INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 14, Issue 2, April-June 2023: 635-648 www.ijcs.ro

DOI: 10.36868/IJCS.2023.02.17

RISK ASSESSMENT OF VARIOUS TREES GROWN IN THE INNER PART OF FIRST ZONE TO THE PRESERVATION OF THE BOROBUDUR TEMPLE

Destario METUSALA[1,*], TRIMANTO[2], Laily MUKAROMAH[2], Dewi Ayu LESTARI[2], FAUZIAH[2], Shofiyatul MAS'UDAH[2], Mohamad HABIBI[3], Ari SWASTIKAWATI[3], Albertus Widyo PURWOKO[3]

[1]Research Center for Biosystematic and Evolution, Indonesian Research and Inovation Agency (BRIN), Jalan Raya Bogor KM 46 Cibinong, Bogor, 16911, West Java, Indonesia.
[2]Research Center for Plant Conservation, Botanic Garden and Forestry, Indonesian Research and Innovation Agency (BRIN), Jalan Raya Bogor KM 46 Cibinong, Bogor, 16911, West Java, Indonesia.
[3]Borobudur Conservation Office (Museum dan Cagar Budaya Warisan Dunia Borobudur), Jl. Badrawati, Borobudur, Magelang, Central Java, Indonesia.

Abstract

The Borobudur complex temple constitutes an architectural masterpiece representing the nature of Buddhist symbols and their natural surroundings. Vegetation around the temple, especially the trees grown in the inner part of zone 1, plays a very important role as green barrier to the temple and also preserving the ecological function as well as the spiritual value of this historical heritage. Any plants grown in this area may have a direct impact on the temple through various risks, such as lateral root systems, falling trees or branches, insect hosts, or seed dispersal. Therefore, this study aimed to evaluate the potential risk of various existing trees in the inner part of zone 1 of the Borobudur conservation area. The result showed that there were 613 individual trees from 93 different species grown in this area. Among these, there were 12 individuals categorized as high risk (1.96%), 73 individuals (11.91%) classified as medium risk, and 521 individuals (84.99%) were low risk, and only 7 individuals (1.14%) had lesser risk. All the individual trees that have been categorized as high-risk should be carefully managed in order to reduce the hazard risk that may harm the Borobudur temple preservation. The tree risk monitoring and evaluation should be done periodically as the anticipation system to control any of possible risk that may threats the preservation of Borobudur temple. The assessment model performed in this paper can be used as an approach to identify the potential risk of various trees to the preservation of heritage building.

***Keywords**: Biological characteristics; Borobudur temple; Heritage building; Risk assessment; Tree species*

Introduction

Indonesia is committed to the preservation of cultural heritage as well as sustainable tourism. Currently, Indonesia has seven sites listed as UNESCO World Heritage, and one of the most famous sites is the Borobudur temple [1]. Since 1991 Borobudur Temple has been designated as a UNESCO World Heritage Site. This temple is one of the greatest archaeological sites in Southeast Asia. The temple is a major tourist destination in Indonesia, attracting around 3 million domestic and foreign visitors annually [2]. Borobudur temple is located in Magelang

* Corresponding author: metusala.destario@gmail.com

Regency, Central Java Province. The king of ancient Mataram built the Borobudur temple during the Syailendra Dynasty around the mid of 8^{th} Century. Borobudur temple is the world's largest Buddhist temple with a giant stupa representing Buddhist cosmology. Borobudur temple is structured by nine stacked platforms, 6 square and three circulars, and topped by a central dome with 504 Buddha statues and 2,672 relief panels [3, 4].

One of the fundamental issues in modern society's cultural life is preserving archaeological heritage appropriately by considering various related aspects. The surrounding landscape, especially the trees that grow in the temple area, has become an integral part of the historical heritage. Vegetation around the temple compounds represents culturally important plant species that has not only a historical connection to the traditions of Buddhism but also aesthetic values to visitors. Ecologically, this "temple park" can be seen as a habitat for some urban trees and native communities that also play an important role in maintaining the ecological function, such as slope stability, groundwater content, wind barrier, and reducing air pollution. Temple Park is also important for urban space and larger village landscapes. A study on the development of the National Archaeological Parks in Java (i.e., Borobudur and Prambanan) was conducted by the Japan International Cooperation Agency (JICA) and a master plan of those Archaeological Parks was completed in 1979 [5]. According to the JICA master plan, the existence of vegetation around the temple is very important component in creating a comfortable environment as well as fostering spiritual sensation for visitors.

JICA masterplan proposed the Borobudur zonation and divided the region into five zones, i.e., zone 1 (Sanctuary Area), zone 2 (Archeological Park Zone), zone 3 (Land Use Regulation Zone), zone 4 (Panoramic View Preservation Zone), and zone 5 (National Archeological Park Zone). The first zone (zone 1) is the Borobudur temple monument and its closest yard, which the Borobudur Conservation Office manages under the Ministry of Education and Culture. Zone 2 is located in the outer part surrounding zone 1 as a tourist park. State Minister manages it for State-Owned Enterprises. Zone 3 is a settlement and agricultural land area around the Borobudur temple complex. Zone 4 is a zone for preventing the destruction of undiscovered archaeological monuments shown in zone 5. Zone 4 also serves to the maintenance of the historical scenery. Zone 5 is the 78.5 km^2 area within a radius of 5 km from the Borobudur temple zone. This outermost zone serves to undertake archaeological surveys over a wide area and prevent undiscovered monuments destruction. Zone 3 to 5 are managed by the Local Government of the Magelang Regency [5, 6].

Since the inner part of zone 1 is the closest area surrounding the Borobudur temple (7.84 hectares). Therefore this area has a very important function as a direct green barrier to the temple. Any trees planted in this area may have a direct impact on the temple through various risks, such as lateral roots growth, falling trees or branches, insect hosts, or seed dispersal. Therefore, this study aimed to evaluate the potential risk of existing trees in the inner part of zone 1 to the preservation of Borobudur temple. At this inner area, trees situated close to the temple also represent a potential risk to both staff and visitors injuries.

In this study, we design a quantified tree risk assessment to provide a framework for evaluating all existing trees and the potential impact that may arise and highlighting scientific evidence of both the likelihood and consequences faced in balancing characteristics of trees and management challenges for the preservation of archaeological heritage sites.

Experimental part

Study area and criteria

Tree inventory was conducted on four quadrants in the inner part of zone 1 (Sanctuary Area) in June 2019. As an observed area, the inner part of zone 1 is an area within zone 1 that is the closest part to the temple and is bordered by a high iron fence. This area, also a place where the most of trees have been densely planted surround the temple. The definition of tree used in this study is a perennial woody plant that has a more or less spreading crown that is supported at some distance off the ground by the main stem (diameter ≥ 10 cm at breast height) [7, 8]. The inner part of the zone 1 has become an integral component of preserving the Borobudur temple. Various tree species planted in this zone, including the bodhi tree *(Ficus religiosa*), pine (*Pinus* sp.), tamarind (*Tamarindus indica*), trengguli (*Cassia fistula*), acacia (*Acacia auriculiformis*), kasia (*Cassia javanica*), santenan, nyamplung (*Calophyllum inophyllum*), violin tree (*Ficus lyrata*), and palm coconut (*Cocos nucifera*) [9].

Methods

Tree inventory in the inner part of zone 1 of Borobudur temple

An inventory has been done for all existing trees grown in the inner part of zone 1. Global Positioning System (GPS) data were recorded for each individual tree using a GPS unit Garmin 76 CSX. Data collection includes species name, stem diameter (diameter at breast height/DBH), plant height, and canopy diameter. Data on all of those elements are important in order to provide information on each individual tree within the framework of its risk.

Additional data were calculated for each individual tree. The closest distance of each individual tree was measured as the closest distance between the tree to the outermost temple structure. The GIS point layers created from the GPS data consist of the locations for each individual tree (latitude and longitude coordinates), and the point database of the study subjects was then overlaid on Google Earth. Spatial analysis was then performed to measure the closest distance for each individual tree to the temple (Fig. 1). Other data, i.e., Total Zone Radius (TZR) of the root, was calculated based on equation 18*(DBH (in centimeters) * 0.01), and this is considered as the maximum extent of root area of a healthy tree [10].

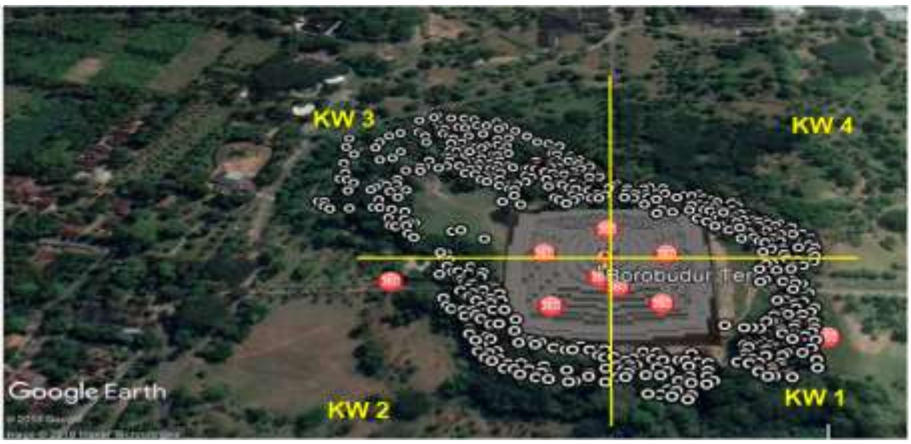

Fig. 1. Spatial distribution of the 613 observed trees in the four quadrants [3] of zone 1 of Borobudur temple.

Risks analysis of various trees to the preservation of Borobudur temple

We have designed a set of criteria and developed indicators for the tree risk assessment procedure. The risk analysis was measured through two main steps. These two steps represent two different approaches. The first step has been designed to identify various risks related to "species" characters. This step has been proposed by evaluating the biological characteristics of tree species and determining the appropriate criteria in order to obtain a total quantitative score related to species characters. The second step was developed to identify various risks related to the characters of the "individual" tree. This includes the concept of tree's roots penetration risk that may damage the building structure and tree failure risk associated with the relative distance of individual trees to the temple.

STEP 1 (Species-related variable)

Risk's analysis was conducted based on the biological characteristics of each species that can jeopardize the preservation of the Borobudur temple. A different score is given to each species that meets the following criteria:

1. Small seeded species (seed diameter ≤ 2 mm) (score = 1)
2. Seeds easily germinate and grow on rocks (as lithophytes) (= 7)
3. Fruits/seeds are dispersed by animals or small insects, especially those with high mobility and can reach quite far distance (= 1)
4. The secondary growth of the stem could potentially reach a diameter ≥ 30 cm (= 1)
5. The taproot system is not active (= 1)
6. Flowers that produce a large amount of nectar or attract insect visitation (= 1)

STEP 2 (Individual-related variable)

Risk analysis was conducted based on the growth characteristics and health conditions. Score (= 10) per criteria is given to each individual tree that meets the following criteria:

1. TZR value ≥ closest distance of the tree to the temple (risk damage to the temple structure due to lateral root penetration) (score = 10)
2. Fall distance (risk damage to the temple structure caused by fallen trees) calculated as tree height value ≥ the closest distance of the tree to the temple (= 10)
3. Heavily damaged tissue that reduces the physical strength of the trunk (risk damage to the temple structure caused by falling trees or branches) (= 10)

FINAL STEP

The final score is calculated based on the total score of Step 1 and Step 2. Based on the set of criteria and indicators of those previous steps, the final scores were calculated for each of the 613 observed trees. We have also designed a risk index score to group those observed trees so they can be divided into several categories (Table 1). A higher score indicates a greater hazard risk of the tree as well as a greater potential to cause damage to the temple.

Table 1. Criteria of risk category of trees based on Risk Index Score

Risk Index (Range of Score)	Risk Category
0	Lesser risk
1 - 4	Low risk
5 - 10	Moderate risk
> 10	High risk

Results and discussion

Tree species in the inner part of zone 1 of Borobudur temple

A total of 613 existing individual trees from 93 different species were inventoried and measured from the inner part of zone 1. The total number of trees varied among 4 quadrants (Fig. 2). Quadrant 3 had the highest number of trees (252 individuals), while the quadrant with the lowest number of trees was quadrant 2 (98 individuals).

There were five most frequent species that often found in the observed area, namely *Calophyllum inophyllum* (Calophyllaceae), *Ficus religiosa* (Moraceae), *Tectona grandis* (Lamiaceae), *Swietenia macrophylla* (Meliaceae) and *Satakentia liukiuensis* (Arecaceae). Species *of Calophyllum inophyllum* was the most abundant tree (54 individuals) followed by *Ficus religiosa* (48 individuals) and *Tectona grandis* (39 individuals). Among these 93 tree species, 20 of the most abundant tree species in the observed area are shown in Fig. 3. The trees planted in the observed area have shown various canopy architectures, ages, and sizes. Some of those are illustrated in Figure 4.

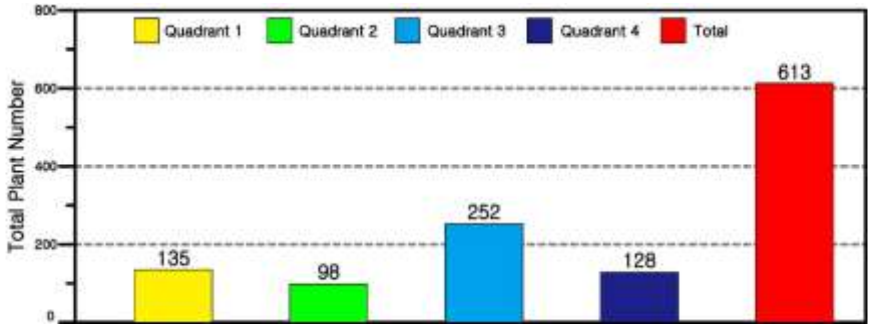

Fig. 2. Distribution and the total number of trees in the observed area in (zone 1) of Borobudur temple.

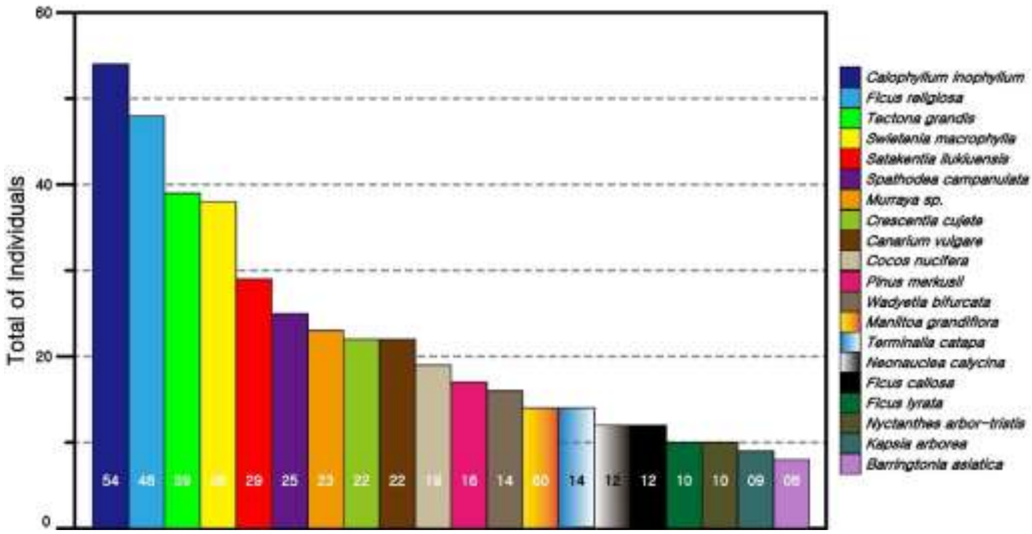

Fig. 3. Tree species and the number of individuals in the conservation area (zone 1) of Borobudur temple.

Species of *Calophyllum inophyllum* is an Indonesian native tree species that has chiefly valued for its wood hardiness. It also provides shade and shelter from the wind [11]. This species is widely distributed from eastern part of Africa, South Asia, to Southeast Asia and the eastern part of Australia [12]. In Indonesia, *Calophyllum inophyllum* can be found in all main islands where it often grows in coastal regions and lowland areas. The figure of this species was also carved in many relief panels of Borobudur temple [4]. Species of *Ficus religiosa* is one of the sacred trees that frequently mentioned in the early ancient Indian literatures and it also has a great significance in the history of Buddhism. This sacred fig tree, commonly known as the Bodhi tree (Fig. 4), is often documented to be very closely related to Buddhist religious ceremonies and its figure also very often appeared in the relief of Borobudur temple [4]. The Bodhi tree is also cultivated as a shade tree or as an ornamental plant in yards or parks in tropical and subtropical climates [13]. However, its roots structure is capable of penetrating rock crevices and if neglected, will damage buildings [14]. Species of *Tectona grandis* was also dominant tree found in the inner zone 1 of the Borobudur temple. This species has been known as one of the most valuable timbers in the tropics and it is occurs naturally in the Southeast Asian region (e.g., India, Burma, Thailand and Laos), while this teak species was estimated to have been introduced to Indonesia about 400-600 years ago [15].

Fig. 4. Tree species planted in the inner part of zone 1 of Borobudur temple; a. *Terminalia catappa,* b. *Crescentia cujete,* c. *Tectona grandis,* d. *Ficus lyrata,* e. *Tamarindus indica,* f. *Artocarpus altilis,* g. *Pinus merkusii,* h. *Satakentia liukiuensis,* i. *Barringtonia asiatica,* j. *Calophyllum inophyllum,* k. *Canarium vulgare* and l. *Corypha utan.*

The risk analysis of various trees in the inner part of zone 1

The results of risk analysis showed that there were 613existing trees in the inner zone 1. Among these, there were 12 individuals categorized as high risk (1.96%), 73 individuals (11.91%) classified as medium risk, and 521 individuals (84.99%) were low risk, and only 7 individuals (1.14%) had lesser risk (Fig. 5). Those 12 trees have been categorized as high-risk to the preservation of the temple, namely *Terminalia catappa* (3 individuals*), Canarium vulgare* (1 individual), *Tamarindus indica* (1 individual), *Ficus lyrata* (2 individuals), *Ficus callosa* (1 individual), *Pinus merkusii* (2 individuals), and *Tectona grandis* (2 individuals) (Table 2). All of those trees are located near the temple, approximately 5.5 to 21.0 metres distance from the outermost structures of the temple**.**

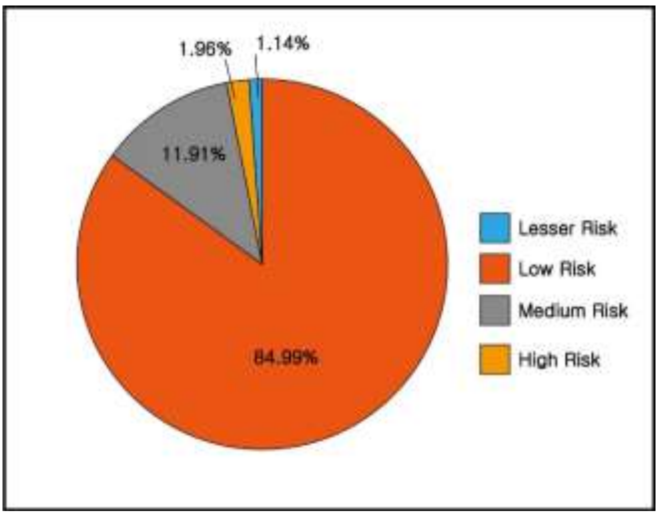

Fig. 5. Percentage of four risk categories based on the assessment result.

Among these 12-individual categorized as high-risk trees, 2 individuals of *Terminalia catappa* have shown the highest risk index score (risk index = 32) (Table 2). Both individuals of

Terminalia catappa had relatively low scores at Step 1, but their scores on Step 2 were relatively high due to their individual characteristics. In Step 2, these two individuals of *Terminalia catappa* meet with all of three criteria, so they may have risk damage to the temple due to their lateral root penetration and also risk damage caused by fallen trees or branches since their TZR and height value ≥ the closest distance of the tree to the temple. These both *Terminalia catappa* also showed heavily damaged tissues in the basal main trunk that may reduce their physical strength, especially when the main trunk withstands the heavy canopy at the top.

The tree height of both *Terminalia catappa* that exceed their relative distance to the temple presents a serious threat associated with the possibility of falling trees or branches. It is known that *Terminalia catappa* has long horizontal branches that are arranged in obvious tiers, giving a broad pagoda-like canopy shape. On the other hand, the wood density of this species is categorized as moderately strong (0.46 g/cm^{-3}) [16]. Therefore, the old large tree of *Terminalia catappa* or even its huge branches are very vurnerable to collapse due to strong winds, especially those that are planted in open area. Large tissue damage in their lower trunks can reduce the trunk's physical strength. Thus, it will further increase the risk of falling trees. Moreover, many of *Terminalia* species, including *Terminalia catappa*, have a relatively fast growing rate and usually can grow into very large trees (the basal stem is up to 1.5 m in diameter) with broad horizontal branches as well as their lateral roots [17]. Therefore, this species is not best choise to be planted close to the heritage building without carefully routine maintenance.

Another tree categorized as high risk was *Canarium vulgare* (risk index = 23) due to its relative distance to the temple. This tree with a height of about 18 m and grows near the temple with a distance of about 6 m. In addition, a primary symptom of decayed tissue was found to perforate the basal stem, while hollow at the basal stem and root may also sign of the decaying more of stem tissue at the unseen lower part of that living tree. These conditions can reduce the physical strength and weaken the robustness of the stem and so it will cause the tree to fall down anytime (Figs. 6-8). By considering the huge diameter of the trunk and the height of the tree, if it falls towards the temple building then it may cause a very serious physical damage.

Table 2. Trees categorized as high risk to the preservation of Borobudur temple

No	Spesies	A	B	C	D	Total score of Step 1	The total score of Step 2			Total Final Score
		Diameter at breast height (cm)	Tree's height (m)	The closest distance to the temple (m)	TZR (m)		D ≥ C	B ≥ C	Heavily damaged tissue/ stem decay	
1	***Canarium vulgare***	65	18	6	11.70	3	0	10	10	23
2	***Ficus callosa***	54	17.5	17	9.72	10	0	10	0	20
3	***Ficus lyrata 1***	37	12	9	6.71	10	0	10	0	20
4	***Ficus lyrata 2***	22	15	15	3.96	10	0	10	0	20
5	***Pinus merkusii 1***	41	21	21	7.39	1	0	10	0	11
6	***Pinus merkusii 2***	67	21	17.22	12.10	1	0	10	0	11
7	***Tamarindus indica***	81	19	11	14.56	2	10	10	0	22
8	***Tectona grandis 1***	44	23	17	7.85	1	0	10	0	11
9	***Tectona grandis 2***	44	20.5	15	7.92	1	0	10	0	11
10	***Terminalia catappa 1***	75	15	5.5	13.59	2	10	10	10	32
11	***Terminalia catappa 2***	131	18	9	23.50	2	10	10	10	32
12	***Terminalia catappa 3***	125	19	20	22.53	2	10	0	0	12

The TZR of root and their relative distance to the temple explained lateral root systems that extend beneath the ground and pose a serious threat through root penetration, especially at a 0-1 m depth from the ground surface [18]. The TZR of root value that exceeds the closest distance between the tree and the temple indicates a high risk of the lateral root penetration into the temple's underground structures. Tree roots may be caused damage to structures of historical buildings through direct or indirect ways. The direct damage is usually through root penetration to the building structure. These penetrated roots will enlarge and harden due to secondary thickening and wood lignifications, giving physical pressures that may damage the building structure. The indirect structural damages are usually related to the changes of soil volume (shrinkage or expansion) as a response to the interaction between tree roots activity and soil moisture [19, 20]. Based on the field observations, some tree species planted in the inner zone 1 have a natural characteristic in developing expansive lateral woody root systems. These species including *Terminalia catappa*, *Canarium vulgare*, *Ficus religiosa*, and other *Ficus* spp. Therefore, this type of tree species should be avoided to be planted very close to the structure of the heritage building.

Fig. 6. a. *Terminalia catappa* that grows near the Borobudur temple; b. Large cavity with decayed tissue in the base trunk of *Terminalia catappa*

Fig. 7. a. *Terminalia catappa* trees planted around temples are often used by visitors as a shelter; b. The root of *Terminalia catappa* that begin to decay.

Fig. 8. a. An old *Canarium vulgare* tree grown very close to the Borobudur temple; b. Large cavity with decayed tissue in the stem base of *Canarium vulgare*; c. The basal area of *Canarium vulgare* with tissue damaged symptoms.

Based on the risk analysis, the 12 trees categorized as high-risk can be classified into four different groups:

1. **Group 1** represents the tree species associated with all three criteria in Step 2: a high risk of root penetration, risk of falling tree, and heavily damaged main trunk. For example, *Terminalia catappa* 1 and *Terminalia catappa* 2 that have tree's height value that exceed the closest distance to the temple (high risk from falling tree and branches), heavily damaged main trunks which may reduce its strength, and a greater TZR value (13.59 metres) that may cause a high risk of root penetration beneath the temple. Several studies have shown that vegetation close to walls can occasionally cause wall cracks. The growing root of the tree can penetrate the building foundations and walls, causing cracks to form [21]. Another research indicates that *Terminalia catappa* is a fast-growing tree species, with rapid growth causing cracks in the walls due to the expanding action of developing lateral roots [17, 22, 23]. Severe tissue damage in the trunk of both trees (*Terminalia catappa* 1 and *Terminalia catappa* 2) will reduce the physical strength of the trunk and it becomes more vulnerable to collapse (Figs. 6 and 7).
2. **Group 2** represents the tree species associated with a high risk of falling down. The risk index of this group was based on the score of tree height that is greater than the closest distance of the tree to the temple. For example, *Pinus merkusii* 1, *Pinus merkusii* 2, *Tectona grandis* 1, *Tectona grandis* 2, and *Canarium vulgare* (Fig. 8). Any decayed tissue that is spreading on the the basal stem of *Canarium vulgare* also exaggerates the probabilities of this tree falling down and causing damage to the structure of the temple. All of those observed trees have large stem diameters (41-65 cm); thus, their falling trees may give significant damage to the temple.
3. **Group 3** represents the tree species associated with high risk of species characteristic (Step 1) and falling trees (Step 2). For example, *Ficus callosa* and *Ficus lyrata*. Many of *Ficus* species, especially those from *Urostigma* section, are known to produce numerous of tiny seeds that can grow epiphytically on the tree trunks or even grow in crevices of rocks as lithophytes [24, 25, 26]. Those tiny seeds are easily dispersed at a great distance by the wind or by animals (e.g. insects, birds, bats) [27,28]. Once those tiny seeds have entered in the rock crevices of the temple, then it will start germinating and growing epiphytically on the temple structures. Moreover, planting *Ficus* species (especially from *Urostigma* section) close to the temple may also exaggerate the threat of the temple's structural damage from a falling tree, since the height of these fast-growing tree species exceeds the closest distance between the tree and the temple.
4. **Group 4** represents the tree species associated with the risk of root penetration combined with the risk of fall down. This group has a greater TZR value than the closest distance between the trees and the temple, as well as the height of the trees that was greater than the closest distance between the trees and the temple. There was only 1 individual trees in this group, i.e., *Tamarindus indica*. This tree has shown high TZR values indicating that their lateral root growth may reach the closest underground structure of the temple. On the other hand, this tree also showed the height value that exceed the tree's closest distance to the temple, therefore very risky if the tree falls toward the temple. An increase in tree height, which is less adaptable to variations in wind speed, will contributes to the risk of tree failure [29].

All the individual trees that have been categorized as high-risk should be carefully managed in order to reduce the hazard risk. The most efficient strategy for long-term period, probably can be done by translocating all those high-risk trees to a new place that far away from the temple. However, if those high-risk trees are decided to remain in its position, then the intensive high-risk tree management strategies should be done, these including: (a) establishing an artificial barrier to maintain the tree roots, so they cannot penetrate to the temple's structures; (b) regular stem pruning to keep the trees at a certain height with lesser risk; (c) regular extreme stem pruning and regular fruit trimming to keep the trees at a very short height in order to minimize the seed dispersal distance by wind as well as to decrease the fruit quantity, (d) stop the process of decaying plant tissue by using chemical treatment, (e) improving the strength of decayed trunk with concrete to fill the cavities, (f) put the warning sign board for the trees with high risk of falling tree or branches.

Fig. 9. a. A large tree of *Ficus religiosa* planted in the inner part of zone 1;
b. *Pinus merkusii* with a climber of *Ficus* sp. from *Urostigma* section.

The scoring results also showed that the group of trees included in the medium risk criteria was dominated with the tree species from genus *Ficus*, especially section *Urostigma*. Species of *Ficus* found in the observed area were *Ficus benjamina*, *Ficus callosa*, *Ficus kurzii*, *Ficus lyrata*, and *Ficus religiosa*. Although the *Ficus* trees were planted at a quite far distance from the edge of the temple structures (lower score from Step 2), but many criteria of the Step 1 were fulfilled, these including the tiny seeds that easily to germinate and grow in the narrow gaps of the temple stones. Therefore, this genus gained a fairly high score from the Step 1 due to its biological characteristics. Tree species of *Ficus* spp., especially section *Urostigma* can grow by strangling its host tree, thereby threatening the sustainability of other trees. Large numbers of adventitious roots also appear on the section *Urostigm*a; thus, they can produce large systems of roots with anastomose characteristics [30]. Other research indicated that *Ficus* also has the potential to become invasive [31].

The most common *Ficus* species planted in the inner part of zone 1 was *F. religiosa* or Bodhi tree (Fig. 9). Species of *Ficus religiosa* is a long-lived large tree which adapted to the environment with limited water, soil, and nutrient content. This species also can grow as epiphytes or even lithophytes to colonize the rock permanently [24]. However, the aggressive lateral root character is thought to threaten the temple structure if it grows close to the temple or even grows in the narrow gap of the temple stones. The seed characters of *Ficus religiosa* that are small and easily grow in the narrow cleft of the temple stones make this species need to be managed with special attention [32].

Based on the results of the scoring, there were 522 existing trees that categorized as low-risk. Some of these trees include *Garcinia mangostana, Satakentia liukiuensis, Roystonea regia, Wodyetia bifurcata, Psidium guajava, Crescentia cujete, Calophyllum inophyllum, Kopsia arborea, Chrysophyllum cainito, Swietenia macrophylla, Cocos nucifera, Alstonia scholaris, Nyctanthes arbor-tristis, Inocarpus fagiferus, Syzygium oleinum, Mangifera indica, Cynometra ramiflora, Diospyros discolor, Cinnamomum verum, Cassia fistula, Phyllanthus virgatus, Tamarindus indica, Heterospathe elata, Annona muricata, Plumeria rubra, Cananga odorata, Cerbera odollam, Murraya sumatrana, Maniltoa grandiflora, Thevetia peruviana* and *Maniltoa grandiflora*. All those mentioned plants have a low Risk Index Score, since their scores in Step 1 (species-related variable) and Step 2 (individual-related variable) were also relatively low as they were planted quite far from the temple structure.

However, the result also showed that there were only 7 individuals (from 3 different species) that were categorized as lesser risk: *Manihot esculenta* (2 individuals), *Bridelia stipularis* (2 individuals), and *Magnolia liliifera* (3 individual). Although the species of *Manihot esculenta* can have a stem with diameter up to 20 cm, but all of those species are categorized as woody shrub to small tree (treelet) without a masive roots growth [33]. Therefore those trees might give a less risk to the preservation of the temple, as long as they are planted at certain safe distance to the temple.

The tree species that can grow as large trees with very tall stem characters, great stem diameter, or aggressive lateral root systems should be planted at the bottom of the slope area at a radius of > 30 metres from the temple's outermost structure. Moreover, tree species that have harmful seed characteristics for the temple preservation, such as *Ficus religiosa* and the other *Ficus* species from *Urostigma* section, are adviced to be planted outside of zone 1. In the future, it is hoped that the manajement of the Borobudur temple area can be more selective, both in choosing plant species and determining the planting locations in the inner part of zone 1.

Conclusions

The risk analysis for existing trees in the inner part of zone 1 of Borobudur temple area has showed that there were 613 individual trees from 93 different species grown in this area. Among these, there were 12 individuals categorized as high risk (1.96%), 73 individuals (11.91%) classified as medium risk, and 521 individuals (84.99%) were low risk, and only 7 individuals (1.14%) had lesser risk. All the individual trees that have been categorized as high-risk should be carefully managed in order to reduce the hazard risk that may harm the Borobudur temple preservation. The tree risk monitoring and evaluation should be done periodically as the anticipation system to control any of possible risk that may threats the preservation of Borobudur temple. The assessment model performed in this paper can be used as an approach to identify the potential risk of various trees to the preservation of heritage building.

Acknowledgments

We thank DIPA of the Research Center for Biology - LIPI through the IBSAP (International Biodiversity, Strategic and Action Plan) and to our colleagues (Prof. Ibnu Maryanto, Dr. Cahyo Rahmadi, and Dr. Hari Nugroho) for their helpful supervision and motivation during the study. We also thank the Borobudur Conservation Office (Museum dan Cagar Budaya Warisan Dunia Borobudur) for the valuable support during the study. D. Metusala, Trimanto, L. Mukaromah, D.A. Lestari, Fauziah, and S. Mas'udah are the **main contributors**, while M. Habibi, A. Swastikawati, and A.W. Purwoko are supported contributors.

References

[1] I.U. Canny, *An empirical investigation of service quality, tourist satisfaction and future behavioral intentions among domestic local tourist at Borobudur Temple*, **International Journal of Trade, Economics and Finance**, **4**(2), 2013, pp. 86-91.

[2] T. Fatimah, *The impacts of rural tourism initiatives on cultural landscape sustainability in Borobudur area*, **Procedia Environmental Science**, **28**, 2015, pp. 567-577.

[3] H. Setyawan, **Plants Species and Contexts of Their Descriptions on Relief of Borobudur and Mendut Temples**, Report on The Study of Vegetation Management in Borobudur Area, Magelang, 2017.

[4] D. Metusala, Fauziah, D.A. Lestari, J. Damaiyani, S. Mas'udah, H. Setyawan, *The identification of plant relief in the Lalitavistara story of Borobudur temple, Central Java, Indonesia*, **Biodiversitas**, **21**(5), 2020, pp. 2206-2215.

[5] * * *, **Borobudur Prambanan National Archaeological Parks,** JICA, Government of the Republic of Indonesia, Jakarta, 1979.

[6] F.D. Ekarini, *The landscape of Borobudur Temple compounds and its environment*, **Journal of World Heritage Studies**, 2017, pp. 24-29.

[7] T. Gschwantner, K. Schadauer, C. Vidal, A. Lanz, E. Tomppo, L. di Cosmo, N. Robert, D. Englert Duursma, M. Lawrence, *Common tree definitions for national forest inventories in Europe*, **Silva Fennica**, **43**(2), 2009, pp. 303-321.

[8] * * *, **State of the World's Trees**, BGCI, Richmond, UK, 2021, p. 52.

[9] S. Yudi, E. Dian, C.S. Achmad, **Study of Vegetation Evaluation for Zone 1 and 2 of Borobudur Temple according to the JICSA Master Plan Compared,** Borobudur Heritage Conservation Center, Magelang, 2010.

[10] J.I. Iniguez, *Geometric Modelling of Tree Roots with Different Levels of Detail*, **ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences**, 2nd International Conference on Smart Data and Smart Cities. Puebla, Mexico, 4-6 October 2017, **4**, 2017, pp. 29-35.

[11] J.B. Friday, D. Okano, *Calophyllum inophyllum (Kamani)*, ver. 2.I., **Species Profiles for Pacific Island Agroforestry, ver 2.I** (editors: C.R. Elevitch), Permanent Agriculture Resources (PAR), Holualoa, Hawai'i, 2006, http://www.traditionaltree.org.

[12] * * *, Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew, 2023, Published on the Internet; http://www.plantsoftheworldonline.org/. Retrieved 07 June 2023.

[13] G.P. Choudhary, *Evaluation of Ethanolic Extract of Ficus religiosa Bark on Incision and Excision Wounds in Rats*, **Planta Indica**, 2, 2006, pp. 17–19.

[14] V. Sitaramam, S.R. Jog, P. Tetali, *Ecology of Ficus religiosa Accounts for Its Association with Religion***, Current Science**, 97(5), 2009, pp. 637-640.

[15] A. Kaosa-ard, *Teak (Tectona grandis Linn. f) its natural distribution and related factors*, **Natural History Bulletin of the Siam Society**, **29**, 1981, pp. 55-74.

[16] A.E. Zanne, Lopez, G. Gonzalez, D.A. Coomes, J. Ilic, S. Jansen, S.L. Lewis, R.B. Miller, N.G. Swenson, M.C. Wiemann, J. Chave, **Global Wood Density Database**, Dryad, 2009, Identifier: http://hdl.handle.net/10255/dryad.235.

[17] D. Metusala, D.D. Al Farishy, *Rediscovery and an additional new record of Terminalia kangeanensis (Combretaceae), a long lost threatened species from Indonesia*, **Phytotaxa**, **570**(2), pp. 209-216.

[18] T. Lakshmipriya, *Conservation and restoration of Ta Prohm Temple*, **Structural Analysis of Gistoric Construction** (editors: D'Ayala, Fodde), Taylor & Francis Group, London, 2008.

[19] R. Driscoll, *The influence of vegetation on the swelling and shrinking of clay soils in Britain*, **Geotechnique**, **33**, 1983, pp. 93–105.

[20] A. Satriani, A. Loperte, M. Proto, M. Bavusi, *Building damage caused by tree roots: laboratory experiments of GPR and ERT surveys*, **Advances in Geosciences**, **24**, 2010, pp. 133-137.

[21] A. S. Zanke, *Building Cracks: Causes and Preventions*, **International Journal of Engineering Applied Sciences and Technology**, 5(8), 2020, pp. 165-169.

[22] Marjenah, Karyati, S. Sarminah, M. Syafrudin, Irwan, A. Aswar, I. Ruardianto, *The Role of Canopy Structure of Terminalia catappa Linn. on Decreasing Light Penetration and Ambient Temperature as Climate Change Mitigation*, **Wood Research Journal**, **12** (1), 2021, pp. 35-40.

[23] D. Harinkhede, N. Rahangdale, H. Darne, H. Meshram, L. Jaiwar, P. Sahare, *Study on Causes and Prevention of Cracks in Building*, **International Journal of Creative Research Thoughts**, 10(5), 2022, pp. d456-d462.

[24] P. Jayanthi, A. Rajendran, B. Thomas, V. Aravindhan, R. Sivalingam, *Biodiversity of lithophytes in Madukkarai Hills of Southern Western Ghats of Coimbatore district, Tamil Nadu, India*. **International Journal of Biological Technology**, **2**(2), 2011, pp. 76-82

[25] J. Galil, L. Meiri, *Drupelet germination in Ficus religiosa L.*, **Israel Journal of Botany**, **30**(1), 2013, pp. 41-47.

[26] V. Sharma, S. Mishra, R. Yesudas, R.S. Rajput, *A review on Ficus religiosa (sacred fig)*, **International Journal of Research and Analytical Reviews, 6**(2), 2019, pp. 901-906.

[27] S. Kaufmann, D.B. McKey, M. Hossaert-McKey, C.C. Horvitz, *Adaptations for a two-phase seed dispersal system involving vertebrates and ants in a hemiepiphytic fig* (*Ficus microcarpa*: Moraceae), **American Journal of Botany**, **78**(7), 1991, pp. 971-977.

[28] K. Milton, D.M. Windsor, D.W. Morrison, M.A. Estribi, *Fruiting phenologies of two neotropical Ficus species*, **Ecology**, **63**(3), 1982, pp. 752-762.

[29] C. Collet, O. Lanter, M. Pardos, *Effects of Canopy Opening on Height and Diameter Growth in Naturally Regenerated Beech Seedlings*. **Annal of Forest Science**, **58**, 2001, pp. 127-134.

[30] C.C. Berg, *Flora Malesiana precursor for the treatment of Moraceae 1: The main subdivision of Ficus: The subgenera*. **Blumea– Journal of Plant Taxonomy and Plant Geography of Plants**, **48**(1), 2003, pp. 166-177

[31] R.T. Corlett, *Figs (Ficus, Moraceae) in Urban Hong Kong, South China 1*. **Biotropica**, **38**(1), 2006, pp. 116-121.

[32] J. Galil, *Ficus religiosa* L.*–the tree-splitter*. **Botanical Journal of the Linnean Society, 88**, 1984, pp. 185-203.

[33] P.C. an Welzen, Q.D. Nguyen, R.C.K. Chung. *A revision of the introduced species of Manihot (Euphorbiaceae) in Malesia*. **Rheedea**, **7**, 1997, pp.77-85.

Received: August 20, 2022
Accepted: April 25, 2023