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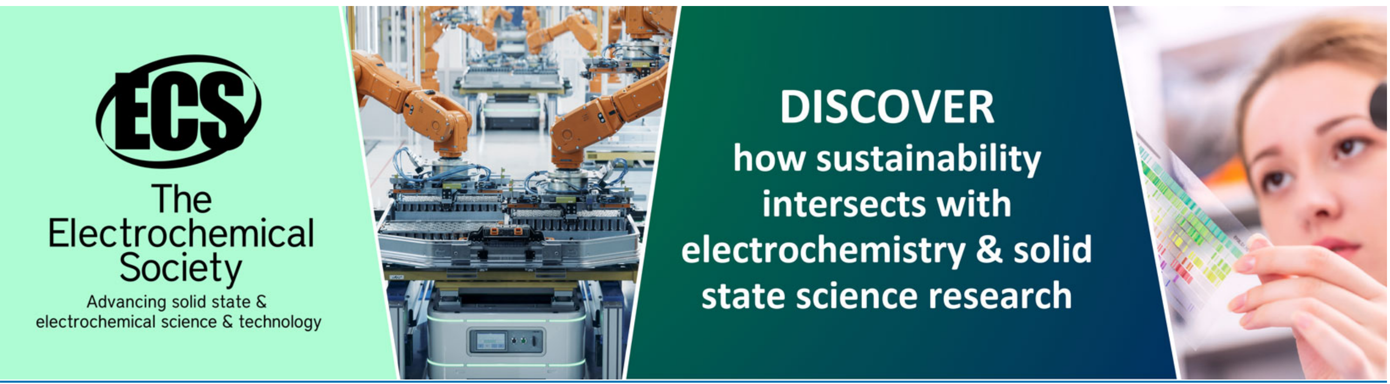

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Health asessment of large and old trees in Ragunan Zoo, Jakarta

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Abstract. Taman Margasatwa Ragunan (TMR) or Ragunan Zoo in Jakarta is the largest zoo in Indonesia. The zoo has around 52,700 trees that serve as part of the landscape and shades for animals and visitors. However, the presence of the trees in zoo also carries some risks, such as broken branches or even falling trees, that may threaten the safety of the animals, visitors, and infrastructures. Because most of the trees are large and old with high historical and ecological values, their health needs to be evaluated regularly. A study was conducted to evaluate it with around fifty selected trees, particularly the ones that were old and located closest to the targets (i.e. animals, visitors, infrastructures). The evaluation used visual observation as well as integrated with sonic tomography technology. The result showed that five trees (10%) were healthy and safe, 31 trees (62%) were healthy and fairly safe, 12 trees (24%) were less healthy and fairly dangerous, and the rest trees were unhealthy or dangerous and very dangerous. The most common defects found in them are poor tree architecture (62%), root problems (58%), and codominant trunks or branches (40%). Therefore, it is vital to take care of the tree health in Ragunan Zoo. Trees with the risk of endangering its surroundings need to be cut off immediately. Biomechanics on sloping trees with codominant trunks need to be strengthened with the help of dynamic bracing sling system and support.

1. Introduction

Taman Margasatwa Ragunan (TMR) or Ragunan Zoo in Jakarta is the biggest zoo in Indonesia. This zoo covers 140 hectares with an animal shelter capacity of 2000 animals. Based on the tree inventory in 2014, TMR has 92 tribes of trees with 252 genera and 426 species. If they are divided into two utilization groups, at least 222 species belonging to 150 genera and 51 tribes are classified into ornamental plants, while, 223 species from 159 genera and 51 tribes with a total of 52,733 trees are grouped as shade trees [1].

The presence of trees in TMR is vital in supporting the zoo's role and function. Shade trees in the middle of a metropolitan not only serve as an identity but also to absorb air pollution, reduce noise, and support the conservation of the city's soil and beauty. Trees in urban areas also provide important resources to other species. Any damages in them will reduce their functions and benefits. Early identification of risks can reduce tree fractures or fall and increase the efficiency of the management [2].

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Monitoring tree health can be done through visual observation of its physical condition. However, this method cannot reveal the overall health condition of the tree, considering that some parts of it cannot be seen visually (ex. inside the trunk). Meanwhile, various technologies to determine the inside of the trunk have now developed nondestructively, including a technology based on the velocity of sound wave propagation. This tool can determine the internal condition of the tree [3,4]. It is spot on to observe the internal of the trunks because it doesn't require over-damage actions on the tree [5]. Study by Nicolotti *et al.* [6] reported that the most effective technology for detecting tree decay is sonic tomography. It can determine the position of anomalies and estimate the size and shape of the tree trunks. The technique starts with creating a database of trees in TMR then conducting their comprehensive health evaluation. This is important considering if the tree is unhealthy, they can be prone to falling and threatening the safety of their surrounding in TMR. This study aims to evaluate tree health in TMR based on sonic tomography technology as a scientific basis for the management of the trees in the zoo.

2. Materials and Methods

2.1. Identfication of targeted tree

The research was conducted from October to December 2019 at Taman Margasatwa Ragunan, Jakarta. Fifty trees which diameter more than 30 cm, age more than 30 years, and closed to "target" i.e. animal, visitor, property targetedwere then identified by location, species, and dendrometry, such as diameter, height, canopy proportionality, and special markings. Each of them was labeled with a mica plastic of 6 x 5 cm then numbered using colored paint and tied using a rope around the trunk (Figure 1)

Figure 1. Labelling of target tree

2.2. Visual tree assessment

Visual Tree Assessment (VTA) was done by observing the condition and characteristics of all parts of the targeted tree, in all 360° directions around it [7]. It is important to find signs and symptoms of defects in each targeted tree, especially the roots, stems, branches, canopies, leaves, and micro-environmental conditions. Visual inspection was conducted following the modified VTA form from the International Society of Arboriculture (ISA). This form provides information on (1) tree characteristics, (2) tree defects or damages, (3) environmental conditions, and (4) the level of risk of failure. The intended target was people, animals, and infrastructures around trees that were potentially affected if there was any failure on the trees (e.g. falling trees).

IOP Conf. Series: Materials Science and Engineering **935** (2020) 012072 doi:10.1088/1757-899X/935/1/012072

2.3. *Tree assessment using sonic tomography*

Sonic Tomography (SOT) was developed as a nondestructive test tool to detect internal damages in tree trunks by producing velocity of sound wave propagation that was transformed into tomogram image forms (two-dimensional images) [8]. SOT became a sufficient tool to identify the presence of intial deterioration in the tree trunks or branches, because inspection using this technology was very effective [9-11].

Testing using Picus®*Sonic* was carried out by installing 10-12 Picus®*Sonic Tomography* transducers on the surface of the targeted tree trunk with a height of ±130 cm from the ground. Sound wave generation was done by hitting a nail near the transducer using an electronic hammer. Each transducer was connected each other so that the propagation of sound waves could spread from one point to another (Figure 2). All of these were connected to computer software that processed the velocity of sound wave data. Data recorded were the speed of sound waves propagation, then turned into image gradations of color following the speed of sound waves reflected in the internal trunk of the tree. The results of the tomogram analysis of each tree could complement the results of visual observations that had been made, especially increasing accuracy in trials that prevented the failure of the trunks that could be done on defective trees [12].

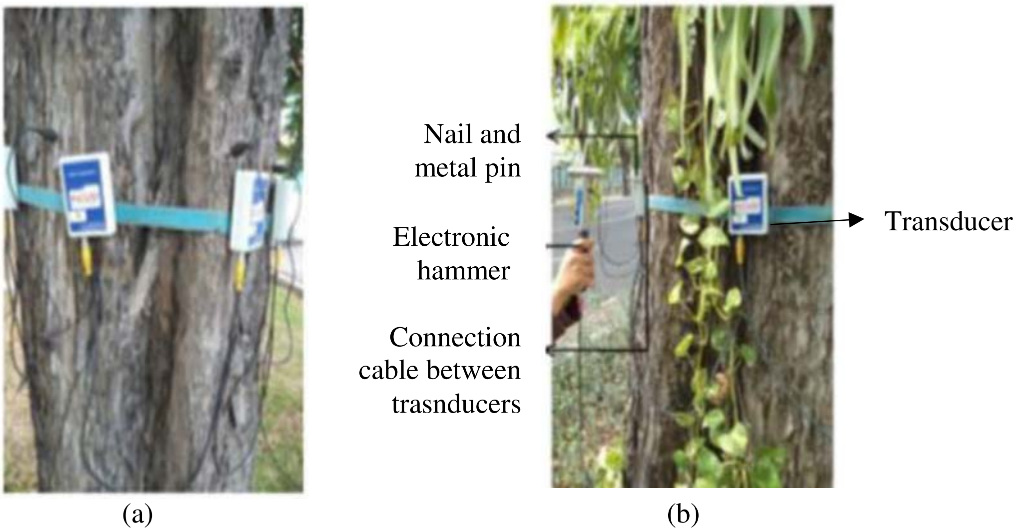

Figure 2. (a) Transducers in targeted tree trunk (b) Testing activity by tapping the electronic hammer into the metal pin

2.4. *Interpretation of tree's condition based on sonic tomographye*

The health of targeted trees in TMR was determined based on the color image produced from the processing of the sound velocity matrix with the sonic tomography tool. Based on the results of the tomogram on the device, it was known if the trees contain solid or damaged wood. Table 1 shows the criteria developed for the inner-part trees reunk condition namely solid, moderate, and deteriorated based on the percentage (5) of solid wood conditions [13].

Table 1. Inner-pat tree condition based on solid wood volume percentage (%) and recorded volume of the tree trunk in the tomogram (SOT) [13]

Solid wood percentage (%)	Innermost condition of target tree
80-100	Solid
50-79	Moderate
<50	Deteriorated

2.5. Determination of targeted tree vigor
The determination of the targeted tree vigor was based on the proportion ratio of solid wood or wood thickness with a cross-section radius (t/r ratio). This study found that when most trees reached linear decay measurements greater than 70% or the thickness was less than 30% (2/3 of cross-section), the tree had a high probability of failure [7]. The wood thickness percentage was a result of the tomogram image, while the cross-section radius was measured directly through those results. Furthermore, the ratio calculation was assisted with the ImageJ application.

2.6. Integration of visual and sonic tomography assessment
In determining the risk of tree failure, visual observations data were integrated with sonic tomography observations. It was presented in a table and analyzed with Microsoft Office Excel 2010. Table 2 shows the category of tree failure risk ranking [13].

Table 2. The category of targeted tree failure risk ranking based on visual observations and *sonic tomography* (SOT) [13]

Visual assessment result (risk category)	Sonic tomography result (based on the percentage of solid wood)		
	>80%	50% -79%	<50%
Low	Safe	Fairly safe	Dangerous
Moderate	Fairly safe	Fairly dangerous	Dangerous
High	Fairly dangerous	Fairly dangerous	Very dangerous
Extreme	Fairly dangerous	Dangerous	Very dangerous

3. Results and Discussion

3.1. Characterisation of targeted trees
The result showed that the 50 targeted trees consisted of 12 species, namely Sengon (*Paraserianthes falcataria*) 3 trees, Trembesi (*Samanea saman*) 12 trees, Khaya (*Khaya anthotheca*) 11 trees, Kemenyan (*Styrax benzoin*) 10 trees, Beringin (*Ficus benjamina*) 1 tree, Kedawung (*Parkia timoriana*) 2 trees, Cempaka (*Magnolia champaca*) 4 trees, Petir (*Parkia javanica*) 1 tree, Kapuk (*Ceiba pentandra*) 2 trees, Nyatoh (*Palaquium rostratum*) 1 tree, Karet (*Hevea brasiliensis*) 2 trees, and Mahoni (*Swietenia mahagoni*) 1 tree (Figure 3).

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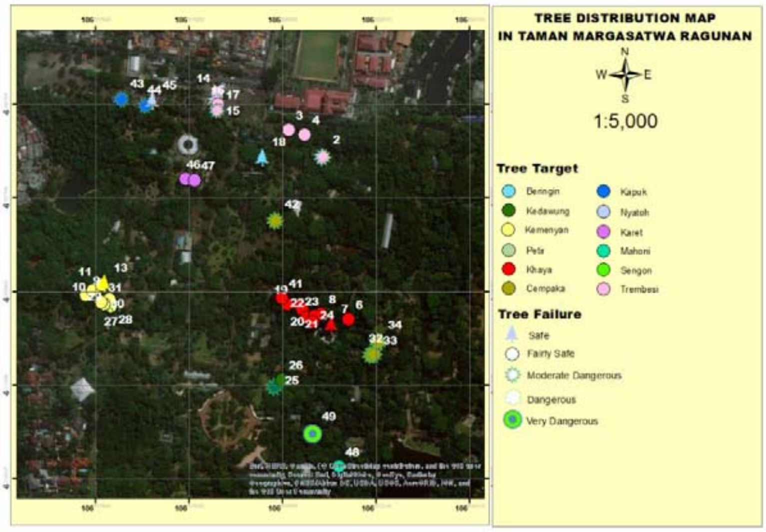
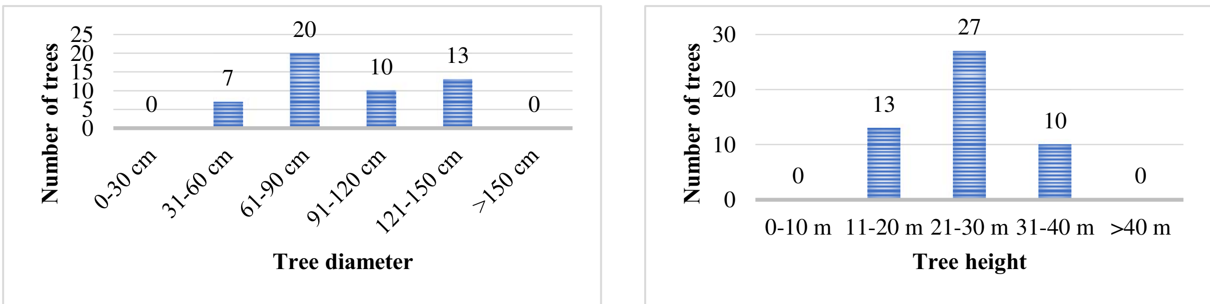


Figure 3. Spatial distribution of targeted tree in TMR

The fifty targeted trees have various diameters, ranging from 31-150 cm. Most of them have 61-90 cm diameter (20 trees), followed by 121-150 cm (13 trees), then trees with 91-120 cm diameter (10 trees), and lastly 31-60 cm (7 trees). Meanwhile, the height ranges from 11-40 m. Most of them are 21-30 m of height (27 trees), followed by 11-20 m of height (13 trees), and 31-40 m (10 trees) (Figure 4).



(a) (b)

Figure 4. (a) Tree diameter distribution and (b) Tree height distribution of targeted tree

The results of the target trees diameter and height distribution indicate that most of them are old. Old trees are defined as the main ecological structure because they provide resources for other species. They also have high cultural values because of their aesthetic and spiritual qualities [14,15]. Old trees are characterized by large volume appearance, peeled bark, spiral grains on the trunks, and some dead branches [16,17]. Large and old trees are most likely to face removal in urban landscapes because they have more safety risks (fallen branches or trees) posed to the public and infrastructures. Their removal can cause serious ecological implications. Therefore, the regular health evaluations at TMR are necessary to monitor the condition of the tree to maintain critical habitats for biodiversity in the long run and prevent any safety risks.

3.2. Visual tree asessment result

This result shows several case findings found in the targeted trees. Most of them are bad tree architecture (31 cases), followed by root problems (29 cases), codominant branches (14 cases), termite attacks (10 cases), other pests attacks (8 cases), cracks/ruptures (4 cases), cancer (2 cases), and dead tree tips (1 case) (Figure 5). The root problem that usually arises is the disruption of root development by infrastructures such as roads and sidewalks, causing the roots to be cut off or mechanically compressed.

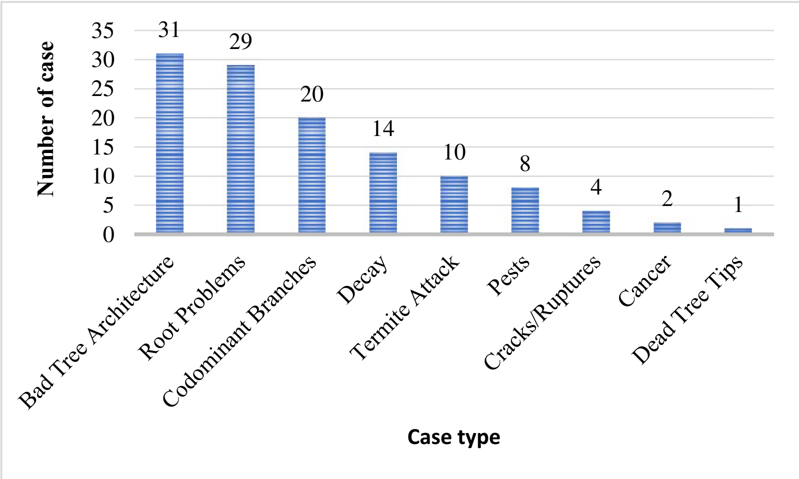
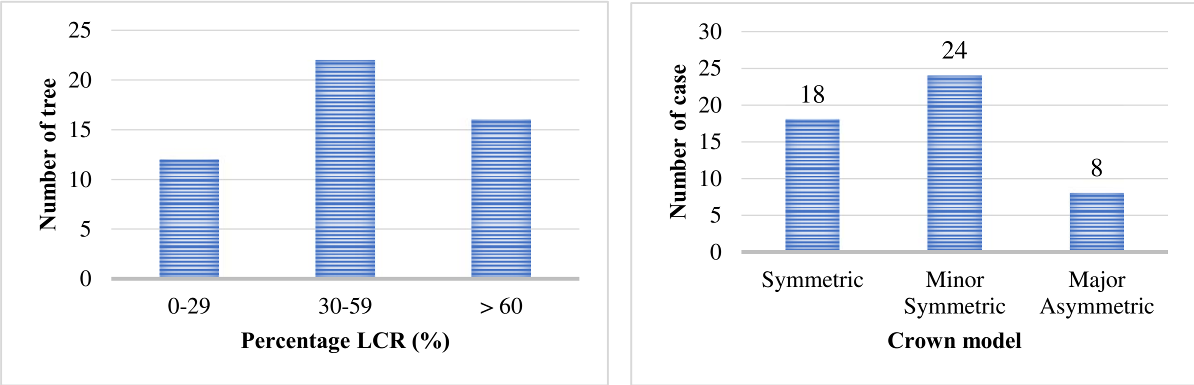


Figure 5. Case distribution on targeted tree

The measurement of tree architecture was conducted to find out the symmetry of the tree canopy and Live Crown Ratio (LCR). LCR is calculated based on the ratio of the height of the canopy to the total height of the tree expressed in percentage (%). LCR is a characteristic of canopy condition which correlates with tree growth [18,19]. Whereas according to Zhao *et al.* [20], LCR indirectly becomes an indicator of photosynthetic capacity and stands density. That is why it becomes a general indicator of the tree fitness. Tree fitness and normal diameter growth are not less than 30% of LCR. LCR itself can be categorized as high (>50%), moderate (30-50%), and low (<30%) [21].

The Live Crown Ratio (LCR) measurements showed that 22 trees had LCRs ranging from 30-59%, followed by 16 trees with LCR ≥ 60%, and 12 trees have ≤ 30% of LCR. This shows that some targeted trees need special care for their canopy symmetry, considering it is not only related to the fitness and photosynthesis of the tree, but also the beauty and safety of its surrounding environment. The canopy width is positively correlated with how the roots obtain minerals in the soil, which means photosynthesis will automatically affect the growth of many parts of the tree [22]. From photosynthesis, the tree crown provides carbohydrates for the roots, while the roots are absorbing water and nutrients from the soil to meet the canopy needs. The distribution of LCR percentage and the shape of the tree crown is shown in Figure 6.

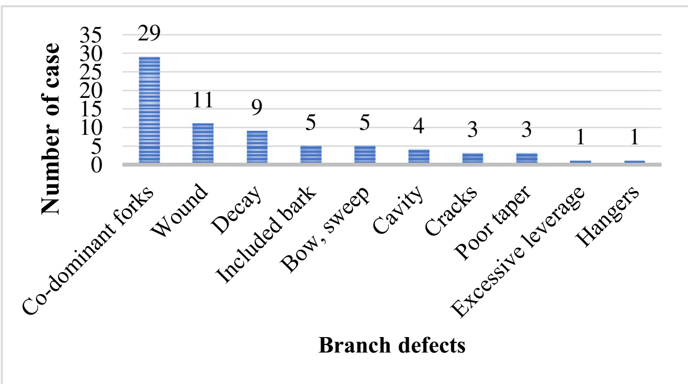


(a) (b)

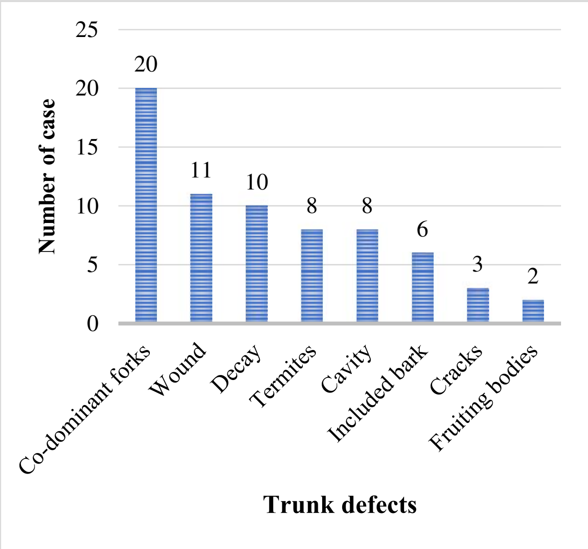
Figure 6. (a) Distribution of percentage LCR and (b) Crown model distribution of targeted tree

Every damage to every part of the targeted tree was observed (Figure 7). The most common defect on the roots was mechanical damage, such as cut off roots, wounds, and others caused by the surrounding's construction and buildings. Weathering and decay that occurs in trees can be caused by many factors, such as termite attack, fungus, or water infiltration. According to Tainter and Baker [23], decay usually starts from the middle (heart decay), but it can also start from the outside (tree bark). If decay occurs from the middle, it will reduce more than double the wood volume. Economically, trees that experience decay will have low value [24]. In terms of security, trees with large diameter and are located in human-accessible locations are considered dangerous, especially if the stems are weathered and porous. Therefore, they need regular maintenance so as not to endanger the tree structure.

The sympthom defects, such as subterranean termite tunnels, and the fungus fruiting bodies on the targeted tree must be anticipated because they can endanger the condition of the tree. The presence of subterranean termites was marked by soil traces in the tree. According to Zulkaidhah *et al.* [25], subterranean termites always come in contact with the soil because they live there. Meanwhile, the pests absorb food sources from the host tree so its health will be affected. The higher the attack frequency, the higher the aggressiveness, which means more damages to the host tree [26]. The wound, cavity, and cracks of the stem need to be anticipated so that they will not interfere with the tree structure. If not, they will trigger infection from various pathogens (fungi, bacteria, viruses, microplasma, nematodes) into plant tissue [27].



(a)



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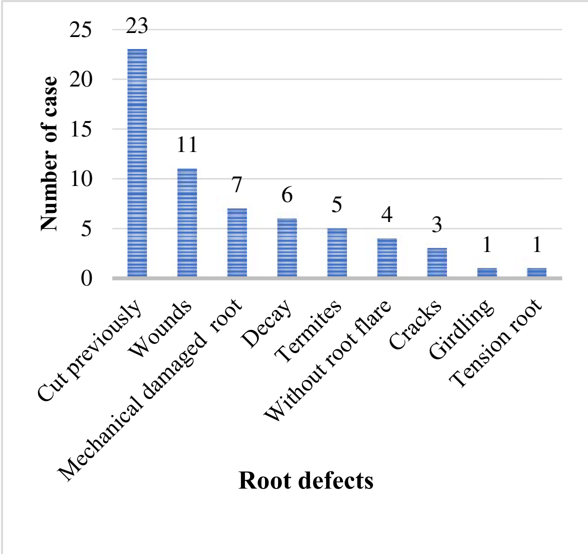

(c)

Figure 7. (a) Branch defects distribution and (b) Trunk defects distribution of targeted tree (c) Root defects distribution of targeted tree

The recapitulation result of visual assessment showed that 41 trees were at moderate risk of failure, 6 trees at high risk of failure, and 3 trees at low risk of failure. Six trees at high risk of failure were Trembesi (no 2), Trembesi (no 15), Kedawung (no 25), Kemenyan (no 28), Cempaka (no 32), and Sengon (no 49) (Figure 8).

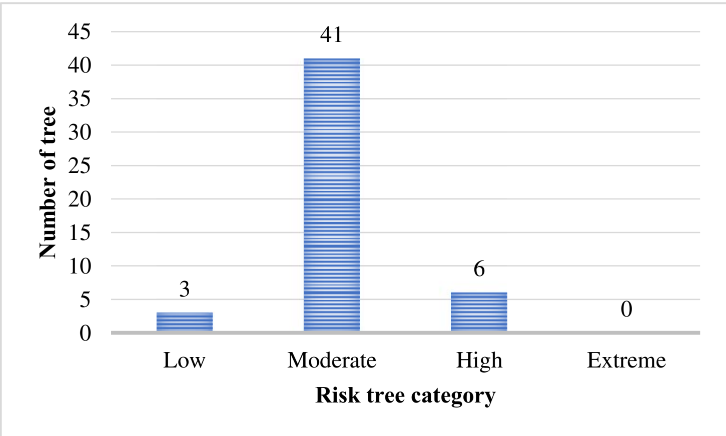

Figure 8. Frequency of risk tree category based on visual assessment

3.3. *Tomogram of trunk*

The *sonic tomography* result showed there were 41 trees in solid condition, 7 trees in moderate condition, and 2 trees in a deteriorated condition. This refers to the percentage of solid wood on the tomogram results of each tree (Figure 9). Trees with moderate conditions ranged from 70-79% of solid wood found in number

17 (Trembesi), number 33 (Cempaka), number 34 (Cempaka), number 36 (Petir), number 42 (Cempaka), number 43 (Kapuk), and number 44 (Kapuk). Meanwhile, the deteriorated trees are shown by number 37 (Sengon) and number 49 (Sengon).

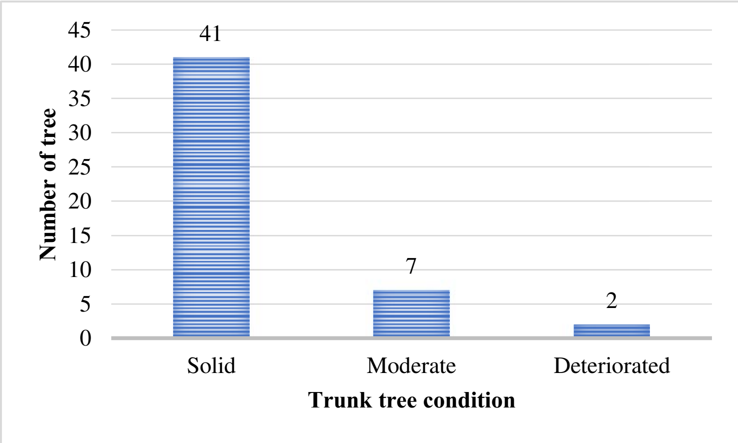

Figure 9. Frequency of trunk tree condition based on *sonic tomography*

3.4. Integration of visual and sonic tomography assessment results

The result showed 31 trees were only fairly safe, while 5 of them were classified as safe. The dangerous and very dangerous trees have one tree each (Figure 10). Number 37, which is classified as dangerous, is a Sengon tree whose trunks are damaged due to a subterranean termite attack. Meanwhile, number 49 (Sengon) is categorized as very dangerous because it also has some heavily damaged trunks and was located on a puddle that causes heavy weathering. The LCR of both trees is at <45%.

Figure 10. Tree failure risk based on visual dan *sonic tomography* observation

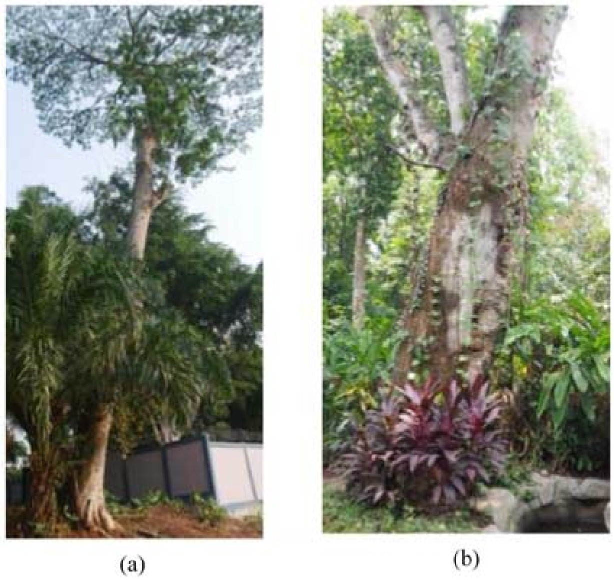

Figure 11. Targeted tree number 37 (Sengon, a) and number 49 (Sengon, b)

3.5. Tree fitness

The percentage of solid wood is related to the integrity and fitness of the inner-part of the tree trunk. This percentage can also be used to determine the value t/R ratio, which is the percentage of solid wood mass to the diameter of the tree trunk. This method was adopted from [28] that requires trees to have a t/R ratio of more than 0.3. A value of t/R ratio that is less than 0.3 indicates that the percentage of the mass is too small compared to the diameter of the tree trunk, so the action needed is to cut down the tree.. The result showed that 48 trees have a t/R ratio of more than 3.0. Meanwhile, trees with a ratio of less than 0.3 only amounts to 2 trees (number 37 and 49) (Figure 12).

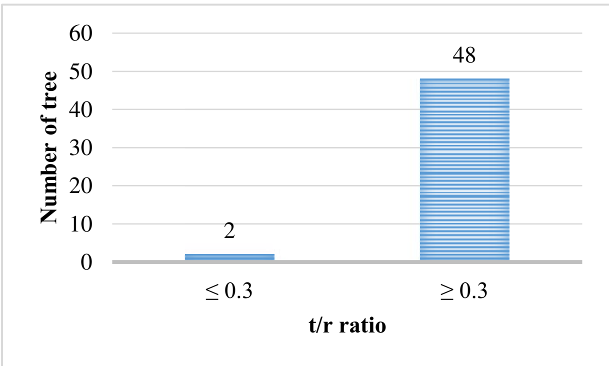

Figure 12. Frequency of t/R ratio of targeted tree

3.6. Recommendation

Several target trees have a tree trunk with a slope of >20° that requires treatment with the support of a certain height using reinforced construction made from two intersected galvanized iron trunks (10 cm in diameter). For some of the trees with codominant branches, dynamic slings can be made (Figure 13). Trees with a risk of failure are fairly dangerous to make similar observations no later than 6 months after the previous one. Meanwhile, trees with a risk of very dangerous failure are recommended to be cut down. Most of them are Sengon a species which are not historical tree.

(a)

(b)

Figure 13. Simple lines for (a) Application technique of dynamic "sling" (b) Tree stand for leaning targeted tree

4. Conclusion

All targeted trees in Taman Margasatwa Ragunan (TMR) are old. Most of them have symmetrical and minor asymmetrical crowns. However, 68% of them have Live Crown Ratio (LCR) of less than 60%, which indicates the disproportionation of the canopy. The most common defects found in targeted trees are poor architecture, roots disturbance, decayed, and codominant branches. Regarding the risk of failure, most of the trees are in a reasonable and safe condition. Some of them are in dangerous and very dangerous conditions in urgent need of intensive treatments. The evaluation results of the tree fitnees through the t/r ratio state that in general, the trees are still in a solid condition.

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