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TREE STRATIFICATION BASED ON ERUPTION DAMAGE LEVEL IN MOUNT MERAPI NATIONAL PARK YOGYAKARTA INDONESIA

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ABSTRACT

Mount Merapi's eruption has caused damage to the forests in the Mount Merapi National Park (MMNP). Nine years after the eruption, the vertical structure of vegetation can illustrate the progress of succession. This study aimed to analyze the tree composition and stratification in different forest damage levels after the 2010 Merapi eruption. The study was conducted in March 2019 at three stations, namely station A (heavy damage area), station B (moderate damage area), and station C (minor damage area). Vegetation parameters in each station were taken in a 10x100 plot and were processed using a tree profile diagram. Abiotic parameters were measured in each plot and analyzed using the correlation test. The results showed that the three stations were still dominated by the tree in Stratum C, but the tree density and tree height varied in proportion to the damage level. Station A in the heavy damage area has the lowest tree density (23 trees/0.1 ha) with a maximum tree height of 12 meters, in contrast to Station C in the minor damage area with tree density reaching 195 trees/0.1 ha and maximum tree height reaching 30 meters. Nine years after the Mount Merapi big eruption, the MMNP forests in Yogyakarta Province are still classified as young secondary forests.

Key words: *diagram, profile, succession, structure, vertical*

INTRODUCTION

Succession is a form of adaptation or natural recovery process on disturbed land, marked by changes in the vegetation community to achieve complex and stable conditions (Chokkalingam & Jong, 2001; Molles, 2008; Chang et al., 2019). The volcanic eruption is one of the disturbances that can change forest vegetation cover dan change the existing substrate (Rahayu et al., 2014). Many local people live around the volcano forest area using agriculture resources (Fitria et al., 2018), livestock, and tourism (Muhamad, 2017). Because the role of forest area in the volcano is significant for the ecosystem and people, the succession process after disturbance is also necessary to be studied to design strategies for forest rehabilitation as a basic for sustainable forest management (Sarmiento et al., 2003; Cakir et al., 2007; Prach et al., 2018). Vegetation structure can be used as an indicator in managing the post-disturbed ecosystem (Rutten et al., 2015).

Mount Merapi National Park (MMNP), located in Yogyakarta and Central Java Province, functions as a buffer for Mount Merapi (Afrianto et al., 2016). Mount Merapi is the most active volcano in Indonesia (Utami et al., 2018), even in the world, which has a constant eruption interval, and one of the largest occurred in 2010 (Surono et al., 2012; Troll et al., 2013). The disruption caused damage estimated at 38.3 trillion rupiahs, including ecological damage, the cost of decreasing carbon sequestration productivity, and restoration costs (Marhaento & Kurnia, 2015). Around 1.3 million people live up to 20 km from the Mount Merapi summit (Mei et al., 2013). As severe as disturbance occurs, the habitat, food sources, and sources of clean water for flora, fauna, and humans that live around Mount Merapi will be less frequent. Pioneer plant growth as a vegetation succession part of post-eruption has begun to be reported, especially in heavy damage area. Sutomo & Fardila (2013) reported in 2011, five herbs, five shrubs, and five saplings were found in Kalikuning, while Sunardi et al. (2017) reported in 2014, 27 herbs, four saplings, and three poles were found in Cangkringan.

One of the factors that influence succession in nature is location conditions with varying disturbance levels (Meiners et al., 2014; Utami et al., 2021). The disturbance in location can trigger differences in succession in primary or secondary succession (Prach et al., 2018). According to McNaughton & Wolf (1990), terrestrial succession in the former eruption area will start from volcanic ash deposits forming to the formation of forests in decades and even centuries. The soil in a forest contains reserves of pioneer plants in the form of dormant seeds during the disturbance.

At the stage of colonization, the seeds will respond to favorable environmental conditions to germinate and master the initial succession stages. According to Saharjo & Gago, 2011, secondary succession affected by disturbance lasts 15 to 20 years to form a young secondary forest. It will form an old secondary forest to a climax after 50 years. The secondary succession is different from the primary succession that has accumulated in soil organic carbon during the first 50 years and the formation of a moss layer and followed by vascular plants' growth (Zehetner, 2010; Fiantis et al., 2016). After that, the density, height, and complexity of plant community structure, especially understorey and trees, will be increased. Stratification, species diversity, and microclimate will be developed as a particular stage of succession (Swanson et al., 2010). This study analyzes trees' composition and stratification in a variation of forest damage after the 2010 Merapi eruption. Hopefully, this study's results can provide information on the extent of succession carried out in the MMNP forest area affected by the Merapi eruption in 2010 and see the development of the ecosystem recovery process after nine years of eruption.

RESEARCH METHOD

This research was conducted in the southern part of MMNP, precisely in Turi-Pakem Resort and Cangkringan Resort in Yogyakarta Province. Data was taken in March 2019. Sampling location was determined by purposive sampling based on the level of damage after the 2010 Merapi eruption (BTNGM, 2011; Gunawan et al., 2013). According to the analysis of the MMNP officer after the 2010 eruption, there are three levels of damage as shown in Figure 1, namely red color for a location that is severely damaged where vegetation is completely destroyed by a pyroclastic flow, yellow color for a location that is moderately damaged where 60% of the vegetation burned and necromass stakes remained, while the green color is for a location that is minor damaged with the appearance of relative vegetation intact (BTNGM, 2011). Data was collected at Station A on heavy damage area at Cangkringan Resort (7°34'54.33"S 110°26'31.17"E), Station B on moderate damage area at Turi-Pakem Resort (7°35'19.71"S 110°26'10.98"E), and Station C on minor damage area at Turi-Pakem Resort (7°34'50.64"S 110°25'3.82"E).

This research consists of several stages, starting from the location survey, data sampling, and data analysis. The site survey was carried out in stages by matching the data collection area with the land damage map issued by BTNGM (2011). Each level of damage is determined by one station that represents the area. After the stations was obtained, the forest's interior was re-determined to be placed 100 meters into the forest edge. After that, the vegetation parameter data was collected for making tree profile diagrams and analyzing species diversity.

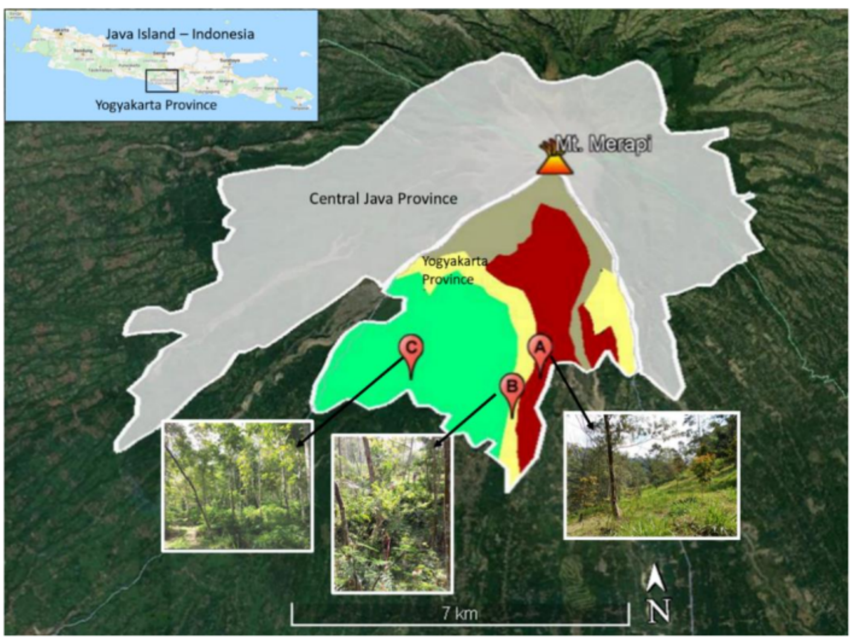

Figure 1. Sampling stations in MMNP Yogyakarta Province

Tree stratification was analyzed using a profile diagram (Baker et al., 2000; Wulandari et al., 2018) at each station by making a plot of a square in a transect line or called a belt transect (Mueller-Dombois & Ellenberg, 2016). The belt transect was made 100 x 10 meters long and divided into ten plots sized 10x10 meters from the forest's interior to the edge (Oosterhoorn & Kappelle, 2000). Tree stratification is illustrated by making vertical and horizontal profile diagrams. The x-axis was expressed from the interior to the edge forest along the 100 meters. In comparison, the tree's height represented the y-axis in the vertical profile diagram, and in the horizontal profile diagram is illustrated with a plot width of 10 meters (Desi et al., 2017). Tree parameters data taken include species name, diameter at breast height (DBH), tree height, the height of the first branch, tree position concerning the x-axis and y-axis, and canopy width (Desi et al., 2017).

This belt transect is also used in the tree structure and composition analysis, where the vegetation parameters measured are the density, frequency, and dominance of trees in each 10x10 meter plot. Trees lifeform in this study divided into small trees (woody vegetation with branches above 1.5 meters and DBH <10 cm) and large trees (DBH ≥ 10 cm). All tree species in the plot were sampled to be made herbarium and identified by identification book Flora of Java (Backer & van den Brink, 1965) and validation by checking theplantlist.org website. Vegetation parameters that have been recorded are analyzed using the calculation of the Importance Value Index (IVI) to observe the dominance or see tree species that have an essential role in the location (Indriyanto, 2006; Utami & Putra, 2020). Besides, to describe the level of diversity in a stage of community development, the Shannon-Wienner Diversity Index (H') (1) calculation was used (Mueller-Dombois & Ellenberg, 2016). Tree carbon stock will be calculated based on the calculation of tree biomass (2) in tropical areas with rainfall between 1,500 – 4,000 mm yr^{-1} (Brown, 1997; Hairiah et al., 2001). Vegetation carbon stocks are obtained from 46 percent of the total tree biomass (Hairiah & Rahayu, 2007). Abiotic parameters, such as air temperature, air humidity, light intensity, wind speed, soil temperature, soil pH, soil moisture, are also measured in each 10x10 meter plot. Elevation, slope, and point of coordinates were also taken as supporting environmental factors.

$H' = -\Sigma\, pi \log pi$ .... (1)

Note:

H '= Shannon-Wiener Diversity Index

pi = ni / N species

ni = total individual the-i species

N = total individual of all species

$Bt = 0.118 \times DBH^{2,53}$ .... (2)

note:

B = tree biomass (t C ha^{-1})

DBH = Diameter at Breast Height (cm)

Stratum data in the profile diagram, essential species with the highest Important Value Index (IVI), tree density, and tree carbon stock at each station were analyzed descriptively to compare tree stratification and composition at each damage levels of eruption. The abiotic parameters data at the study site and tree density were analyzed inferentially using the correlation test. This study's correlation test was the Pearson parametric test because the data were normally distributed and homogeneous.

RESULT AND DISCUSSION

Vegetation stratification can show a forest community's vertical structure with various levels or strata (Soerianegara & Indrawan, 2005; Indriyanto, 2006; Utami & Putra, 2020). There are five levels of the vertical structure of vegetation in the forest, namely Stratum A for an emergent layer which consists of trees with a height of more than 30 meters; stratum B for upper canopy consisting of trees with a height 20-30 meters; stratum C for middle canopy consisting of trees with a height of 4-20 meters; stratum D for saplings and shrubs 1-4 meters; and stratum E for the ground layer (understorey) consisting of herbs and seedling with a height of 0-1 meters (Dinanti et al., 2018). Station A at Cangkringan Resort which suffered heavy damage after the 2010 Merapi eruption, was only dominated by trees in stratum C with a height range of 4 to 12 meters, as many as 16 trees/0.1 ha (Figure 2, Table 2). *Acacia decurrens* or Akasia Hijau from the Fabaceae family (Table 1) dominates at station A, which was also reported by Afrianto et al. (2017) and Haryadi et al. (2019) dominate in the Cangkringan and Kemalang Resort. *Acacia decurrens,* purple color in figure 2, occupy open areas affected by heavy eruptions (Sunardi et al., 2017) and even tend to reduce species diversity in the MMNP area (Sutomo, 2019a). *Trema orientalis* or Anggrung, light green color in figure 2, has the second-highest of important value index (IVI) in this station. According to Mangopang (2016), *T. orientalis* is a fast growing species and a pioneer plant that can proliferate in open land experiencing disturbances. Stratum D or a sapling dominated by *Syzygium polyanthum* from Myrtaceae family, Green color in Figure 2, with a height range of 3 to 3.5 meters with density 7 trees/0.1 ha (Table 2). According to Gunawan et al. (2015), Salam, local name of *S. polyanthum*, and Puspa, local name of *Schima walichii,* are the native MMNP species commonly planted for the Merapi Volcano ecosystem's post-eruption restoration. Station A has a tree diversity (H') of 0.55, classified as low (Utami & Putra, 2020). The low diversity index value is due to the small number of individuals and species found at that location. The vertical profile diagram image (Figure 2) shows that after the 2010 Merapi eruption, Station A has still very few tree stands scattered in the research plot. Besides, the dominant tree stands only came from *A. decurrens* and spread in groups. The horizontal profile diagram image (Figure 2) shows that there are still very few tree canopies covering the areas. There is also a large gap between one tree canopy and another.

Station B at Pakem-Turi Resort, which suffered moderate damage after the 2010 Merapi eruption, has the highest stratum B trees reaching 21 m with a density of 5 trees/0.1 ha (Figure 3, Table 2). The Stratum B at this station is controlled by *A. decurrens* (purple color in Figure 3). The highest density at this station was 82 trees/0.1 ha of trees in stratum C (20m<height≤4m), and *A. decurrens* also dominated it. Stratum D dominated by *Caliandra calothyrsus* (Dark Tan color in Figure 3) from the Fabaceae family has the second-highest density of 40 trees/0.1 ha. Tree diversity (H') in station B as a representative of moderate damage area has a value of 1.18, which is classified as moderate. Based on Figure 3, the vertical profile diagram shows that after the eruption of Merapi in 2010, tree stands had begun to form scattered across the research plots with different strata. Besides, several species are evenly distributed with the dominant altitude in this plot, namely *A. decurrens*. The horizontal profile diagram shows that many tree canopies cover and piled up at the sampling station. Besides *A. decurrens,* there are several species such as *Albizia chinensis* (orange color in Figure 3), *C. calothyrsus* (black color in Figure 3), *Eugenia uniflora* (Dark blue in Figure 3), *Trema orientalis* (light green color in Figure 3) appear to have a larger canopy diameter than other species.

Station C at Pakem-Turi Resort which suffered minor damage after the 2010 Merapi eruption, was also dominated by 172 trees/0.1 ha of trees in Stratum C (Table 2). Stratum C at this station is dominated by *Schima wallichii* (red color in Figure 4) and *Syzygium polyanthum* (green color in Figure 4). In contrast, stratum D is only dominated by *S. polyanthum* with a density of up to 22 trees/0.1 ha (Table 2). There is only one tree *S. wallichii,* with a height of 21.7 m at station C, classified as a B stratum. Tree diversity (H') in station C as a representative of the minor damage area has a value of 1.08, classified as moderate diversity. The vertical profile diagram image (Figure 4) shows a tree stand structure that is very tight between one stratum and another. Figure 4 also shows much piling up of tree canopies covering the research station to look lush and causes limited sunlight. The tree density at station C is higher than at station B. However, the tree canopy diameter at station C is all under 10 meters.

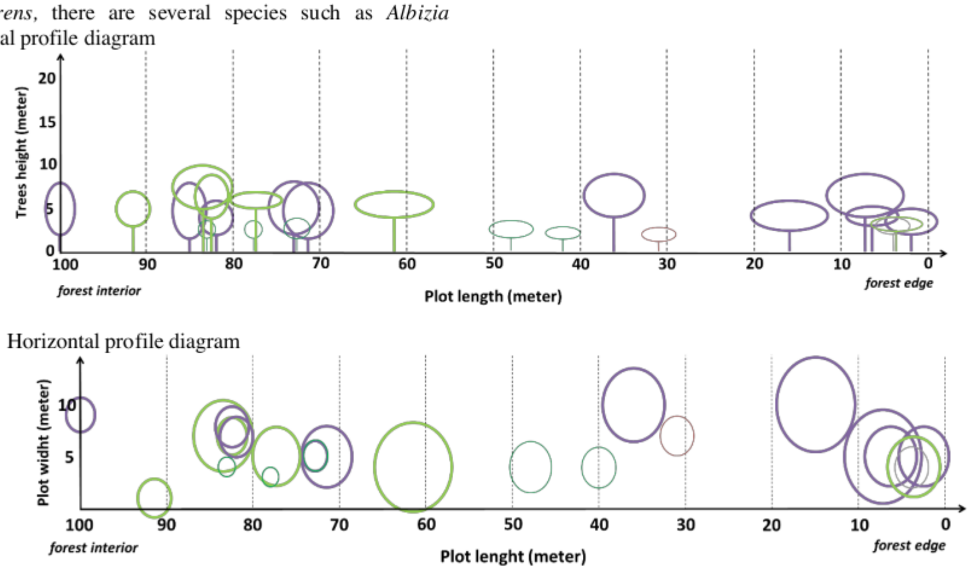

Figure 2. Profile diagram in Station A as a representative of heavy damage area

Table 1. Important value index of tree species in Station A

Rangking	Species Name	Family Name	Importance Value Index (IVI)
1	*Acacia decurrens* Willd.	Fabaceae	135.28
2	*Trema orientalis* (L.) BI.	Cannabaceae	97.31
3	*Syzygium polyanthum* (Wight) Walp.	Myrtaceae	44.31
4	*Mallotus paniculata* (Lam.) Mull.Arg.	Euphorbiaceae	11.85
5	*Schima wallichii* (DC.) Korth.	Theaceae	11.25

The tree arrangement in the profile diagram describes the forest stand's structure, the architectural shape, the distance between the trees, the tree size range, and the forest's age range (Leslie & Wilson, 2009). These trees' size and age can predict the history of a forest ecosystem and predict the future dominance of tree communities (Leslie & Wilson, 2009). The development of vegetation at the three research stations can be predicted through the profile diagram and vegetation density. Nine years after the Merapi big eruption in 2010, three stations are still classified as a young secondary forest characterized by the highest tree dominance in stratum C between 4 and 20 meters or sapling. If analyzed from tree height and tree density, stations B and C enter the stage of young secondary forest, which is more mature than station A. Stations B and C have grown stratum B trees with a height of more than 20 meters and density of 127 to 195 trees/0.1 ha. Station A, which has experienced primary succession, is described as entering the early stages of a young secondary forest phase. The beginning of the formation of young secondary forests is marked by species' growth with species richness that are still limited and of the same age (Finegan, 1996; van Breugel; 2007). Station A, the heavy damage area, experienced the slowest succession among the other two stations with the lowest tree vegetation parameters (density, richness, a high tree, carbon stock) (Figure 2 and Table 2). Development in the secondary forest will be in line with the increase in the plant community's productivity, the development of the substrate (Indriyanto, 2006), the increase in diversity, and stratification (Odum, 1993).

Table 2**.** Density, richness, and carbon stock of tree species in sampling stations

Details	Unit	Station A	Station B	Station C
Stratum A (height(h)≥ 30m)	tree / 0.1 ha	-	-	-
Stratum B (30m<h≤20m)	tree / 0.1 ha	-	5	1
Stratum C (20m<h≤4m)	tree / 0.1 ha	16	82	172
Stratum D (4m<h≤1m)	tree / 0.1 ha	7	40	22
Tree Density	tree / 0.1 ha	23	127	195
Tree Dominance	$m^2\ ha^{-1}$	3.97	11.75	24.32
Tree richness	Species	5	25	26
H' Shannon Wiener		0.55	1.18	1.08
Tree carbon stock	$t\ C\ ha^{-1}$	12.73	35.32	88.85

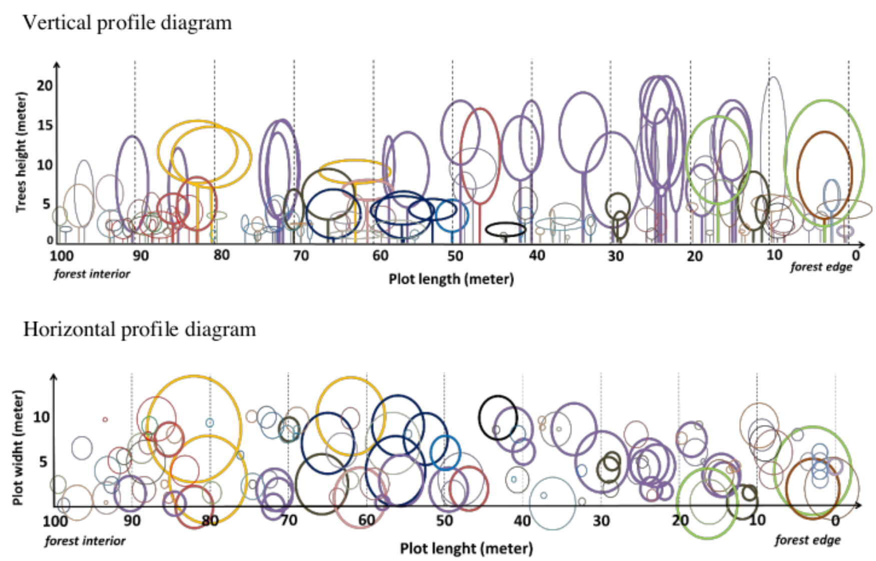

Figure 3. Profile diagram in station B as a representative of moderate damage area

Table 3. Important value index of tree species in Station B

Rangking	Species Name	Family Name	Important Value Index (IVI)
1	*Acacia decurrens* Willd.	Fabaceae	76.57
2	*Caliandra calothyrsus* Meisn.	Fabaceae	36.35
3	*Schima wallichii* (DC.) Korth.	Theaceae	23.08
4	*Leucana leucocephala* L.	Fabaceae	18.30
5	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	17.50

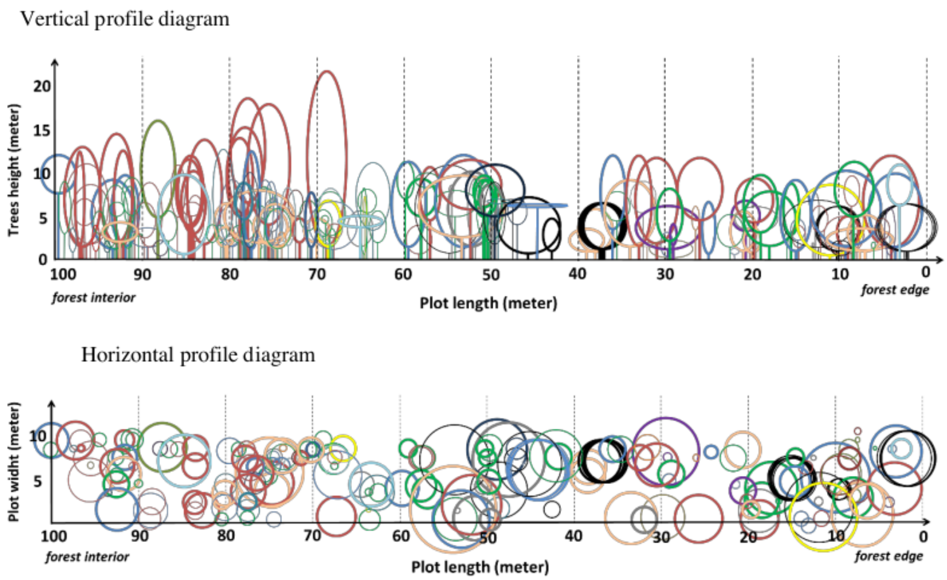

Figure 4. Profile diagram in station C as a representative of minor damage area

Table 4. Important value index of tree species in Station C

Rangking	Species Name	Family Name	Important Value Index (IVI)
1	*Arenga pinnata* (Wumb) Merr.	Arecaceae	63.37
2	*Schima wallichii* (DC.) Korth.	Theaceae	53.65
3	*Syzygium polyanthum* (Wight) Walpers	Myrtaceae	44.68
4	*Altingia excelsa* Noronha	Altingiaceae	30.88
5	*Cestrum nocturnum* L.	Solanaceae	23.42

Forest areas with high diversity can be achieved if there is an even distribution of different species and are not dominated by one species (Samin et al., 2016; Toni et al., 2017; Sutrisna et al., 2018). Stations A and B, which have an average soil pH ranging from 5-6, an area slope of 4° - 21°, and both in an area of 1,170 m asl and 891 m asl, now appear to be dominated by *Acacia decurrens*. The Cangkringan area was previously composed of diverse vegetation such as *Altingia excelsa, Schima wallichii, Pinus merkusii* (Sutomo, 2019b). However, after the 2006 eruption, which opened the crater towards Kaliadem Cangkringan, Cangkringan Resort to the east of Pakem-Turi Resort was controlled by *A. decurrens* (Utami et al., 2021). This plant is predicted to be an alien invasive species that grows in areas affected by eruptions both in Merapi and in Merbabu National Park (Purwaningsih, 2010; Untoro et al., 2017). Initially, this species was introduced by Perhutani in the 1980s to border the plantation area to the forest in MMNP. *Acacia decurrens* resistance to extreme conditions, this species began to invade the areas affected by the volcano eruption (Sunardi et al, 2017).

Acacia decurrens species can germinate and grow at low pH, high substrate temperature (Afrianto et al., 2017) and steep slopes area (Untoro et al., 2017). The Mount Merapi National Park Office has anticipated this expansion by planting local species in the area as rehabilitation action (Gunawan et al., 2013). Planting local species such as *Schima wallichii* has begun to appear at the Cangkringan Resort, although it is still in a sloping area. Station B also contains introduced plants such as *Albizia chinensis*, starting to have a high density.

Albizia chinensis plants were found in residents' agricultural land right next to the MMNP station B area. Station B is also included in the utilization zone (BTNGM, 2016) so the resident is still free to enter this area even though they cannot plant plants for personal gain.

The stratification or vertical structure of a forest can be used as an indicator that describes the diversity of vegetation and other ecosystem services, such as estimates of carbon storage (carbon stock) (Houghton, 2005; Treuhaft et al., 2008; Ensslin et al., 2015). The level of diversity was influenced by number of individuals, number of species, and tree basal area (Hidayat, 2017). The lowest tree carbon stock at station A (12.73 t C ha^{-1}) and its low diversity (H' 0.55) are predicted to be associated with several vegetation parameters. Station A has the lowest tree dominance, namely 3.97 m^{2} ha^{-1}, the lowest species richness is five species and the lowest tree density compared to the other stations are 23 trees/0.1 ha (Table 2). The tree vegetation at stations B and C are included in the medium category (1 <H '<3) (Table 2). The diversity value also can be influenced by the high density, dominance, and richness at stations B and C, which is higher than station A (Table 2). Table 2 shows that the tree density at station C reaches 195 trees/0.1 ha and contributes to the highest tree carbon stock value, namely 88.85 t C ha^{-1}. According to the Intergovernmental Panel on Climate Change (IPCC), the recommended carbon stock for secondary forests in Southeast Asia is above 138 t C ha^{-1}. This value includes aboveground biomass, necromass, and soil organic carbon (IPCC, 2006). In this study, only tree biomass was calculated, so it cannot be accurately compared with the IPCC recommendation.

The three sampling stations have varying mean values in several abiotic parameters that describe specific microclimate conditions in the field (Figure 5). The condition with the lowest tree density and the canopy most open, Station A has the highest wind speed and light intensity values (Figure 5). The light intensity at station A ranges from 24,000 to 118,900 lux, and the wind speed ranges from 2.0 to 4.5 kph. The high light intensity makes the average value of air temperature and soil temperature at station A the highest, namely 28 °C and 22.7 °C. Air humidity and soil humidity at Station A were the lowest among the other two locations, namely 51.3% and 48.4%. At station C, the microclimate conditions are the opposite of station A. Station C, which has the highest tree density with a reasonably dense canopy, has the lowest light intensity and wind speed values, ranging from 1.148 to 8.390 lux and 0.4 to 1.6 kph. This situation makes the air temperature and soil temperature at location C the lowest with an average of 24.9 °C and 18.2 °C. Air humidity and soil humidity at Station C were relatively high, namely 75.2% and 52.5%. The three research stations are above 800 m asl, where station A occupies the highest point, namely 1,170 m asl, and station B is in the lowest location at 891 m asl. The measured abiotic parameters, with Pearson test, such as wind speed, air temperature, humidity, soil humidity, soil temperature, light intensity, and elevation, correlate with tree density at the three research stations (Table 5). Air humidity and soil moisture positively correlate with tree density, while other abiotic have a negative correlation. In this study, only soil pH does not correlate with tree density.

The microclimate in terrestrial ecosystems, such as in tropical mountain forests, plays an essential role in vegetation growth and development (Xu et al., 2004; Behera et al., 2012). These environmental parameters will also be dynamic and environmental changes that occur due to human activities or natural disasters. In Figure 5, it can be seen that microclimate conditions in open areas such as at station A with areas with dense vegetation such as stations B and C are quite different in several parameters. High enough light intensity at station A can affect the process of seed germination plus rainfall during sampling, which is in the high category, namely 300-400 mm (Ridwan, 2019). Fundamentally, the processes of photosynthesis, germination, nutrient cycling, to growing height are influenced by solar radiation, wind speed, air, and soil temperature, humidity, and other abiotic properties (Gehlhausen et al., 2000; Davies-Colley et al., 2000; Beckage & Clark 2003). Even in forest ecosystem, changes in the structure and composition of vegetation above ground level are influenced by environmental parameters and affect these parameters (Rodríguez-Ramírez et al., 2018). Ground level, slope, topography, and even gaps between the canopies influence the succession that occurs after the disturbance (Xu et al. 2004; Godefroid et al., 2006).

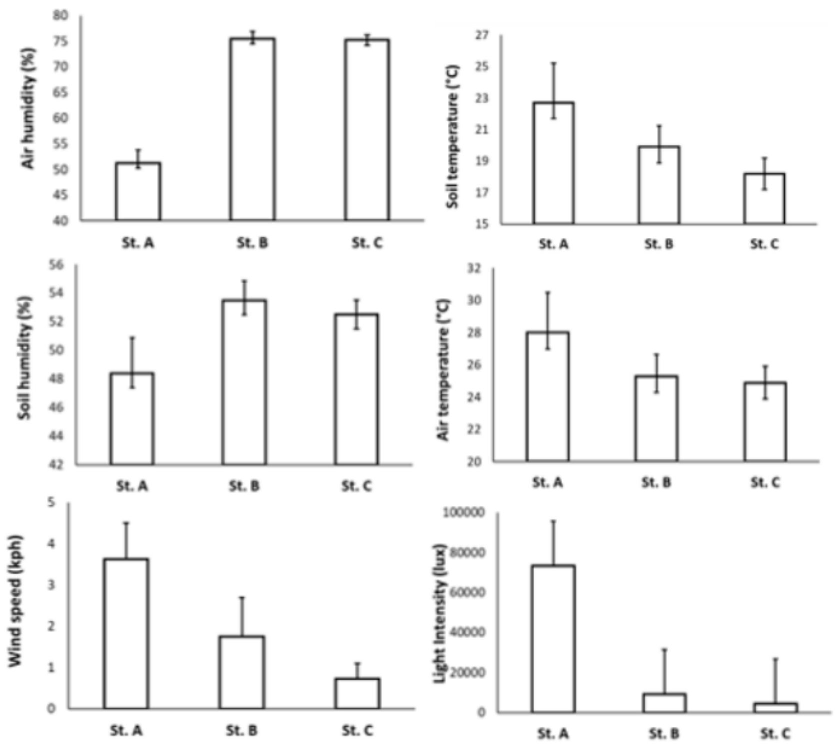

Figure 5. The average of abiotic parameters in three sampling stations

Table 5. Correlation between tree density and abiotic parameters

Compared Parameters		**Correlation coefficient**	**Sig (2-tailed)**
Tree density	Wind Speed	-.801**	.000
	Air temperature	-.473**	.008
	Air humidity	.677**	.000
	Soil humidity	.678**	.000
	Soil temperature	-.817**	.000
	Light intensity	-.771**	.000
	Elevation	-.504**	.005

CONCLUSION

Nine years after the Mount Merapi big eruption, the MMNP forests in Yogyakarta Province are still classified as young secondary forests. The three sampling stations with varying damage levels after Mount Merapi's eruption in 2010 were dominated by trees from stratum C. However, the tree composition varies at each station. Station A in the heavy damage area is still entering the early stages of the young secondary forest phase, characterized by the lowest tree density of around 23 trees/0.1 ha and a maximum tree height of only 12 meters. In contrast, Station C in the minor damage area with tree density reaching 195 trees/0.1 ha and maximum tree height reaching 30 meters. abiotic parameters, such as wind speed, air temperature, air humidity, soil humidity, soil temperature, light intensity, and elevation, correlate with tree density at the three research stations.

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