BIODIVERSITAS
Volume 24, Number 7, July 2023
Pages: 3723-3734

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240709

Natural regeneration of *Alstonia spectabilis* in small-scale privately-owned forest in Gunungkidul, Yogyakarta, Indonesia

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Manuscript received: 11 April 2023. Revision accepted: 6 July 2023.

Abstract. *Wardani BRP, Atmanto WD, Widiyatno, Romadini NP. 2023. Natural regeneration of* Alstonia spectabilis *in small-scale privately-owned forest in Gunungkidul, Yogyakarta, Indonesia. Biodiversitas 24: 3723-3734. Alstonia spectabilis* is a species that serves as an indicator of the dry deciduous forest type and has the potential to be utilized commercially or to support conservation programs. The development pattern, specifically in small-scale privately-owned forest (SSPF) in Gunungkidul, still relies on natural regeneration. The differences in management between agricultural (*tegalan*) and forested land (*wana*) affect the abundance and characteristics of *A. spectabilis* natural regeneration. Due to its great potential to be developed in the future, information on the abundance and natural regeneration in SSPF is needed. This study was conducted by creating observation plots in *tegalan* and *wana* in Sidoharjo Village, using uniform systematic sampling with a random start method and a sampling intensity of 10%. This study aimed to determine the density and diversity of tree stand as well as the distribution pattern of *A. spectabilis* natural regeneration. A total of 13 nested sampling plots (0.52 ha in total size) were made to observe seedlings, saplings, pole, and tree in each study area. The number and characteristics of natural regeneration were shown to be impacted by management differences between *tegalan* and *wana*. Wana had a high canopy closure of 91%, compared to 72% for *tegalan*. Additionally, the greater density value of 9423 ind. ha^{-1} in *wana* compared to *tegalan*, which had 1154 ind. ha^{-1} at all growth levels with a random distribution pattern, showed a stronger potential for *A. spectabilis* for natural regeneration. The findings indicated that *wana* has a greater potential for seed sources with favorable environmental conditions for the survival of *A. spectabilis* natural regeneration.

Keywords: *Alstonia spectabilis*, natural regeneration, *wana*, *tegalan*, Gunung Sewu mountain

INTRODUCTION

Small-scale privately-owned forest (SSPF) is defined as a forest that grows on land burdened with ownership rights, has a minimum area of 0.25 hectares (ha), and a canopy cover of more than 50% for wood and non-wood plants, such as 500 trees/ha (Puspitojati et al. 2014). In Java Island, Indonesia, SSPF is traditionally managed by the community (Siarudin et al. 2022) and can meet the wood needs for the wood industry. According to a report (Ministry of Environment and Forestry of the Republic of Indonesia 2019), the standing stock of SSPF ranged between 18.9 and 23 million m^3 between 2015 and 2019. This indicates that SSPF has great potential to support the supply of raw materials for the forestry industry in the furniture and building sectors.

Small-scale privately-owned forest in Gunungkidul District, Yogyakarta Province, Indonesia is primarily located in the Gunung Sewu mountains, a karst land with a special shape and hydrological conditions that arise from high rock dissolution and well-formed secondary porosity (Ford and Williams 2007). Gunungkidul has the most private forest in Yogyakarta's Special Region, accounting for 60.7% of the district's total area affected by the Private Forest Transition (Wicaksono 2020). The transition of Gunungkidul people's forest from the 1950s to the present can be divided into four phases: (i) critical period, (ii) intensive planting, (iii) pre-industrialization of community timber, and (iv) industrialization of community timber (Wicaksono et al. 2020). The current development of forest in Gunung kidul has entered the fourth phase, namely the period of community timber industrialization (Wicaksono et al. 2020), characterized by increasing marketing of community forest wood and the existence of collective management units since the early 2000s to 2019. Roundwood from SSPF can also meet the demand for local wood in several other districts, including Jepara, Klaten, Bantul, and Sleman (Bakhtiar et al. 2014). Because of the long transition period that began in the early 1970s, Gunungkidul is no longer known as a barren and arid region, but as a verdant area with plants and trees (Wicaksono 2020).

In Gunungkidul, SSPF has a variety of woody plant species, including *Alstonia spectabilis* R. Br (*legaran*) which is a tropical tree native to northern Australia, Malesia, and Southwest Pacific and belongs to the Apocynaceae family (Wiersema and León 2013). It belongs to a species with wide distribution (BGCI 2018) that can grow naturally on marginal to fertile soils at an altitude of 0-1000 meters above sea level. The species is commonly found in Gunungkidul, generally growing in small populations on rocky hilltops or alone/mixed with other species in large populations.

In Indonesia, *A. spectabilis* serves as an indicator of the monsoon forest (Laumonier and Nasi 2018) and has the potential to be utilized for commercial purposes as well as to support conservation programs. *A. spectabilis*, a timber plant (Trimanto et al. 2019; Ngongo et al. 2022), can be used to make bridges, household equipment, crates, matchsticks, shoe heels, handicrafts, pencils, and pulp. Furthermore, the bark, stem, and flower have also been traditionally used as medicinal plants (Taek et al. 2019) and contain phytochemicals such as lipids, saponins, tannins, alkaloids, phenols, steroids, as well as flavonoids which have the potential to be used as medical ingredients. According to other research (Taek et al. 2021), *A. spectabilis* has the potential to be developed as a new source of antimalarial. In Indonesia, *A. spectabilis* is one of the plants used in restoration activities, specifically in monsoon forest types (Indrajaya et al. 2022).

The development pattern, specifically in SSPF Gunungkidul District, still relies on natural regeneration as seen in *tegalan* and *wana* of Paliyan, Purwosari, and Tepus Sub-districts. The difference in management between *tegalan* and *wana* affects the abundance and characteristics of *A. spectabilis* natural regeneration. Previous research by Goldsmith et al. (2011) and Jakovac et al. (2015, 2016) found that an increase in land-use intensity, weed infestations, and a lack of seed dispersal can all have a significant impact on species composition. Information on the species composition of a forest is critical for wise management in terms of economic value, regeneration potential, and, ultimately, biological diversity conservation. Therefore, further studies are needed specifically regarding its abundance and distribution in *tegalan* and *wana* for the development and preservation. In this paper, we investigate the ability of natural regeneration of *A. spectabilis* to promote long-term SSPF in Gunungkidul.

MATERIALS AND METHODS

Study area

This study was conducted in the *wana* (8º07′37″ S, 110º37′26.2″ E) and *tegalan* (8º05′47.5″ S, 110º37′49.8″ E) areas in Sidoharjo Village, Tepus Sub-district, Gunungkidul District, Yogyakarta Province, Indonesia, between March and April 2021 (Figure 1).

Procedures

Individual density, canopy cover, basal area, Margalef index, and Shannon index

Plots were established in tegalan and wana using uniform systematic sampling with a random start, whereas nested sampling designs were used in species-area studies (Barnett et al. 2003). To determine the number of plots, an area calculation is performed. The *tegalan* and *wana* observation areas were 5.149 ha and 5.138 ha, respectively. The number of plots to be created at each location can be calculated using the Sampling Intensity (IS) value. Because the sampling intensity used for areas less than 1,000 ha is 5-10%, this study employs an IS of 10% to reduce error with the total number of plots. Each *tegalan* and *wana* has 13 observation plots. Furthermore, each land had a total of 13 nested sampling plots measuring 20 m x 20 m. For the seedlings level, observation plots measuring 2 m x 2 m were used, 5 m x 5 m for the saplings level, 10 m x 10 m for the pole level, and 20 m x 20 m for the tree level specifically for those with diameters greater than 20 cm. At seedlings level, the species diversity index and number of species were counted, while at saplings, pole, and tree levels, the number, height, and diameter at breast height (DBH) were measured for all species found in the observation plots.

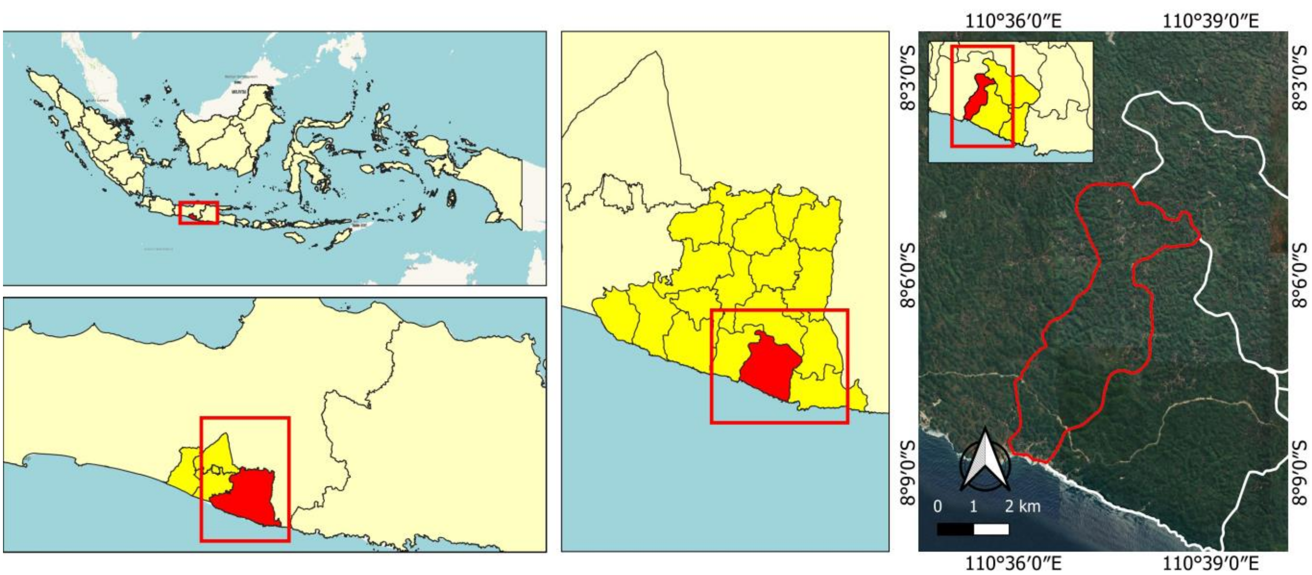


Figure 1. Location of *wana* and *tegalan* in Sidoharjo Village, Tepus sub-district, Gunungkidul District, Yogyakarta, Indonesia

Natural regeneration and distribution patterns of A. spectabilis *in tegalan and wana*

The number of *A. spectabilis* seedlings, saplings, pole, and tree was counted on plots measuring 2 m x 2 m, 5 m x 5 m, 10 m x 10 m, and 20 m x 20 m using nested sampling. Meanwhile, the tree level was observed on a 20 m x 20 m plot, assuming it was the source of seed supply in this study. The geographical coordinate of each individual was marked using a Garmin 64S handheld GPS. We also use the Avenza Maps and Mobile Topographer app to backup data.

Observation and measurement of environmental factors that may affect the natural regeneration success

Seedbed (micro-environment), which includes leaf litter thickness (cm), leaf litter coverage (%), and shade level or percentage of canopy closure were observed. Litter thickness was measured in 2 x 2 m sections of a 20 x 20 m main plot. The leaf and ferment horizons (L and F) are referred to as litter. Humus horizon (H) is not taken into account because its boundary is frequently difficult to determine; similarly, freshly fallen leaves are not taken into account. A ruler was used to measure the thickness of the litter to an accuracy of 0.1 cm. Leaf litter coverage (%) was measured in 2 x 2 m section of 20 x 20 m main plot. The percentage value of canopy cover can be calculated using Viti canopy software (De Bei et al. 2016). The canopy condition in each observation plot was taken 3 times, and then the image was entered into the software.

Soil parameters including soil thickness (cm), soil texture by feel analysis (Ritchey et al. 2015), soil color by Munsell soil-color charts and pH were observed. The pH is determined on a 1:5 soil:deionised water suspension. Observation of seed availability in each individual was used to estimate the potential of seed supply and fruiting time of *A. spectabilis*. The environmental (macro-environment) parameters including light intensity (%), air temperature (°C), air humidity (%), and rainfall in the study location were also observed.

Data analysis

Individual density, canopy cover, basal area, Margalef index, and Shannon index in tegalan *and* wana

Species richness index. Species richness index can be obtained from the Margalef Index (R1) (Kanieski et al. 2018) which is calculated using the formula (Death 2008):

$$R_1 = \frac{S-1}{ln\ (N)}$$

Where: R_1: Margalef index, S: number of species; N: number of individual plants for all species; ln: natural logarithm

Species diversity index. Species diversity can be obtained from the Shannon index of general diversity (H'), with the formula (Zar 2010):

$$H' = -\sum_{i=1}^{s}\left\{\left(\frac{ni}{N}\right) ln\ \left(\frac{ni}{N}\right)\right\}$$

Where: H': Shannon Wienner diversity index; s: number of species observed in the sample; ni: number of individuals of the i-th species; N: Total of all individuals; ln: natural logarithm

Individual density (ind. ha^{-1}). Individual density including seedlings, saplings, pole, and tree can be determined by calculating the total number of each level of plant life found in the measuring plot and dividing by the area of the observation site (ha) (Legendre and Legendre 2012). The formula to determine the density of individuals is:

$$\textit{Individual density} = \frac{\Sigma \text{ Number of individual (individual)}}{\Sigma \text{ area of observation site (ha)}}$$

Basal area on pole and tree. Basal area per ha is a cross-section of the trunk diameter at chest height namely 1.3 m from the ground (Kershaw et al. 2016; Wang et al. 2020). The amount of basal area of a tree is calculated by the formula (Bettinger et al. 2017):

$$lbd = 0.25 \times p \times d^2$$

Where: lbd: basal area of individual tree (m^2), p: constant (3.14) d: trunk diameter (1.3 m from ground level).

Differences in the values of the species richness index, species diversity index, individual density, basal area, and canopy cover in *tegalan* and *wana* were analyzed using the T-test at α 0.05 level (Kim 2015).

Natural regeneration and distribution patterns of A. spectabilis *in tegalan and wana*

The potential for natural regeneration and distribution of *A. spectabilis* in *tegalan* and *wana* was also analyzed using several calculation methods, namely:

Individual density of *A. spectabilis* (ind. ha^{-1}). Individual density of *A. spectabilis* can be determined by calculating the total number of each plant life level found in the measuring plot divided by the area of the observation land site (ha). The formula to determine the individual density is as follows:

$$\textit{Individual density} = \frac{\Sigma \text{ Number of individual (individual)}}{\Sigma \text{ area of observation site (ha)}}$$

Dispersion index of *A. spectabilis.* The distribution pattern of a species can be calculated using the index of dispersion (ID) formula. Meanwhile, the index or coefficient of dispersion is the ratio of the population variance value to the mean population value Dispersion Index can be calculated using the formula (Ludwig and Reynolds 1988):

$$M = \frac{\Sigma X}{N} \qquad V = \frac{\Sigma X^2 - \left[\frac{(\Sigma X)^2}{N}\right]}{N-1} \qquad ID = \frac{V}{M}$$

Where: M: Mean individuals of a species in each measuring plot; V: Variance; X: Number of individuals on a species in the measuring plot; N: Total number of measuring plots

The distribution pattern of *A. spectabilis* natural regeneration is random assuming the value of V = M

The distribution pattern of *A. spectabilis* natural regeneration is even or regular assuming the value of V < M

The distribution pattern of *A. spectabilis* natural regeneration are clustered assuming V > M

A statistical test was then carried out if the number of N < 30, by using the formula:

$$X^2 = \text{ID}\ (\text{N} - 1)$$

Where: X²: Chi-square, ID: index of dispersion, and N: number of measuring plots in the field

Where, the value of :

α = 0.025; db = N-1

α = 0.975; db = N-1

Based on the above calculations, there are three provisions, namely: (i) The distribution pattern is clustered assuming the X² value is > X² table (α = 0.025; db = N-1). (ii) The distribution pattern is regular or evenly distributed supposing the calculated X² value is < X² table (α = 0.975; db = N-1). (iii) The distribution pattern is random assuming the value of X² table (α = 0.975; db = N-1) is < X² count < X² table (α = 0.025; db = N-1).

Differences in the abundance and distribution of *A. spectabilis* at seedlings, saplings, pole, and tree levels in *tegalan* and *wana* were analyzed using a T-test at α 0.05 level.

RESULTS AND DISCUSSION

Individual density, canopy closure, basal area, Margalef index, and Shannon index in *tegalan* and *wana*

Table 1 showed that the value of individual density between *tegalan* and *wana* for seedlings, pole, and tree levels was not significantly different (p>0.05), but there was a significant difference for saplings level (p<0.05). The average individual density (ind. ha^{-1}) at seedlings level in *tegalan* and *wana* amounted to 4615 and 8029 ind. ha^{-1}, while saplings was 76 and 209 ind. ha^{-1}. Moreover, the average individual density (ind. ha^{-1}) for the pole level was 6 and 9 ind. ha^{-1}, while the tree growth level was 0.01 and 0.01 ind. ha^{-1} in tegalan and *wana*, respectively.

Individual density values in *wana* were generally higher than in *tegalan*, specifically at seedlings, saplings, and pole growth levels as shown in Table 1. This difference was because *tegalan* which was closer to the settlement allowed for more intensive management than *wana*. Management efforts on *tegalan* such as tillage and weeding activities could accelerate the rate of carbon and nitrogen mineralization while decreasing soil nutrients and organic matter loss, destroy the chunks usually formed and influence the structure and function of the soil microbial community, particularly the biochemical process dominated by bacteria (Zhang et al. 2022). In contrast, the community rarely carried out maintenance activities in *wana*, such as fertilization, weeding, watering, and replanting, due to the belief that woody plants could grow well without maintenance activities.

Density describes the availability of stands at each growth level, which can affect the ability to regenerate or grow stands, as well as the basal area, canopy cover, and species diversity. Basal area, an important indication of stand density, incorporates both tree size and number (Kershaw et al. 2016). The varying individual density at all growth levels caused a significant difference in the basal area for the pole level (p<0.05), while in the tree level, there was no significant difference (p>0.05). The pole basal area in *tegalan* and *wana* amounted to 0.02 m^2 ha^{-1} and 0.011 m^2 ha^{-1}, respectively. Meanwhile, the basal area of tree in both land was 0.035 m^2 ha^{-1} and 0.032 m^2 ha^{-1}, respectively, as presented in Figure 2.

The increase in basal area and density values at the pole and tree levels on *tegalan* was not accompanied by a corresponding high canopy cover (Figure 3). This was evidenced by the higher percentage of canopy cover in *wana* as shown in Figure 3. However, the value of total basal area on tree in *tegalan* was higher but not significantly higher than in *wana*. The results showed that the canopy cover in *wana* was higher than in *tegalan*, while the basal area value in *tegalan* showed a greater value. Therefore, the increase in the basal area can improve the forest microclimate. According to a previous study (Hardwick et al. 2015), the vegetation structure strongly correlates with the microclimate. The size of the canopy gap can affect the plant regeneration process, causing changes in important factors such as light intensity, soil moisture, and soil biology (Muscolo et al. 2014). Gavito et al. (2021) also found that basal area, litterfall, plant richness, and litter mass were the vegetation properties most related to soil and microclimate recovery using bivariate and stepwise regressions. Soil P recovery, a key soil property, was found to be most closely related to basal area.

Table 1. Individual density (ind. ha^{-1}) at each growth stage on *tegalan* and *wana*

Type of management	Individual density (ind. ha^{-1})			
	Seedlings	Saplings	Pole	Tree
Tegalan	4615	76	6	0.01
Wana	8029*	209*	9ns	0.01ns

Note: *significantly different at α 0.05 level; ns: not significantly different at α 0.05 level

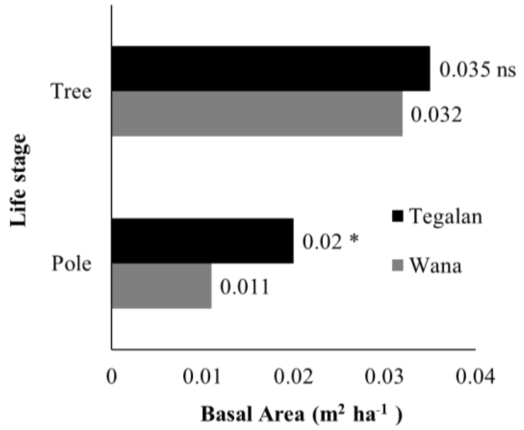


Figure 2. Basal area on pole and tree at *tegalan* and *wana*

The difference in the value of canopy cover in *tegalan* and *wana* is due to variations in the dominant plant species. The canopy cover in *wana* was higher even though the individual density value at the pole and tree level was lower than in *tegalan*. This is because the dominating species at *wana*'s pole and tree growth levels are *Acacia auriculiformis*, *A. spectabilis*, and *Swietenia macrophylla*. *Acacia auriculiformis* and *A. spectabilis* generally form wide, relatively dense crowns and are evergreen tree species. Another species is *S. macrophylla* which has the basic characteristics of high crown density and thick leaves. These three species reportedly belong to the closed and semi-closed canopy systems. Meanwhile, the dominating species on *tegalan* is the *Tectona grandis* which has a wide and irregular canopy, is dome-shaped, and is included in the open canopy system (Figure 3).

Differences in individual density and constituent species in a community cause variations in Margalef and Shannon indexes on *tegalan* and *wana*. The values of both indexes for pole and tree levels indicate a low plant species diversity status, except for the Shannon index of tree levels in *wana* which had a medium status. The Margalef index for seedlings and saplings levels on *tegalan* tends to be higher than *wana*, even though it is not significantly different (p>0.05). Furthermore, the species diversity status in both lands is low. The Shannon index of seedlings and saplings levels was in the medium category, with *tegalan* having a higher value. This indicates that *tegalan* has a better regeneration rate as shown in Figures 4A and 4B.

The Shannon index value depends on the number of individuals in each plant species, hence, the greater the value, the higher the species diversity. Plant species found in *tegalan* can be grouped into seven families consisting of 13 species which are illustrated in Figures 5A, 5B and Table 2. Meanwhile, the types found in *wana* are grouped into six families of 12 species as shown in Figures 5C, 5D, and Table 3. The most dominating plant species in both lands is *A. auriculiformis,* with 59 and 145 individuals at all growth levels in *tegalan* and *wana*, respectively. *A. spectabilis* is also among the dominant species, specifically in *wana*. The most found plant species come from the Fabaceae Family, which consists of 7 species followed by the Apocynaceae family, comprising *A. spectabilis* and *A. scholaris.*

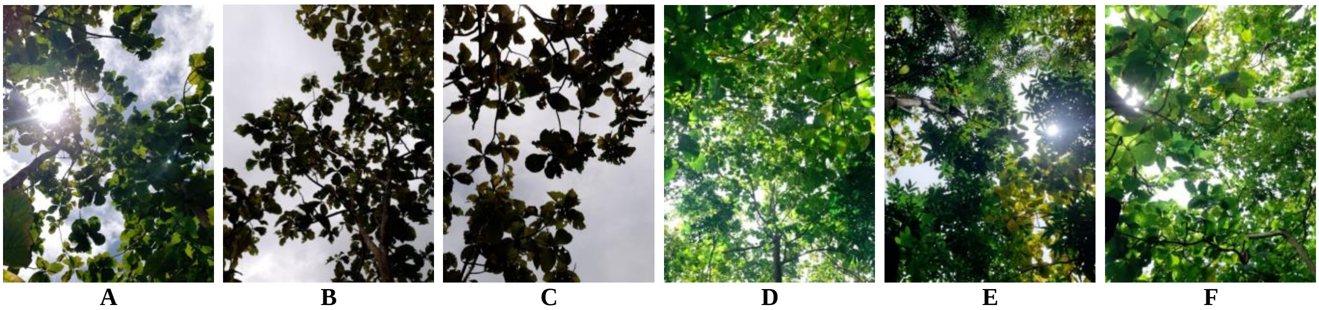


Figure 3. Canopy condition in A, B, C *tegalan*, and D, E, F *wana*

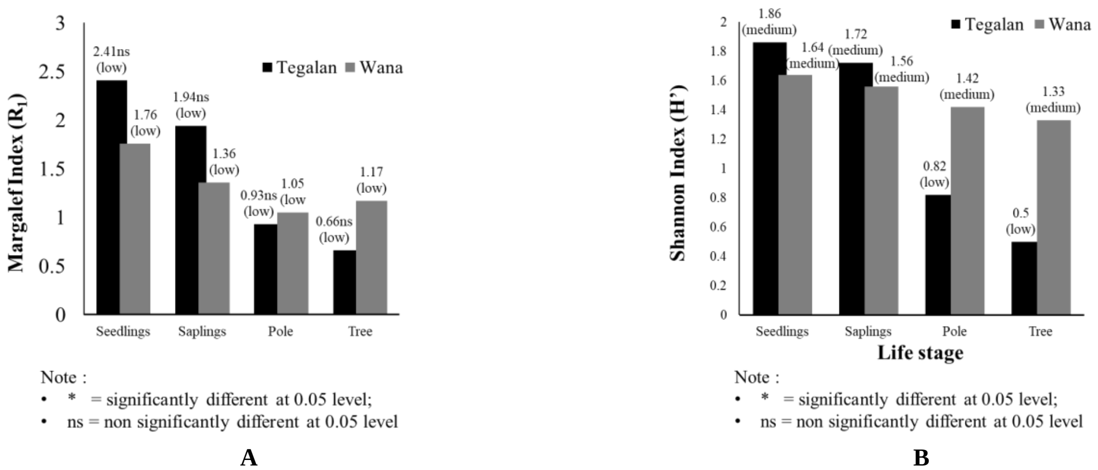


Figure 4. A. Margalef and B. Shannon index at each *tegalan* and *wana* growth stage. Note: *significantly different at α 0.05 level; ns: not significantly different at α 0.05 level; The value of the Margalef Index calculation has three categories, namely: The value of species richness is high or abundant if the value of R1 is R1> 4; The value of species richness is medium if the value of R1 is 2.5- 4; The value of species richness is low or small if the value of R1 is R1<2.5. The calculation value of the Shannon Wienner Diversity Index (H') has three categories, namely: High or abundant species diversity value if the value of H' is H'>3; Medium species diversity value if the value of H' is 1 ≤ H'≤3; Low species diversity value if the value of H' is H'< 1

At the tree stage, the plant species that dominate *tegalan* and *wana* are *Acacia auriculiformis, Tectona grandis and A. spectabilis*. The dominance of *Acacia auriculiformis* in both locations is due to its wide adaptability (Rahman and Hossain 2019) in dry areas and is also a fast-growing species (Asif et al. 2017). People in Gunungkidul used acacia tree foliage for fodder and the wood for firewood and building. The second dominant species in tegalan at tree levels is *T. grandis*. This plant is commercially valuable with high economic value and is cultivated, particularly in company-owned forest. *T. grandis* has been cultivated in Java for a long time, both vegetatively and generatively, and this plant is classified as light-tolerant because it has a high economic value (FAO 2015) and is widely used for the construction of wood, furniture (Seta et al. 2023), as material of glued products and other purposes. The dominance of *A. spectabilis* at the sapling level in *wana* is because its species can produce abundant fruit, seeds, and flowers, which takes place twice a year. According to observations, the seeds of *A. spectabilis* have many hairs, are smooth, and easily dispersed by the wind, just like the seeds of Alstonia species (Solomon Raju et al. 2021; Sadili et al 2022). Meanwhile, at *tegalan*, *A. spectabilis was* placed in third place because *A. spectabilis* people prefer *Acacia auriculiformis* and *T. grandis* for local needs. Local people used *A. spectabilis* as building timber, bridge timber, raw materials for household appliances, crates, matchsticks, shoe heels, handicrafts (puppet shows and masks), pencils, and pulp.

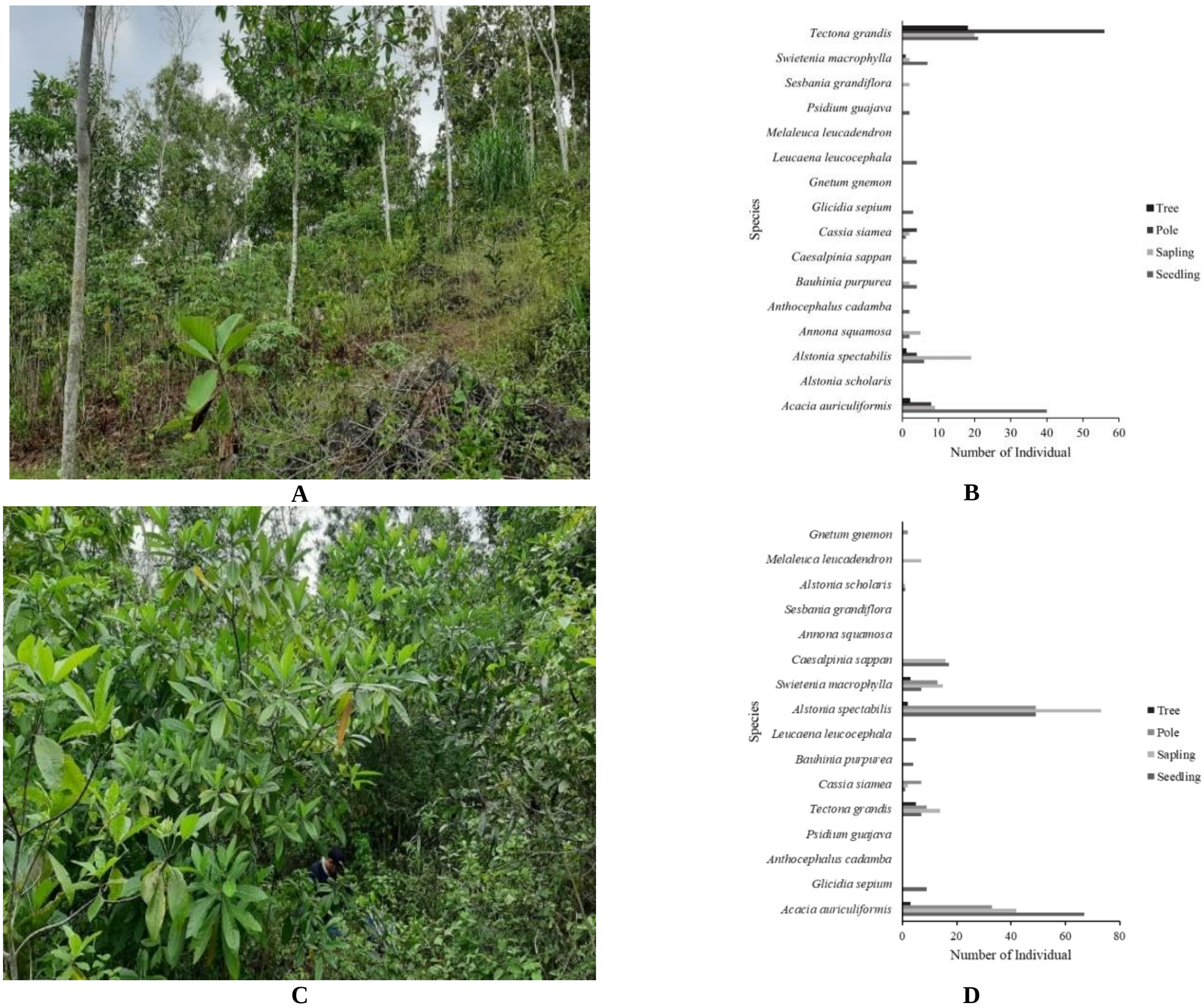


Figure 5. Conditions and individual density in A, B. *tegalan*, and C, D. *wana*

Tables 2 and 3 showed that the species distribution pattern on the *tegalan* and the *wana* is dominated by a random pattern. Random dispersion patterns are common in nature and may indicate a uniform or random distribution of resources or a lack of interactions among individuals in the population (Walker 2011). Random patterns in a population indicate that the environment is homogeneous and that individual behavior is not selective. Because the distribution of species on the *tegalan* and *wana* is random, the majority of the species that make up the *tegalan* and *wana* are not selective in obtaining their subsistence needs because the environment is relatively homogeneous. This demonstrates that the *tegalan* and *wana* have little competition and relatively uniform environmental conditions. Plant species with wind-dispersed seeds are also examples of randomly distributed organisms. These organisms settle wherever conditions are viable, regardless of the location of resources or individuals. Furthermore, the composition and structure of vegetation types that make up *tegalan* have fewer species than *wana* as shown in Figure 5. This is due to human intervention in plant development on *tegalan*. Plant species in *tegalan* are deliberately planted according to the owner or manager's preference to increase productivity and income. However, the majority of *wana* species grow naturally with little or no human intervention.

Based on Tables 2 and 3, in general, most species found in both lands are from the Fabaceae family, a type of plant that can be utilized for animal feed. These plants are evergreen in the dry season; therefore, it can support the development of silvopasture which is quite developed around *tegalan* and *wana*. Another advantage of this plant is that it can grow well in less fertile soil conditions, with high forage production and protein content. One of the plants that has high economic value and is developed by the community besides *T. grandis* is *A. spectabilis*. This plant is widely used as wood for building construction, bridges, raw materials for household appliances, crate making, and handicraft goods, hence, it can support the economy and small industries in the community. The success of the plant development is evidenced in the distribution, which can be used as a basis for the cultivation to ensure sustainability.

The potential of *A. spectabilis* natural regeneration on *tegalan* and *wana*

The potential of *A. spectabilis* was determined from the density at seedlings, saplings, and pole growth stages. Meanwhile, at the tree growth level, calculations were also carried out with the assumption of being a parent tree or seed supply. Previous research has discovered that factors such as advance regeneration interference, browsing pressure, seed supply, and edaphic factors all have an effect on natural regeneration (Kern et al. 2013; Forrester et al. 2014; Walters et al. 2014; Willis et al. 2015). The results showed that individual density values of *A. spectabilis* at seedlings, saplings, and pole levels were significantly different ($p<0.05$) between research locations, while the tree level was not significantly different ($p>0.05$), as shown in Figure 7.

The density of *A. spectabilis* at seedlings level in *tegalan* and *wana* was 1154 and 9423 ind. ha^{-1}, respectively, while for saplings, it was 3654 and 14038 ind. ha^{-1}. The average individual density for the pole level was 759 and 9423 ind. ha^{-1}, while the tree growth level was 192 and 385 ind. ha^{-1} in *tegalan* and *wana*, respectively. Overall, *wana* had higher individual density value.

Table 2. Distribution pattern of each species at each growth stage in *tegalan*

Family	Species	Seedlings	Saplings	Pole	Tree
Annonaceae	*Annona squamosa*	Clustering	Clustering		
Apocynaceae	*Alstonia spectabilis*	Random	Random	Random	Random
Fabaceae	*Acacia auriculiformis*	Clustering	Random	Random	Random
Fabaceae	*Bauhinia purpurea*	Random	Random		
Fabaceae	*Caesalpinia sappan*	Random	Random		
Fabaceae	*Cassia siamea*	Random	Random	Random	
Fabaceae	*Glicidia sepium*	Random			
Fabaceae	*Leucaena leucocephala*	Random			
Fabaceae	*Sesbania grandiflora*		Clustering		
Meliaceae	*Swietenia macrophylla*	Random	Random	Random	
Myrtaceae	*Psidium guajava*	Random			
Rubiaceae	*Anthocephalus cadamba*	Random			
Lamiaceae	*Tectona grandis*	Random	Random	Random	Clustering

Table 3. Distribution pattern of each species at each growth stage in *wana*

Family	Species	Seedlings	Saplings	Pole	Tree
Apocynaceae	*Alstonia scholaris*	Random	Random		
Apocynaceae	*Alstonia spectabilis*	Random	Random	Random	Random
Fabaceae	*Acacia auriculiformis*	Random	Random	Random	Random
Fabaceae	*Bauhinia purpurea*	Random			
Fabaceae	*Caesalpinia sappan*	Regular	Random		
Fabaceae	*Cassia siamea*	Random	Random	Random	
Fabaceae	*Glicidia sepium*	Random			
Fabaceae	*Leucaena leucocephala*	Clustering			
Gnetaceae	*Gnetum gnemon*			Random	
Meliaceae	*Swietenia macrophylla*	Clustering	Clustering	Random	Random
Myrtaceae	*Melaleuca leucadendron*		Random		
Lamiaceae	*Tectona grandis*	Random	Random	Random	Clustering

These results implied that the potential for A. *spectabilis* natural regeneration is greater in *wana* as indicated by the higher density value at all growth levels. The number of seedlings found showed that the species could undergo the regeneration process effectively. This process was affected by three factors namely seedbed, seed supply, and the environment i.e., light intensity, soil moisture, drought, temperature. The pole level was appropriate for seed supply because, based on field observations, *A. spectabilis* at this stage, had already produced flowers and fruit which could support the success of budding.

Individual density value of *A. spectabilis* in *tegalan* land at the pole and tree levels was very small. This was evidenced by the small number of individuals and their distance from the parent tree, which is mostly found in *wana* (Figure 8). This presumably led to the small distribution of *A. spectabilis* on *tegalan* due to the few seeds reaching this location. *A. spectabilis* is an intolerant plant that uses light to support the success of budding but due to its location being closer to settlements and easily accessible by the community, intensive land processing in the form of tillage occurs causing disturbance to seedlings. This will affect the number of seedlings and saplings compared to *wana*.

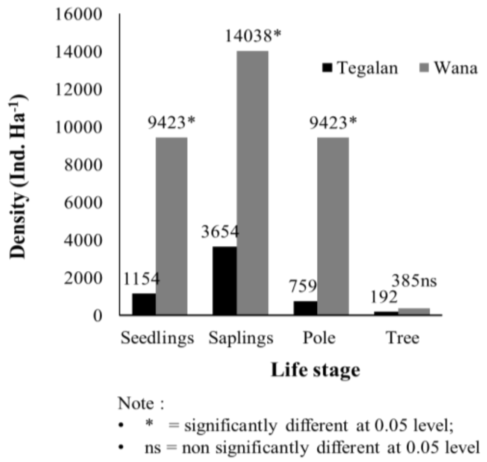
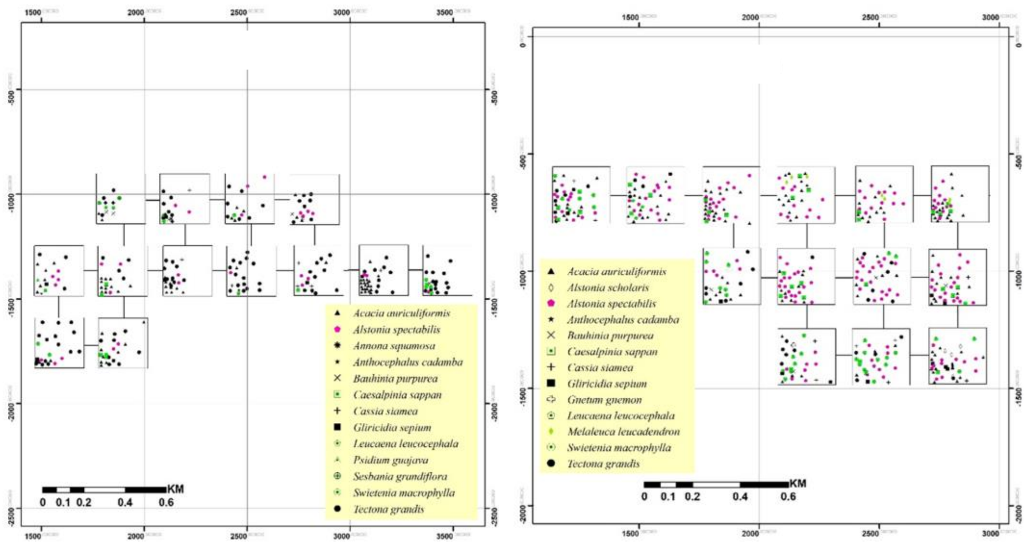


Figure 7. The density of *Alstonia spectabilis* (ind. ha^{-1}) at each growth stage in *tegalan* and *wana*



A B

Figure 6. Illustration of species distribution patterns of *Alstonia spectabilis* in A. *tegalan* and B. *wana* constituents

A B

Figure 8. Seedlings and saplings condition of *Alstonia spectabilis* in A. *tegalan*, B. *wana*

Distribution pattern of natural regeneration of *A. spectabilis* on *tegalan* and *wana*

Based on the calculation result of dispersion index, the distribution pattern of *A. spectabilis* natural regeneration follows a random pattern. The Dispersion Index of seedlings in *tegalan* and *wana* was 0.94 and 0.81, saplings: 0.87 and 1.02, pole: 1.29 and 0.44, and tree: 1 and 0.92, respectively, as shown in Table 4. This shows that the distribution pattern of *A. spectabilis* is not clustered in one place only but is evenly distributed and can be found in the data collection area as depicted in Table 4 and Figure 9. One of the factor causing the random distribution pattern is that the seeds are small and hairy (Solomon Rabu et al. 2021). Therefore, they can be flown by the wind and scattered to various places, even far from their parent location. The random distribution pattern is also due to the natural process of its emergence without human intervention.

The success of natural budding with flower and seed formation is affected by the presence of pollinators, which in turn, is influenced by the size of the flower and the amount of nectar produced. Small flower sizes can produce small amounts of nectar, while pollinators that actively visit *A. spectabilis* flowers are insects such as flies, butterflies, ants, bees, ladybugs, and moths (Solomon Rabu et al. 2021). This also contributes to the random distribution of the plant in *tegalan* and *wana*.

Factors supporting the natural regeneration of *A. spectabilis* on *tegalan* and *wana*

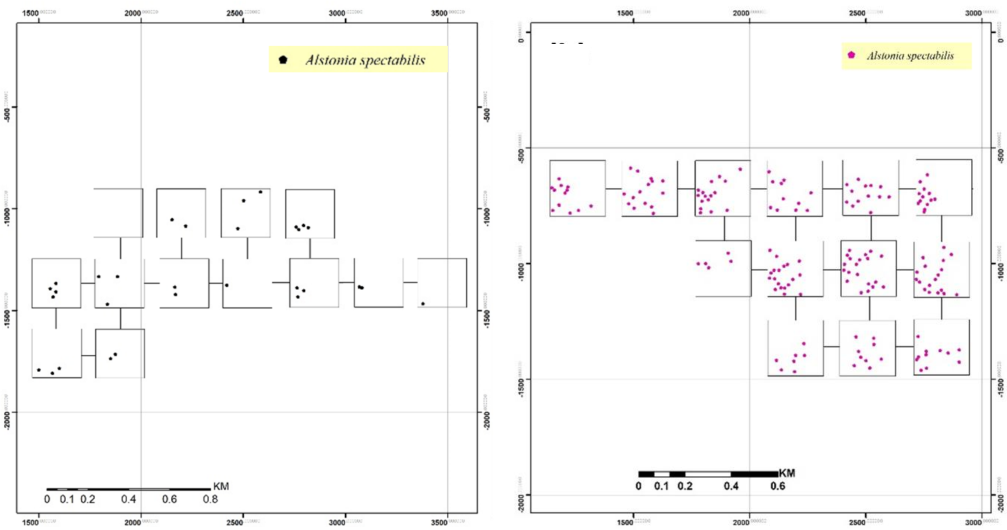
Seed availability. The condition of *A. spectabilis* parent tree found from pole to tree growth level can determine the availability of seeds in the observation location. The success of natural regeneration on Java Island, such as in *Dipterocarpus gracilis* which grows in the shade of forest with minimal human intervention, is also dependent on the number of dry months (Romadini et al. 2022). In the Tepus area (Gunungkidul), the average flowering period of *A. spectabilis* occurs twice in the second month of the rainy season, around December-January and July-August. Therefore, the fruit harvesting period occurs in May and November. This can be an indicator that the parent tree has started to bear fruit with a length of 45-60 cm. Most *A. spectabilis* flowers and fruits can be found in *wana* as shown in Figure 10. This corresponds with the total 49 number of individuals at the pole and 2 number of individuals at tree growth levels, while in *tegalan*, it was 4 and 1 for pole and tree, respectively, indicating that more mother trees were found in *wana*.

Microenvironment and macroenvironment. Other supporting factors of *A. spectabilis* natural regeneration observed in this study activity are microenvironments such as litter thickness, percentage of litter cover and understory, level of shading or canopy cover, as well as soil texture. Meanwhile, macroenvironmental observations comprise air temperature, humidity, light intensity, and rainfall as described in Table 5.

Based on the observation results, *wana* had a high canopy coverage level of 91%, while *tegalan* had 72%. The high canopy coverage in *wana* tended to cause an increase in air humidity and a decrease in air temperature. In addition, the thickness of leaf litter, percentage of canopy cover, and understory vegetation were also higher in *wana* compared to the *tegalan* (Table 5). These environmental conditions were suitable to support the success of *Alstonia* species natural regeneration which generally requires a temperature range of 15-35°C to germinate (Kurniawan 2008). Generally, optimum temperature is required for pollen tube growth, therefore, air temperature, humidity, light intensity, and rainfall are not the main factors affecting the success of natural regeneration in the *wana*. The higher understory vegetation is presumably due to the higher nutrient content in *wana*, which enhances the growth and development of *A. spectabilis* seedlings and saplings. Furthermore, the number of seedlings was lower than saplings due to the thickness of the leaf litter, which can inhibit the germination power of small seeds. High sunlight intensity tends to cause lower shading levels or canopy percentages in *tegalan* compared to *wana*. This culminates in fewer natural regeneration of *A. spectabilis* in *tegalan*. Another possible cause is that the fruiting occurs twice a year in December-January and July-August. Consequently, seeds that fall on the ground, specifically on *tegalan*, cannot develop into individuals due to high light intensity as shown in Table 5. To maintain the microclimate, management of the *tegalan* must pay attention to the thickness of the litter, the presence of undergrowth, and the percentage of canopy cover, especially during the dry season. This study showed that *A. spectabilis* distribution mostly had a random pattern in *wana* and *tegalan*. *Wana* had a higher seed source potential with environmental factors that supported the success of natural regeneration. Therefore, efforts to maintain plantations from the regeneration were needed to ensure the availability of pole and tree in supporting sustainable SSPF management. The *A. spectabilis* population in Gunungkidul, particularly in these research locations, has the potential to grow, but efforts are being made to accelerate the regeneration process. In order to obtain a sufficient volume of wood from this species, silvicultural techniques for community forest must be used to manage space and maintain growth.

Table 4. Dispersion index of *Alstonia spectabilis* at each growth stage in *tegalan* and *wana*

Growth rate	Dispersion index		Distribution pattern	
	Tegalan	Wana	Tegalan	Wana
Seedlings	0.94	0.81	Random	Evenly
Saplings	0.87	1.02	Random	Clustered
Pole	1.29	0.44	Random	Evenly
Tree	1	0.92	Random	Random



A B

Figure 9. Illustration of the distribution pattern of *Alstonia spectabilis* seedlings in A. *tegalan* and B. *wana*

A B C

Figure 10. A. flower, B. fruit, and C. seedlings of *Alstonia spectabilis*

Table 5. The site conditions and environmental parameters measurements results

Parameters	*Tegalan*				*Wana*			
Direction of slope	East	South	North	West	East	South	North	West
Slope degree	Sloping	Steep	Sloping	Steep	Sloping	Steep	Sloping	Steep
Soil thickness (cm)	28.5	14	27	15	23	11	38	16
Structure	Angular Lump	Angular Lump	Angular Lump	Angular Lump	Angular Lump	Angular Lump	Angular Lump	Angular Lump
Texture	Sandy Clay	Clay	Clay	Clay Loam	Clay Loam	Clay Loam	Clay	Clay
Soil color	10 YR 3/2 (Very dark grayish brown)	5 YR 3/2 (Dark reddish brown)	5 YR 3/2 (Dark reddish brown)	7,5 YR ¾ (Dark brown)	5 YR 3/2 (Dark reddish brown)	5 YR 4/2 (Dark reddish gray)	5 YR 3/2 (Dark reddish brown)	7,5 YR ¾ (Dark brown)
pH	6.5	6	6	6	6	6	6	6
Air temperature (˚C)	31.04				30.35			
Air humidity (%)	67.69				71.77			
Light intensity (lx)	35,668				30,625			
Annual rainfall (mm/year)	2.144				2.144			
Canopy coverage (%)	72				91			
Leaf litter thickness (cm)	0.52				1.144			
Leaf litter coverage (%)	91.16				95.68			
Understory vegetation (%)	50				75			

ACKNOWLEDGEMENTS

The authors are grateful to their colleagues at the Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia who have contributed to the data collection process. We would also like to thank Ramadan from the Faculty of Geographic, Universitas Gadjah Mada for his assistance with the map location.

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