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Forest tree dynamics from the first four years of permanent plot in Mount Papandayan, Indonesia: mortality, recruitment, and growth

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Abstract A permanent plot is a powerful tool to study the vegetation's dynamics and regeneration in the forest ecosystem. This study presents the first four-year tree vegetation monitoring in a one-hectare permanent plot established in a mixed forest of Mount Papandayan (MP) Nature Reserve, Indonesia. Besides studying the structure and floristic tree community composition in the plot, this study aims to study the changes and in mortality and growth of the tree community after four years of plot establishment. A one-hectare permanent plot was established in 2010 and all trees inside the plot with a diameter over 5 cm were tagged and measured in 2011 and 2015. There were 1,820 trees from 33 species and 20 families recorded during the first monitoring in 2011. Four years later, there were more trees recorded (1,845 trees) with an average growth rate of 1.17 cm. The mortality rate (2.8%) was lower than the recruitment rate (4.2%) and there were no changes in the domination of *Distylium stellare*. The results of this study will help to provide the preliminary data on actual *in situ* tree mortality and growth, which will help to develop a more complete tree species selection criteria for MP restoration.

Keywords: *Distylium stellare*, forest restoration, tropical montane forest, long-term vegetation monitoring.

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Introduction

Understanding the long-term dynamics of the tree community in the forest through establishing a permanent plot is crucial for conservation and management purposes (Baithalu et al. 2013, Brearley et al. 2019). For instance, changes caused by the increase of human pressure and climate change in the future forest community and how the tree species respond can be predicted (Chazdon et al. 2005, Murthy et al. 2016).

As the country with the 8th largest forest area in the world, yet the top third on global deforestation rate in the last decade (FAO, 2020), Indonesia faces an enormous challenge in restoring its rainforest ecosystem. The equatorial location of this archipelago makes it vulnerable to the predicted scenario of climate change (Cai et al. 2014, Dore 2005, Measey 2010).

Forest restoration is one solution to ensure the delivery of ecosystem services provided by the forest (e.g., carbon sink, carbon sequestration, climate regulation), which may alleviate the climate change effects. The fundamental problem in designing a proper forest restoration project in the multi-diverse tropics was often the availability of knowledge on local or native tree species propagation. Numerous past reforestation projects in Indonesia did not show promising results yet on restoring the forest ecosystem. One of the reasons was the use of non-native, commercial tree species (Otsamo et al. 1997, Subiakto et al. 2016).

Using native tree species in restoring the forest ecosystem has been increasingly recognized as the most effective way to restore ecosystem functions and related biodiversity (Lu et al. 2017, Thomas et al. 2014). Several succesful reforestation projects using native tree species were from the Brazilian Atlantic forest (Rappaport & Montagnini 2014), Green Tide Embankment in Japan (Miyawaki 2014), tropical rainforest of Malaysia (Majid 2014), and tropical forest of Thailand (FORRU 2006, Jalonen & Elliott 2014).

Mount Papandayan (MP) area is an active volcano surrounded by forest area in southwest Garut, West Java, Indonesia. The combination of volcanic activity and other natural disturbances, such as periodic fire, have shaped several unique types of ecosystems in this area. Previous studies have revealed at least five types of ecosystems, i.e., crater vegetation, grassland, mixed forest, post-volcanic eruption forest, and post-agricultural abandoned field with its unique vegetation community (Setiawan & Sulistyawati 2008, Sulistyawati et al. 2006, Sulistyawati & Fitriana 2017). Unfortunately, changes in the government policy and human exploitation (e.g., illegal sulfur mining activity, illegal logging, forest conversion into an agricultural field, etc.) in this area have significantly reduced the vegetation cover (Sulistyawati et al. 2008). As a part of the upper Cimanuk watershed area, the reduction in the vegetation cover of MP area has caused disasters, such as the great flood that caused deaths at Garut regency in 2016.

There were already several tree re-planting program initiated by the government and the local community to rehabilitate the degraded areas of MP. However, these programs mostly used commercially available tree species from the local nurseries since there is a lack of knowledge on how to propagate non-commercial, native tree species from the conservation area. Besides that, comparative data on the actual *in situ* native tree species mortality and growth is also unknown. Studying the dynamics of tree communities in a permanent plot is a way to answer this problem.

This study is a part of a long-term, comprehensive study on Mount Papandayan vegetation and ways to restore its degraded forest areas. Currently, the native tree species selection for restoration in MP is being developed by collecting information on its phenology (Sulistyawati et al. 2012), seed dispersal (Setiawan & Sulistyawati 2020), seedling mortality and growth, also several traits related to photosynthetic and growth capacity (Prasetyo et al. 2017, Sulistyawati & Hidayati 2017). This study aims to: (1) establish a one-hectare permanent plot in the montane area of Mount Papandayan and conduct a tree species inventory, (2) study the structure and floristic tree community composition of mixed forest in Mount Papandayan, also (3) study the changes in mortality and growth of the tree community after four years of plot establishment. The result of this study will help to provide the preliminary data on actual in situ tree mortality and growth, which will help to develop a more complete tree species selection criteria for MP restoration.

Materials and Methods

Study Area

The study area (Fig. 1) was located in Mount Papandayan (MP), West Java, Indonesia. Mount Papandayan is divided into two main areas, i.e., nature reserve area (6.807 ha) and natural park (225 ha) (Balai Konservasi Sumber Daya Alam Jabar II 2003). The study area was located in the nature reserve area at 7º17'56 S 107º43'34.9 E, 2 262 m asl. The plot location was based on preliminary survey results, which show that this area exhibited a typical physiognomy of the surrounding mixed forest area and less disturbed by the people. According to van Steenis et al. (2006), this area is classified as an upper montane zone (Fig. 1). The climate of this area is type B based on Schmidt and Ferguson rainfall classification, with average rainfall 2,500-3,000 mm/year, evaporation 76-85 mm/month, humidity 70-80%, and mean annual temperature of 10º to 25ºC.

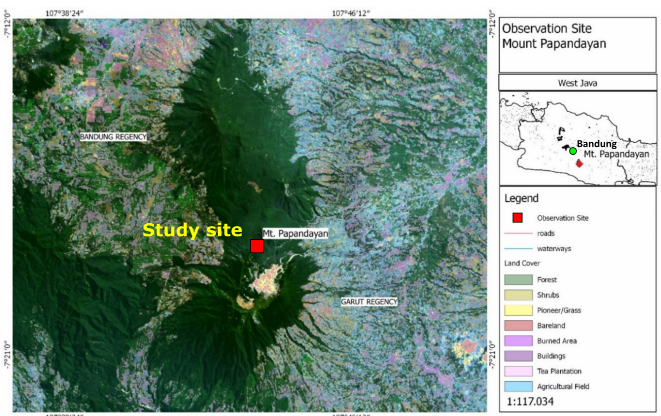

Figure 1 The location of one-hectare permanent plot established in Mount Papandayan, Indonesia.

Tree inventories

In this study area, a one-hectare (100 x 100 m^2) permanent plot was established in the year 2011. Each plot corner was marked with visible stakes and the plot was further divided into workable units of 100 sub-plots (10 x 10 m^2) to make the measurement process and plot orientation easier. All trees with diameter breast height (DBH) more than 5 cm were tagged with aluminum tags containing the position of the tree in the grid (x and y coordinates) and the specific tree number.

The DBH of all tagged trees was measured at 1.3 m above ground. The tree measurement was done in 2011 and 2015. Vines, lianas and mosses on the tree trunk were not measured as a part of DBH; they were gently pulled away, and measurement tape was slid underneath to keep a minimum disturbance. Trees with more than one stem divided below the 1.3 m height were classified as one individual with multiple DBH that summed as one DBH ($=\mathrm{sqrt}(d_{branch1}^2 + d_{branch2}^2 + \ldots + d_{branchx}^2)$) for each individual.

All measured trees were identified to species level at the herbarium of the School of Life Science and Technology, Institut Teknologi Bandung (ITB). The species identification was based on identification books (Backer & van den Brink 1968, van Steenis et al. 2006), comparison with samples from previous studies (Setiawan & Sulistyawati 2020, 2008, Sulistyawati et al. 2012), and information from local informants. The species and family names were also checked with the latest online identification key (www.theplantlist.org, www.worldfloraonline.org) to obtain verified results. All specimens were kept in Herbarium Bandungense, ITB. All trees were also checked for their wood density based on the Indonesian tree functional attributes and ecological database developed by World Agroforestry Center (www.db.worldagroforestry.org/wd). The wood density was classified based on the classification proposed by Melo et al. (1990): light (<0.5 g/cm^3), medium (0.5-0.72 g/cm^3), heavy (>0.72 g/cm^3).

Data analysis

All analyses were done in R version 4.0.2 (R Core Team 2020); graphs were made with the R package *ggplot2* (Wickham 2009). Even though the measurement process was based on the 100 subplots of 10 x 10 m, the overall analysis was based on the main one-hectare plot. The plot diversity level was calculated using the Shannon diversity index (Magurran 2013). The species dominance in the plot level and different diameter size class was measured using Importance Value Index (IVI; Curtis & McIntosh 1950) based on its relative frequency and basal area.

There were 278 trees (16.1% of living trees in both studied years) with lesser DBH recorded in 2015 and mostly were trees with multiple branches with some dead branches in 2015, thus giving a "minus" in the growth value. Thus, to avoid misinterpretation in the analysis, the growth data used for statistical analysis were the "positive growth" or the ones with DBH changes more than 0 cm. The growth data were inspected for normality and log-transformed. Then, ANOVA was used to check whether there were significant differences between the mean growth as a response variable and different explanatory variables (i.e., diameter size class, family name, species name). The residual of ANOVA was inspected for spatial autocorrelation using variogram with package *gstat* and *sp* (Borcard et al., 2011; Pebesma and Wesseling, 1998). Last, regression analysis was used to see the relationship between mean growth as a response variable and initial (2011 data) diameter as an explanatory variable. Residuals were inspected, and a visualization graph was made.

Results

Stand community characteristics

There were 1,820 trees with DBH larger than 5 cm recorded in 2011 (Table 1). Those trees consisted of 20 families and 33 species with the Shannon diversity index of 2.78. In 2015, more trees were recorded (1,845; Table 1), but with lesser species richness (19 families, 32 species) and Shannon diversity index of 2.77.

Table 1 The 20 families of 33 tree species found in the permanent plot and their density per hectare in the year 2011 and 2015.

No.	Loci	Density/ha		Wood density (g/cm^3)*	Wood density class**
		2011	2015		
Araliaceae					
1.	*Macropanax dispermus* (Bl.) Kuntze	47	45	0.31	Light
2.	*Schefflera lucescens* (Bl.) R. Vig.	1	2	0.41	Light
Compositae					
3.	*Vernonia arborea* Buch. Ham.	1	0	0.37	Light
Elaeocarpaceae					
4.	*Elaeocarpus submonoceras* Miq.	11	11	0.52	Medium
Escalloniaceae					
5.	*Polyosma ilicifolia* Bl.	99	98	0.60	Medium
Fagaceae					
6.	*Lithocarpus elegans* (Bl.) Hatus. ex Soepadmo	40	43	0.81	Heavy
7.	*Lithocarpus sundaicus* (Bl.) Rehder	3	3	0.77	Heavy
8.	*Quercus lineata* Bl.	7	7	0.77	Heavy
Hamamelidaceae					
9.	*Distylium stellare* Kuntze	346	340	0.75	Heavy
Juglandaceae					
10.	*Engelhardia spicata* (Lesch.) ex Bl.	48	45	0.37	Light
Lauraceae					
11.	*Cinnamomum parthenoxylon* (Jack) Meissn.	27	25	0.54	Medium
12.	*Lindera bibracteata* (Bl.) Boerl.	7	7	0.52	Medium
13.	*Litsea diversifolia* Bl.	39	42	0.52	Medium
14.	*Neolitsea javanica* (Bl.) Backer	214	214	0.55	Medium

Table 1 The 20 families of 33 tree species found in the permanent plot and their density per hectare in the year 2011 and 2015.

Melastomataceae					
15.	*Astronia spectabilis* Bl.	224	240	0.50	Medium
16.	*Melastoma trachyphyllum* Backer ex Bakh. F.	2	2	0.44	Light
Myrtaceae					
17.	*Syzygium glabratum* (DC.) Veldkamp	52	54	0.71	Medium
18.	*Syzygium glomeruliferum* Amsh.	77	78	0.71	Medium
19.	*Syzygium polyanthum* (Wight) Walp.	8	7	0.53	Medium
Pentaphylacaceae					
20.	*Eurya acuminata* DC.	25	26	0.56	Medium
Phyllanthaceae					
21.	*Antidesma montanum* Bl.	15	14	0.66	Medium
Podocarpaceae					
22.	*Dacrycarpus imbricatus* (Bl.) de Laub.	57	57	0.50	Medium
23.	*Podocarpus neriifolius* D. Don.	38	37	0.52	Medium
Primulaceae					
24.	*Ardisia javanica* A. DC.	6	7	0.58	Medium
25.	*Myrsine affinis* A. DC.	24	25	0.70	Medium
Proteaceae					
26.	*Helicia serrata* Bl.	7	7	0.58	Medium
Rutaceae					
27.	*Acronychia pedunculata* (L.) Miq.	99	103	0.51	Medium
Sapindaceae					
28.	*Acer laurinum* Hassk.	24	22	0.60	Medium
Staphyleaceae					
29.	*Turpinia montana* (Bl.) Kurz	21	19	0.60	Medium
Symplocaceae					
30.	*Symplocos fasciculata* Zoll.	175	186	0.37	Light
31.	*Symplocos lucida* (Thunb.) Siebold & Zucc.	5	5	0.63	Medium
Theaceae					
32.	*Pyrenaria serrata* Bl.	70	72	0.47	Light
33.	*Schima walichii* Choisy	1	1	0.59	Medium
	Total density/ha	**1,820**	**1,845**		

Note:*based on the World Agroforestry Center tree database (2016).
**Wood density based on the classification by Melo et al (1990): light (<0.5 g/cm^3), medium (0.5-0.72 g/cm^3), heavy (>0.72 g/cm^3).

The DBH class frequency distribution of all trees in both measurement years (Fig. 2a & 2b) showed that the highest number of individuals was on the lowest DBH class (5-10 cm). The frequency of DBH classes has a steep declining logarithmic curve with an exponential decrease of frequency along with the increase in DBH size class. Compared to 2015, the curve is slightly steeper in 2011. The frequency of the DBH class 5-10 cm was slightly lower in 2015, meaning that there were fewer smaller trees in 2015.

In both measurement years, basal area per hectare increased with an increase in the tree diameter and reached a peak at DBH class 30-40 cm. Afterward, the basal area decreased with an increase in the tree diameter (Fig. 2c & 2d). In both measurement years, the proportion of trees on three different wood density classes was almost similar. There were more trees with medium wood density (59%) compared to light (19%) and heavy wood density (22%; Fig. 3). When the data was split into each wood density class, the distribution of trees based on their diameter size class also shown a similar cascading pattern where an increase in tree diameter size resulted in a decrease in the tree density (Fig. 4). However, the curve was steeper for trees with light and medium wood density.

The most dominant tree in both measurement years was *D. stellare* (Table 2). Indeed, *D. stellare* was also the most abundant tree species found in both years (19.0% from the total abundance in 2011, 18.4% in 2015). The dominant trees of each diameter size class were consistent in the year 2011 and 2015 (Table 2).

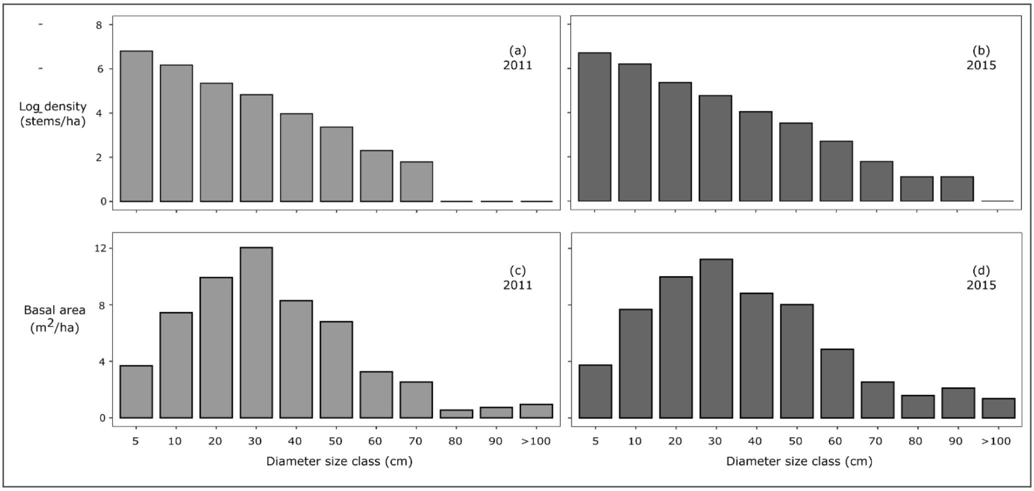

Figure 2 The tree stand structure of one hectare permanent plot in Mount Papandayan: log tree density (stem/ha) based on different diameter size class measured in year 2011 (a) and 2015 (b); and annual basal area (m^2) based on different diameter size class measured in year 2011 (c) and 2015 (d).

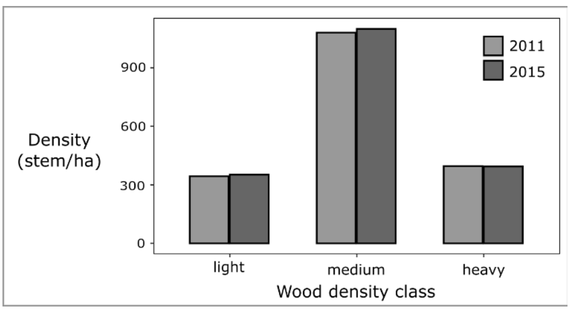

Figure 3 Tree density per hectare based on three wood density classification (Melo et al., 1990; see Table 1 for more detail).

Almost all diameter size classes were dominated by D. stellare, except the smallest DBH class 5-10 cm (*A. spectabilis* and *S. fasciculata*) and biggest DBH class >100 cm (*S. polyanthum*). The dominance of *A. spectabilis* and *S. fasciculata* in the smallest DBH class was due to their high abundance in both years (AS: 15.8% in 2011, 16.2% in 2015; SF: 14.8% in 2011, 15.2% in 2015). Meanwhile, *S. polyanthum* was the most dominant in the biggest DBH class since no other tree species were reaching this diameter size.

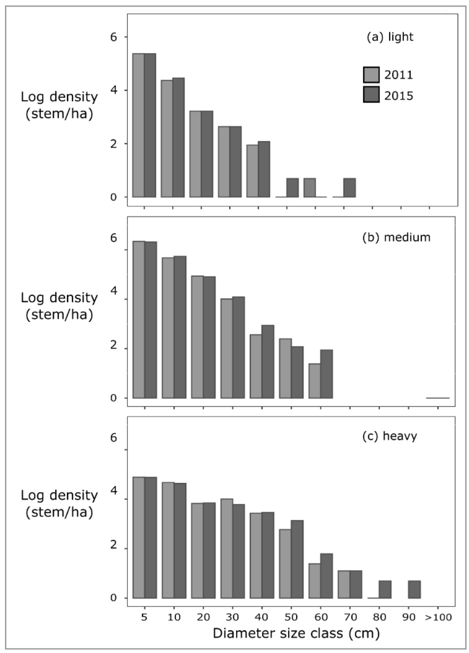

Figure 4 Log tree density per hectare based on different size classes and different wood density classes sampled in 2011 and 2015: (a) light wood density, (b) medium wood density, and (c) heavy wood density.

Table 2 The most dominant species in different diameter size class at two different monitoring years (2011&2015) based on their Importance Value Index (IVI).

Diameter size class (cm)	Number of species		Species with the highest IVI*	
	2011	2015	2011	2015
All class	33	32	D. stellare (58.3)	D. stellare (58.4)
5-10	31	31	A. spectabilis (30.6) & S. fasciculata (29.8)	A. spectabilis (31.6) & S. fasciculata (29.8)
10-20	29	28	D. stellare (38.2) & N. javanica (32.6)	D. stellare (37.3) & N. javanica (32.6)
20-30	21	21	D. stellare (40.5)	D. stellare (40.7)
30-40	18	18	D. stellare (84.7)	D. stellare (85.5)
40-50	10	10	D. stellare (113.7)	D. stellare (115.2)
50-60	9	8	D. stellare (117.3)	D. stellare (128.9)
60-70	7	7	D. stellare (81.1)	D. stellare (82.9)
70-80	3	3	D. stellare (134.9)	D. stellare (136.0)
80-90	1	1	D. stellare (200)	D. stellare (200)
90-100	1	1	D. stellare (200)	D. stellare (200)
>100	1	1	S. polyanthum (200)	S. polyanthum (200)

Notes: *Importance Value Index was calculated based on the species' relative density and relative basal area. The maximum IVI value is 200.

Mortality and recruitment

There were 52 trees dead (21 species, 2.8%) from the ones recorded in 2011, and 77 new trees recruited (17 species, 4.2%). Most of the dead trees were small-sized trees (DBH class 5-10 cm: 28 trees, 10-20 cm: 13 trees; Fig. 5) and from species *D. stellare* (12 trees) and *N. javanica* (8 trees). Most of recruited trees belong to the smallest diameter class (94.8%). The recruited trees were mostly *A. spectabilis* (19 trees) and *S. fasciculata* (12 trees).

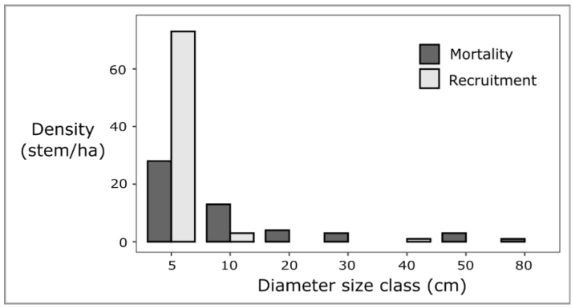

Figure 5 Tree mortality and recruitment found in one-hectare permanent plot during 2011-2015 based on different diameter size classes.

Growth

The overall mean growth in four years was 1.17 ± 0.06 (SE; standard error) cm or 0.29 ± 0.02 cm/year. The highest mean growth was shown by family Phyllantaceae (A. montanum) with a growth rate of 0.75 ± 0.46 cm/year (Fig. 6). The lowest mean growth was shown by family Theaceae (S. wallichii) with a growth rate of 0.10 ± 0.02 cm/year. When mean growth was compared between diameter size classes, the mean growth

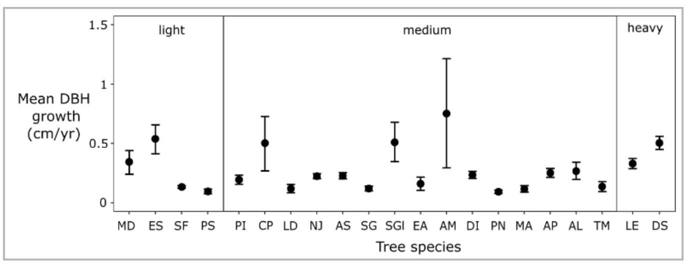

Figure 6 Mean annual diameter growth (± standard error of mean) of 21 tree species with more than 10 individuals showed positive growth during 2011-2015. Species were grouped based on their wood density class (MD: *Macropanax dispermus*, ES: *Engelhardia spicata*, SF: *Symplocos fasciculata*, PI: *Polyosma ilicifolia*, CP: *Cinnamomum parthenoxylon*, LD: *Litsea diversifolia*, NJ: *Neolitsea javanica*, AS: *Astronia spectabilis*, SG: *Syzygium glabratum*, SGl: *Syzygium glomeruliferum*, EA: *Eurya acuminata*, AM: *Antidesma montanum*, DI: *Dacrycarpus imbricatus*, PN: *Podocarpus neriifolius*, MA: *Myrsine affinis*, AP: *Acronychia pedunculata*, AL: *Acer laurinum*, TM: *Turpinia montana*, LE: *Lithocarpus elegans*, DS: *Distylium stellare*; (see Table 1 for more details on each species).

increased along with the increase in the diameter class (Fig. 7). The only exception was the mean growth of DBH class 90-100 cm and 80-90 cm (no growth recorded). It seems that the variation in growth was low in the trees with a low diameter (DBH class 5-10 up to 40-50 cm). There was no variation recorded for trees with a higher diameter (90-100 and >100 cm) since there was only one tree with growth data recorded for each class.

Table 3 Result of analysis of variance (ANOVA) with mean diameter growth as response variable and different explanatory variables (diameter class size, species name, and family name). Significant p-value in bold.

Explanatory variables	Df	Sum Sq	Mean Sq	F-value	p-value (>F)
Diameter size class	9	393.8	43.8	31.7	**<0.001**
Species name	18	89.7	5.0	3.6	**<0.001**
Family	13	35.7	2.7	2.0	0.019
Residuals	1,053	1,453.9	1.4		

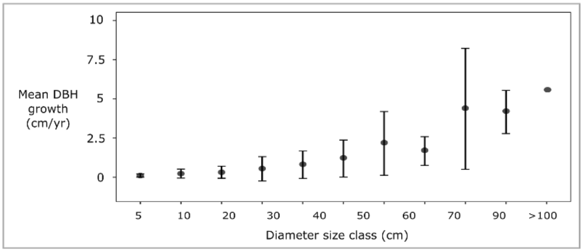

Figure 7 Mean annual diameter growth (± standard error of mean) of different diameter size class trees during 2011-2015.

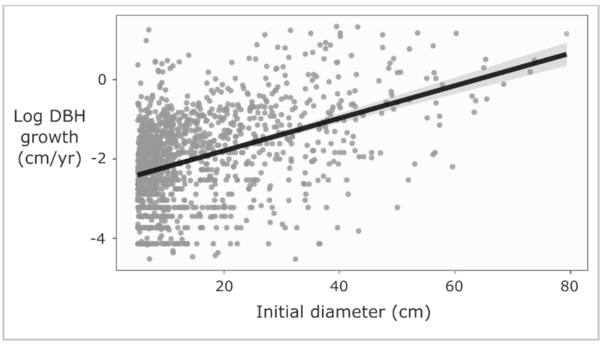

Figure 8 Positive relationship between mean annual growth rate and initial (2011) diameter. The line represents logistic regression with 95% CI.

The analysis of variance on growth data showed that there were significant differences in growth between different diameter size classes and species (Table 3). Indeed, this result strengthens the interpretation from previous data visualization (Fig. 6 & 7). The inspection of ANOVA residuals by plot visualization and variogram did not show any homogeneity of variance nor spatial autocorrelation. Since there were too many categories in the explanatory variables used in ANOVA, a further post-hoc test was considered not appropriate.

The simple regression of overall tree species showed that the initial (2011) tree diameter positively affect the tree diameter growth (Table 4, Fig. 8). Bigger trees tend to have bigger diameter growth compared to the smaller ones.

Table 4 Result of regression analysis with diameter growth as response variable and initial diameter of different groups as explanatory variables. Significant p-value in bold. See Fig. 8 and 9 for visual results.

Explanatory variables	Df	R^2	t-value	p-value (>t)
Initial DBH (2011)				
All species	1,370	0.19	17.9	**<0.001**
Astronia spectabilis	185	0.33	2.7	**0.007**
Distylium stellare	256	0.26	9.4	**<0.001**
Engelhardia spicata	38	0.46	5.8	**<0.001**
Neolitsea javanica	158	0.29	8.2	**<0.001**
Symplocos fasciculata	141	0.02	2.1	0.037
Syzigium glomeruliferum	51	0.46	6.7	**<0.001**

Next, we selected tree species with the highest abundance and consisted of at least five size classes. There were six tree species selected based on those categories, i.e., *A. spectabilis*, *D. stellare*, *E. spicata*, *N. javanica*, *S. fasciculata*, and *S. glomeruliferum* (Fig. 9). In general, there were more individuals with positive growth in the small diameter size class (5-10 and 10-20 cm). The number of individuals in the smallest size class decreased drastically (i.e., more than 60%) in the next size class for *A. spectabilis* and *S. fasciculata*. For

N. javanica, the number decreased drastically from size class 10 to 20. The abundance of the most dominant *D. stellare* also decreased with an increase in the diameter size class, however, it seems that the changes happen gradually (Fig. 5). The variation in mean growth was low in the small diameter size class. The high diameter size class has a high variation or undetectable variation since there was only one individual recorded in the class, for instance, in *D. stellare* (class 50, 70, 90), *E. spicata* (class 30, 40, 60, 70), *S. fasciculata* (class 20, 30, 40), and *S. glomeruliferum* (class 30, 50, 70).

When tree diameter growth of those six selected species was analyzed using simple regression against the initial (2011) tree diameter, five species showed a similar pattern with overall trees (Table 4, Fig. 9). The initial tree size measured in 2011 positively affects tree diameter growth, with a relatively steeper

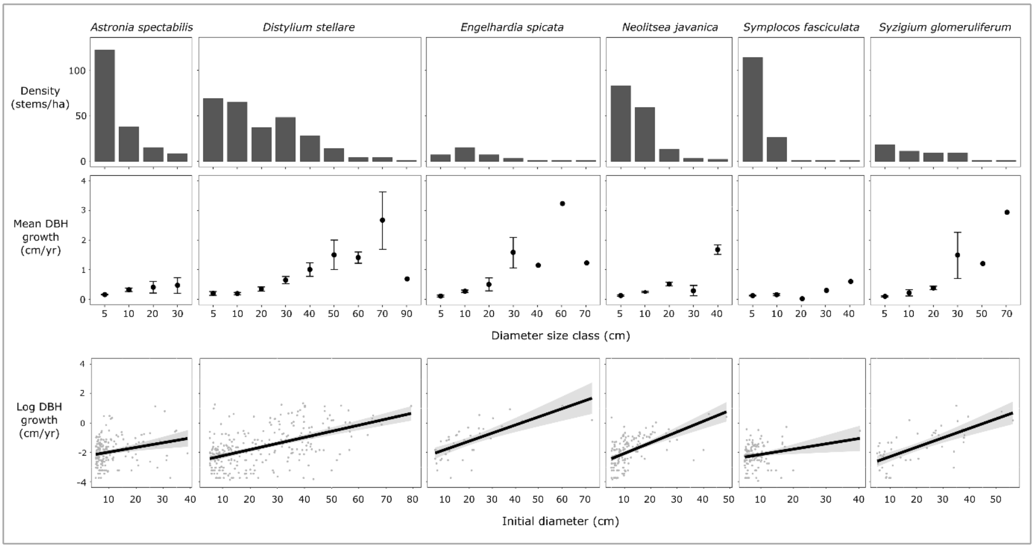

Figure 9 The frequency, mean, and logistic regression of annual diameter growth (± standard error of mean) of six tree species with different diameter sizes during 2011-2015. The species were selected based on their high abundance and consisted of at least five diameter size classes .

Table 5 Comparison with other tree structure and composition studies on montane forests.

Variable	This study (data 2011)	Yamada (1975)	Lieberman (1996)	Mohandass *et al.* (2016)	Yamada (1975)	Culmsee *et al.* (2011)
Location	Mount Papandayan	Mount Gede Pangrango, Indonesia	Volcan Brava, Costa Rica	Western Ghats, Southern India	Mount Gede Pangrango, Indonesia	Central Sulawesi, Indonesia
Area (ha)	1	1	1	1	0.1	0.24
Altitude (m asl)	2,262	1,400	2,300	1,900-2,033	2,100	2,350
Minimum DBH (cm)	10	10	10	10	10	10
Species richness	30	57	44	56	14	40
Number of families	20	30	32	30	13	23
Stand density (ind/ha)	917	427	572	1,224	840	1,025
Average DBH (cm)	23.3	-	24.4	-	-	21.6
Max DBH (cm)	109.9	-	164.9	-	-	81
Basal area (m^2/ha)	52.55	-	41.76	52.36	-	50.8
Shannon-Wiener	2.78	3.35	3.46	3.24	1.9	3.19

regression line showed by *E. spicata*, *N. javanica*, and *S. glomeruliferum*.

Comparison with other studies

Most of the other permanent plot data in Indonesia used trees with at least 10 cm DBH. To make this study comparable to those studies, Table 5 presents the subset data of this study using trees with DBH of at least 10 cm. Compared to other similar studies in the montane forest ecosystem (Table 5), the permanent plot in this study has relatively low family and species richness. However, the stand density was higher than studies in Mount Gede (Yamada, 1975) and Volcan Brava (Lieberman et al., 1996).

Discussion

Stand structure and composition

The tree vegetation structure and composition from the observed permanent plot in this study showed similarities with other tree communities found in Javan montane forest ecosystem (Pratomo et al. 2012, Yamada 1975, Zuhri et al. 2016). The forest observed in this study formed a closed, tall canopy with diverse tree species from genus Juglandaceae, Hamamelidaceae, Myricaceae, Podocarpaceae, and Sapindaceae. These tree genera were also commonly found in the montane forest of Java and Lesser Sunda Island (van der Kaars & Dam 1995). The differences between these montane forests tree communities were their tree species relative proportion and dominance. The occurrences of these genera showed that they are well adapted to the environmental conditions of montane areas in Java.

The tree population in the forest changes over time as a response to environmental changes (e.g., resource availability or natural disturbances) and competition (intra-species and inter-species). By studying changes in population dynamics, the forest successional or maturity stage can be predicted. In our studied site, the tree community showed classic characteristics of mature forest, i.e., a steep logarithmic age/size distribution curve (Fig. 2), observed complex canopy stratification, basal area distribution curve (Fig. 2), and the higher proportion of medium to heavy wood density (Fig. 3). Wood density is one of the reliable predictors of the forest's successional stage (Slik 2005). Forest comprised of a higher proportion of trees with medium to heavy wood density is in a later successional stage compared to ones with a higher proportion of trees with low wood density (Slik et al. 2008). Wood density reflects the tree allocation of resources. Fast growth and light-demanding trees allocate their resources on a low-cost stem, but at the same time more vulnerable to damage and death (King et al. 2006). In contrast, slow growth and shade-tolerant trees may allocate their resources to denser stem and defences to resist biotic or abiotic disturbances.

In our studied plot, *D. stellare* was the most dominant tree species found in almost all size classes, and both measurement years (Table 2). The dominance of *D. stellare* in the mixed forest of Mount Papandayan was also reported from the previous study (Sulistyawati et al. 2006). Even though this tree species found in other forests in Indonesia (e.g., Papua (Marshall & Beehler 2012), Sumatra (Laumonier 1997), Java and lesser Sunda Island (Endress 1993)), no other studies showing the dominance of this species. The slow-growing, dense stem of this species indicates that this tree species belongs to the late-successional species group that can establish in the later stage of forest succession or a mature forest. This species could dominate the studied area, even though they are short-distance dispersed (Vink 1955) and reported suffering from gall-making aphids infestation (Abbot et al. 2018, Holman 2009). There are several main characteristics and strategies of late-successional species owned by this species that made their dominance possible, i.e., their investment in secondary metabolite for defence mechanism (Endress 1993), denser wood and damage resistant stem, and their efficiency on using nutrient.

Compared to the other studies in the montane tropical forest, the tree species richness is lower (Table 5). Possibly, the higher elevation of the studied plot compared to plots of Yamada (1975) and Mohandass et al. (2016) cause a lesser species to thrive and present. Some studies (Culmsee et al. 2011, Lieberman et al. 1996) in an almost similar elevation (Table 5) with the studied plot shown a higher species richness. Possibly, the studied site was less disturbed compared to those studies, since an intermediate level of environmental disturbance can create a suitable environment for both early and late-successional species to coexist (Slik 2005).

Stand regeneration and growth

One of the well-being indicators of the forest is a good regeneration rate (Murthy et al. 2002, 2016). There were not many changes in the tree community in our study site during the past four years. The slightly higher number of recruitments (4.2%) compared to mortality (2.8%) showed a sign of good forest regeneration. Besides that, the regeneration pattern shown as a steep declining logarithmic curve (Fig. 2) showed a mature, old-growth forest community. Recruited trees were mostly small-sized (Fig. 5), while the dead trees were present in various diameter classes. Most mortality cases happen in smaller diameter sizes since young trees are more vulnerable to disturbances or a weak competitor.

Different tree species and size classes in the studied plot showed different growth rates (Fig. 6, Fig. 7, Table 3). Even though species with a higher wood density generally have a lower growth rate than the ones with lower wood density (King et al. 2005), it seems that the growth of tree species in our studied plot was species-specific. Some species outperform the others due to their higher site-adaptability. The higher mean growth in a higher diameter size-class showed that the medium-sized trees were more established in the site; their stem is strong enough to support the entire crown, their rooting system is extensive enough to absorb necessary nutrients from the soil, and their crown area produces enough resources to support their growth.

Several tree species showing the dominance of their small individuals, i.e., *A. spectabilis*, *D. stellare*, *S. fasciculata*, and *N. javanica* (Table 2, Fig. 9). All those species were indeed species adapted to montane forest in Java (Cahyanto et al. 2019, Hakim & Miyakawa 2013, Junaedi & Mutaqien 2010, Pratomo et al. 2012, Zuhri et al. 2016). Among those species, *A. spectabilis* is known for its high regeneration rate and low wood density (Pratomo et al. 2012). Besides that, this species can adapt well to different kinds of habitat, and the wood can be used for construction (Hakim & Miyakawa 2013). Indeed, *A. spectabilis* was found throughout Mount Papandayan in different diameter size classes (Setiawan & Sulistyawati 2008, Sulistyawati et al. 2006).

Implication for forest restoration using tree selection criteria

The proper design of reforestation should integrate different functional traits of tree species. For instance, the differences in resource usage are crucial since they will ensure that different planted tree species will be able to utilize resources differently, thus reducing inter-specific competition. Besides that, differences in the leaf trait will minimize the risk of damage caused by generalist pests. Using native species is also crucial since it ensures the high adaptability of the seedlings to the local environmental factors and maintains the related animal diversity. MPNR itself is an important habitat for several protected species, e.g., Javan leopard (*Panthera pardus melas*), Javan langur (*Trachypitechus auratus*), Javan surili (*Presbytis comata*), Sunda slow loris (*Nycticobus coucang*), and Sunda pangolin (*Manis javanica*). The preservation of the MPNR area is important to support those protected animals.

Based on the tree regeneration and growth data from this study, the candidate species for restoration are *A. spectabilis*, *E. spicata*, *D. stellare*, *N. javanica*, *S. fasciculata*, and *S. glomeruliferum*. Those species shown a high rate of regeneration and growth compared to the other species found in the studied plot area. However, on designing tree planting for a restoration project in MPNR, some points need to be considered, such as the soil physicochemical condition, potential weed, relative location to the forest as the seed source, land-use history, and other related the site condition. However, it is also possible that those recommended species will not be successfully established in the forest restoration location. For instance, a previous study on the post-agriculture field in MPNR that was reforested with *D. stellare* and *S. wallichii* (Setiawan & Sulistyawati 2020) shown that the regeneration of *D. stellare* did not happen after seven years of planting.

Conclusion

The tree vegetation structure and composition in the observed permanent plot of Mount Papandayan showed a typical mature Javan montane forest ecosystem, dominated by a late-successional tree species (i.e., *D. stellare*) in almost all age classes. Repeated tree census and measurement in the plot after four years showed a slightly higher number of trees recruited compared to mortality, indicating a good forest regeneration. The tree growth and survival data of several tree species in this study can be used as a basis in the tree selection process on designing forest restoration at degraded areas of Mount Papandayan. Several suggested candidate species are *A. spectabilis*, *E. spicata*, *D. stellare*, *N. javanica*, S. *fasciculata*, and *S. glomeruliferum*.

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