to explore a single indicator of damage using measurable parameters of visual observation of tree damage.

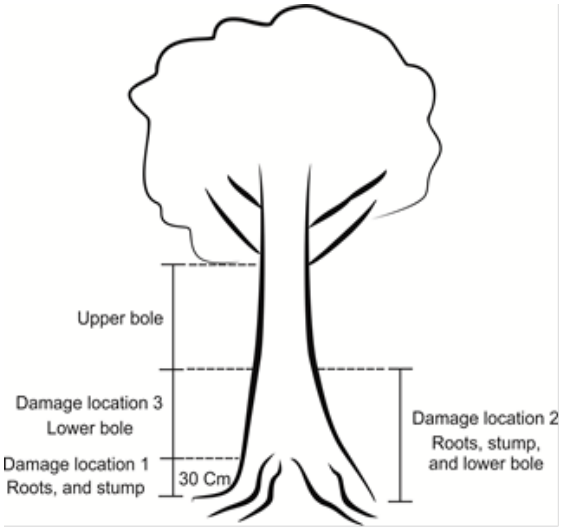
The damages inside the bole could not be monitored directly from the outside. In fact, many fallen trees are caused by the decay inside the bole. Therefore, it is necessary to assess the damage inside the boles using technology, one of which is sonic tomography technology. This method is very effective in evaluating the damage in the stem because of its very high accuracy. There is a high correlation between the amount of damage detected by sonic tomography with the amount of damage found in the cross section of *Querqus alba* and *Carya* spp. [4]. One limiting factor of this testing method is the assessment of tree damage with sonic tomography which requires special skills and a high cost in the procurement of the tool.

This study aims to assess the damage of canary trees using the FHM and sonic tomography technologies, as well as to find a correlation of both methods. The combined use of these two methods to find a simple and inexpensive way, but has a high accuracy in monitoring tree health. The result of this study is supposed to solve the problem of plant collection management.

2. Method

This research used two methods in assessment the condition of canary tree, those were Forest Health Monitoring (FHM) and sonic tomography methods. FHM assessment was done using visual indicator (tree vitality) with one parameter of tree damage. Assessment of tree damage was done at the location 1, 2 and 3 of the lower bole. Location of damage 1 is the root area of 0.91 m radius from the stem to 0.3 m height from the ground (stump). Location 2 are root area, stump and lower bole. Location 3 is lower bole i.e. the bottom half of the bole between stump to the base of the canopy (figure 1). The type of the damage are recorded such as: cancer, gall, conks, fruiting bodies and signs of advanced decay, open wounds, resinosis and gummosis; cracks and seams, termite nest, broken bole or roots, brooms on roots and bole, broken or dead roots [2]. The damage indicator are damage type, location and severity. The tree may have up to three damages, so that becomes Tree Damage Level Index (TDLI). TDLI=[(type1*location1*severity1)+(type2*location2*severity2)+(type3*location3*severity3)].

The sonic tomography method uses the speed parameter of the sound wave in the wood. The damage to the wood of the canary tree is evaluated at level 130 cm or equivalent to location 3. At that location, the canary bole is filled with some nails (6-12) adjusted to the diameter of the bole. Each nail



is connected to the sensor so they can receive sound waves from one tapping of the electric hammer. The tapping of the hammer produces various speeds of sound waves on the logs. The speed of sound waves on decayed wood will be lower than sound waves in solid wood. The speed of the sound wave is illustrated as a tomogram with different colors. Dark (brown black) color illustrates healthy wood, green color illustrates the initiation of wood decay, the purple or blue illustrates the advanced decay.

The results of the sonic tomography assessment is that the tomogram would illustrate the wood damage. The damage was calculated with the ImageJ 1.46r software program. The percentage of damages from the tomogram associated with the Tree Damage Level Index (FHM). The relationship between the two methods is developed by the regression equation model. Both methods are expected to complement each other in evaluating the damage condition of the canary tree.

3. Results

3.1. Assessment of the canary tree damage based on FHM method

Assessment of the damage to the canary tree was done at location 1, 2 and 3 (table 1). The location includes open roots area 91 cm from the stem, the stump to the lower bole. The damages of the canary tree are generally caused by cancer, open wounds and a termite nest. Cancer and open wounds caused damage on the bark. Meanwhile, the fruiting bodies and termites caused decay inside bole.

Table 1. Damage to canary bole based on FHM analysis.

No	Tree Damage	Frequency found		
		Location 1	Location 2	Location 3
1	Cancer, gall	3	2	1
2	Conks, fruiting bodies and signs of advanced decay	4	0	0
3	Open wounds	11	2	3
4	Resinosis or gummosis	0	0	0
5	Cracks and seams	0	2	1
6	Termite nest	1	1	1
7	Broken bole or roots	0	0	0
8	Brooms on roots and bole	0	4	3
9	Broken or dead roots	2	0	0

The damage of location 1 was caused by cancer and gall, fruiting bodies and advanced decay, open wounds, termite nest, and broken or dead roots. Most of the damage were caused by open wounds (11). The roots of canary trees are above the ground. The open wound on roots were caused by human, physical project activities, friction of the grass blades. The damage at location 1 may spread to location 2 and 3, such as the one caused by *Ganoderma* and termites. The damages at location 2 and 3 were caused by cancer and gall, open wounds, broken bole or roots, termite nest, and broom on roots and bole.

3.2. Assessment of canary tree damage based on sonic tomography method

The results of the sonic tomography assessment (table 2) indicated that the highest percentage of the damage to the canary tree reached 76.1% with an average damage of 18.13% (± 21.29%). At damage location 1, Tree Damage Level Index (TDLI) ranged from 3.6 to 4.9, and assessment of the wood damage with sonic tomography showed damage between 2.0% - 74.5%. At the location of damage 2, TDLI ranged from 2.9 to 7.4, and the assessment of wood damage based on sonic tomography ranged

from 2.0% - 76.1%. TDLI of the location 3 ranged from 2.6 to 6.3, and the assessment of wood damage with a sonic tomography ranged from 3.5% - 38.6%.

Table 2. Damage of canary tree based on FHM and sonic tomography methods.

No	Stem diameter (cm)	Tree height (m)	TDLI based on FHM			Damage wood
			Location 1	Location 2	Location 3	Based on Sonic (%)
1	92	36	3.6	3.8	-	2.0
2	60	32	4.2	-	-	5.7
3	62	21	4.9	4.6	-	63.7
4	59	24	3.6	-	-	22.3
5	53	26	3.6	-	-	11.4
6	83	36	3.9	-	-	21.3
7	44	22	3.6	-	-	11.0
8	60	15	3.7	-	-	2.1
9	65	18	4.2	-	-	0.7
10	76	26	3.7	-	-	1.7
11	83	22	4.5	-	-	74.5
12	65	22	4.6	-	-	9.3
13	90	24	4.1	-	-	12.7
14	67	26	3.6	3.9	3.2	5.7
15	110	33	3.6	-	3.6	4.2
16	65	22	3.7	-	-	36.3
17	46	30	3.6	-	-	7.0
18	82	28	3.9	-	-	66.8
19	53.9	30	3.6	-	-	2.4
20	64	36	3.6	-	-	25.0
21	68	18	3.6	-	-	6.1
22	68	20	-	7.4	-	76.1
23	44	23	-	4.8	-	3.8
24	76	26	-	3.6	-	12.2
25	35	15	-	3.5	-	7.0
26	57	26	-	4.8	-	9.3
27	67	19	-	3.5	-	6.8
28	59	17	-	4.6	-	10.5
29	61	25	-	2.9	3.5	13.0
30	70	29	-	-	3.2	22.8
31	70	10	-	-	6.3	38.6
32	67	22	-	-	4.1	28.0
33	89	29	-	-	3.7	20.1
34	60	17	-	-	2.6	5.3
35	67	23	-	-	3.2	3.5

Based on the sonic tomography assessment, there are three highest damage rates (66.8%, 74.5% and 76.1%). Those canary trees have the potential to collapse. The tree damage that has the risk of collapsing can be calculated based on the Matteck's t/R ratio. The t is the width of the healthy wood part and R is the measured log radius. Trees will be categorized as risky when the value of t/R ratio ≤0.3 [5]. To avoid the risk of fallen trees in the Bogor Botanic Garden, the canary trees that have been damaged more than 70% are advised to be handled immediately for visitor safety.

The most dangerous causes of damage are fruiting bodies of *Ganoderma*. Figure 2 displays an example of a *Ganoderma* attack and the tomogram of wood decay in the canary tree. The appearance of fruiting bodies indicates advanced decay inside bole. Advanced decay in the lower bole caused fallen trees when the canopy load is unbalanced. On the tomogram, the black brown color indicates the solid part of the wood that remains only 23.9%, which indicates that 76.1% of the wood have been damaged. The green color indicates the initiation of decay, purple red indicates a decay and the blue color indicates heavy decay.

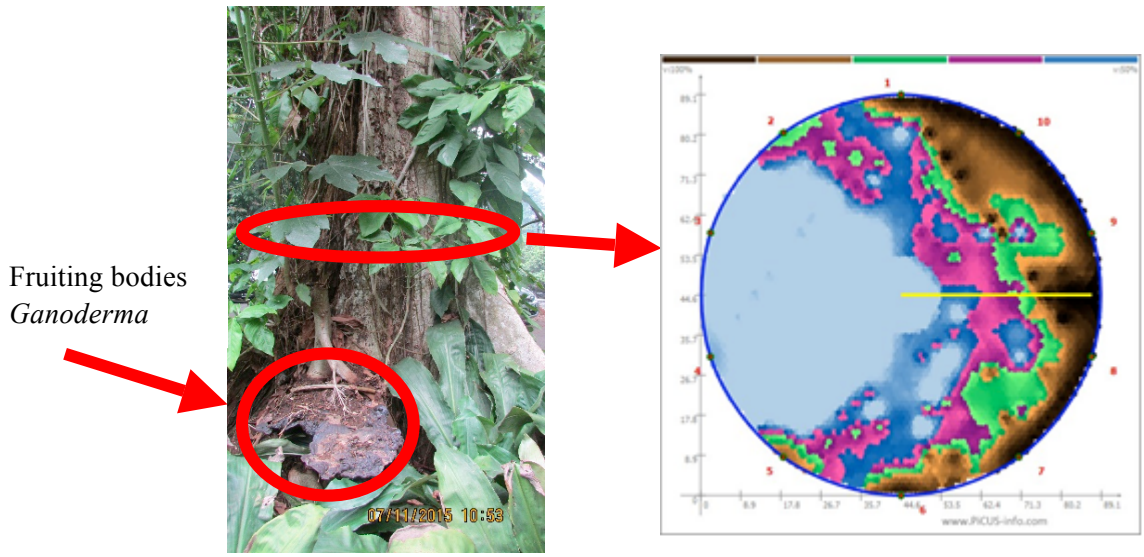


Figure 2. The canary tree was infested by *Ganoderma* (left) and the tomogram (right).

In other tree samples, the canary tree that has a height of 22 m and a stem diameter of 83 cm was infested by termites (figure 3). Heavy decay caused by termites oftenly was not visible from the outside. The termite infested the canary tree from the ground under the stump and continues to the bole. The bark looks intact and does not reveal any termite infestation.

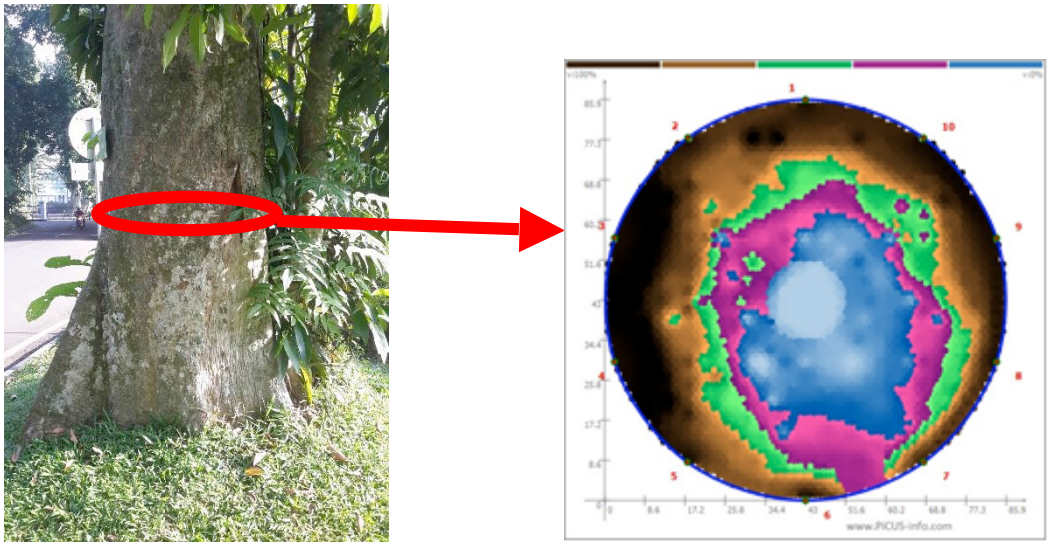


Figure 3. A canary tree infested by termites (left) and tomogram (right)

To determine the percentage of damage inside the bole, the damage assessment is done by sonic tomography. On the tomogram, the black part (25.5%) around it illustrates that the outer part of the stem looks intact. But the middle part (74.5%) suffered damage, ranging from the green color which indicates the initial decay process, the purple -red color indicates the decay, the blue illustrates advanced decay.

3.3. Correlation of sonic tomography and FHM methods

There was a positive correlation between the two methods that were applied on the 35 canary trees (table 3). The higher correlation value was at the damage location 3 where the assessment with the sonic tomography was done.

Table 3. Correlation of sonic tomography and FHM methods.

Correlation of damage (x & y)	Regression model	r
Sonic Tomography vs FHM method at Location 1	y = 0.0090x + 3.7126	0.5
Sonic Tomography vs FHM method at Location 2	y = 0.0334x + 3.6658	0.7
Sonic Tomography vs FHM method at Location 3	y = 0.0721x + 2.5474	0.8

At the damage location 3, the correlation of sonic tomography and FHM methods was very strong (r = 0.8). This was proved that the tree damage at location 3 by FHM assessment had a very strong relationship with the wood damage based on the sonic tomography assessment. The regression equation indicated an increasing curve line that is directly proportional (figure 4).

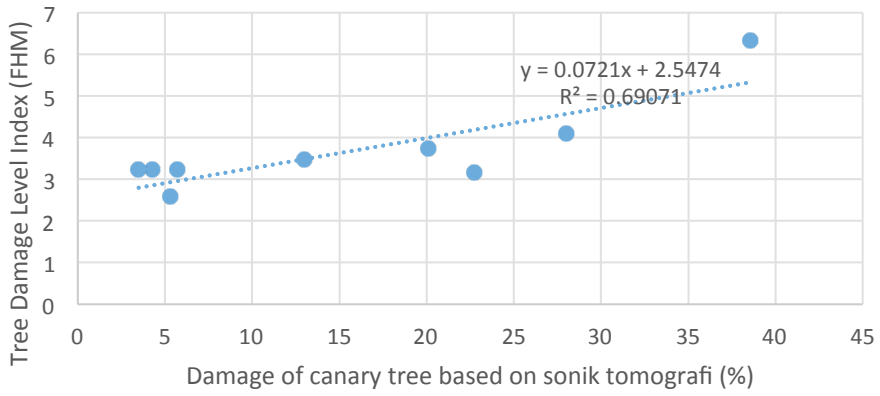


Figure 4. Correlation between the sonic tomography and the FHM method on the location of damage 3.

A correlation of the sonic tomography and the FHM method was strong at damage location 2 (r = 0.7). The location of damage 2 includes the roots area. Damages to the roots were not directly related to the damage inside the bole. A correlation of the sonic tomography and the FHM method at the location of damage 1 was not strong (r = 0.5). This indicated that those were not all damaged at location 1 related to wood damage inside bole.

4. Discussion

The Bogor Botanical Garden as an ex situ plant conservation has many old trees collection. The old trees have a very high risk of falling. The health of the trees are influenced by the environment with air pollution, and the age of the tree [6]. Tree damages that often occur in the Bogor Botanical Garden are due to the rainfall and wind. Lightning often strikes the old trees such as the canary tree and cause them to be dry. Global climate change [7], soil conditions [8], drought [9] and the environment also greatly affect the health of trees [10]. Similarly, the health of tree's crown is affected by rainfall, tree density, plant diseases and tree maintenance [11].

The damages to the canary trees in Bogor Botanical Garden are caused by pest infestation and plant diseases. Some types of Termites and *Ganoderma* infested the canary tree and caused heavy decay. Diseases are closely related to environmental conditions such as fungal attacks in humid conditions [12]. Tree damages due to termite and *Ganoderma* have occurred slowly for a long time. The damage caused by termites and *Ganoderma* is often not known before. *Ganoderma* is known after the fruiting bodies appeared on the surface of the bole or roots. The fruiting bodies indicate that the tree damage inside bole is severe or advanced decay [13].

The Forest Health Monitoring (FHM) was the first step to assess the canary tree damage. Tree health assessment can respond to reliable information needs rapidly. This is an important part of tree health monitoring and contributes to broadening the knowledge of the tree conditions [14]. Assessment of damage to the canary tree focused on the location of damage 1, 2 and 3. Those locations are affects significantly the strength of the tree. Severe damage to those locations may cause the tree to collapse. This incident should be prevented as early as possible, especially in the urban and tourist areas.

The use of sonic tomography is a second step in the assessment of damage inflicting the canary tree. Sonic tomography assesses wood damage with a high accuracy. The results of sonic tomography measurements were analyzed based on the extent of damage described in the tomogram. The percentage of wood damage or the healthy part is visible from the color of tomogram. There were three canary trees that have the highest percentage of wood damage (66.8%, 74.5% and 76.1%). Those canary trees may collapse because they only have a solid wood of bole less than one third (33.2%,

25.5% and 23.9%). The damage inflicted to the wood which may cause it to collapse can be calculated based on the Matteck's t/R ratio, where t is the width of the healthy wood part and R is the measured log radius. Categorized trees start at risk when the value of t/R ratio ≤0.3 [5]. This formula is very simple, easy to apply and accepted by many experts in analyzing the damage that occurs on the inside bole.

The use of two methods between sonic tomography and FHM has a strong relationship in the assessment of canary tree damage, especially on the bole. This is obvious from the assessment of damage to the canary tree at damage location 2 and 3 which has a strong correlation value [15]. At location 2, the correlation value is strong (0.7) and at location 3 the correlation value is very strong (r=0.8). This indicates that damages to the visible part of the bole are related to the damage inflicted to the wood inside the bole. At location 1, the correlation was not strong (0.5). The damages at location 1 were dominated by open wounds on roots that had no relationship to decay on bole.

5. Conclusion

The assessment of Tree health becomes one of the most important efforts to prevent the collapse of a tree. The FHM method assesses tree damage based on the observation of apparent damage symptoms in the tree. Whereas, the sonic tomography method assesses the wood damage inside the bole which is not visible from the outside. The use of both methods in the assessment of the canary tree has a strong correlation (0.7) at the location of damage 2 i.e. the open roots, stump, and lower bole. The correlation becomes very strong (r = 0.8) at the location damage 3 i.e. the lower bole. The combined results of both sonic tomography and FHM methods can be used in the assessment of tree damage from a simple, inexpensive, but high accuracy.

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