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INVASION OF *Acacia decurrens* WILLD. AFTER ERUPTION OF MOUNT MERAPI, INDONESIA

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ABSTRACT

Eruption of Mount Merapi in 2010 caused a dense cover of *Acacia decurrens* Willd., which is an Invasive Alien Plant Species (IAPS). The dense cover happened in all areas of Mount Merapi National Park (MMNP) in Java, Indonesia. This study was aimed to describe the relationship between major natural disturbance from volcanic eruption in triggering the invasion of *A. decurrens* in Mount Merapi National Park. Vegetation data were collected using line transect in two different sites. The first site was Cangkringan which was affected by pyroclastic flow and the second site was Selo which was not affected by pyroclastic flow. Distribution patterns and association of *A. decurrens* with other species in each location was analyzed using ordination analysis of the Non-Metric Multidimensional Scaling (NMDS). Microclimate such as temperature, humidity, light density and soil humidity was recorded in each location. Correlation between species abundance and microclimate data was assessed using Canonical Correspondence Analysis (CCA). The results showed that the population of *A. decurrens* was more dominant in Cangkringan than in Selo site. Cangkringan site was impacted with pyroclastic flow during Mount Merapi eruption in 2010, while Selo site was not affected. In Cangkringan, *A. decurrens* was distributed in clump, while in Selo the plant was randomly distributed. Ordination analysis using NMDS showed that there was positive association between *A. decurrens* and herbaceous plant. Negative association was observed between *A. decurrens* and other tree species. CCA analysis showed that temperature and light density was positively correlated with *A. decurrens* abundance. This study showed that the IAPS invasion in MMNP was correlated with the eruption of Mount Merapi.

Keywords: *Acacia decurrens*, autecology, eruption, invasive

INTRODUCTION

Mount Merapi National Park (MMNP) is a protected forest, rich with various flora and fauna. Mount Merapi, located in the MMNP, is the most active volcano in Indonesia. The eruption of Mount Merapi from 26 October to 6 November 2010 was recorded as the worst disaster since its eruption in 1870 (BNPB 2011). Mount Merapi eruption in 2010 was characterized by pyroclastic flow (a fast moving flow containing high-density mixture of hot lava blocks, pumice, ash and volcanic gas) which reached temperature of 400 – 600 °C and speed of 130 km/h, causing vegetation destruction, among others. Vegetation succession after the eruption showed a decline in the diversity of alpine vegetation. The native plant was replaced by Invasive Alien Plant Species (IAPS) which became dominant in several locations affected by the eruption of Mount Merapi. Dadap (*Erythrina longifolia)* and pine (*Pinus merkusii*), which were initially the most common plant species in this area, were not recorded after the eruption. Pine is not a local species in this mountain area, however, this plant might have been escaped from the neighboring plantation forest managed by state forest enterprises.

Invasive Alien Species (IAS) is a combination of alien species and their invasive characteristics. An alien species is a species (at the level of species, subspecies, varieties) that had been intentionally or unintentionally introduced (as whole organism, part of the body, gametes, seeds, eggs or propagules that are able to live and reproduce in

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the new habitat) into areas outside of its natural distribution range. Invasive species, either native or introduced species, become densely established and broadly affect the habitat and land uses resulting to serious environmental, social and economic impacts (CBD-UNEP 2014).

Acacia decurrens is one of serious Invasive Alien Plant Species (IAPS) in MMNP. The plant became dominant in the areas affected by pyroclastic flow. This plant, originated from Australia, belongs to family of Fabaceae, subfamily of Mimosoidae and genus of *Acacia*. Within their native distribution range, *Acacia decurrens* is considered as fast growing pioneer species and often causes serious concern due to its potential invasion to their new habitat. IAPS can establish themselves in a disturbance area and begin to dominate native vegetation.

Invasion by an alien species can occur in an area if the native species are unable to quickly adapt to the change of environmental conditions. IAPS can significantly suppress the native plant, invertebrate and vertebrate population and communities. For example, *Lantana camara* invaded large areas of tropical Asia and Australia as well as contributed to the declines of several endangered species in Australia (Coutts-Smith & Downey 2006). The invasion of *Acacia nilotica* in Baluran National Park has changed the savanna into a shrub of *Acacia* and contributed to the decreasing number of banteng (*Bos javanicus*) population (Setiabudi *et al.* 2013). Plant invasion can occur due to natural disasters, climate and environment changes. The invasion can also happen in disturbed habitats.

There are only a few studies focused on the impact of natural disturbance from volcano eruption to the invasion of IAPS. Therefore, studying biological invasions in mountains having natural disturbance is scientifically important for nature conservation. This study was aimed at determining correlation between Mount Merapi eruption and the invasion of *A. decurrens* in MMNP and at determining the autecology of *A. decurrens* as basic information for managing plant invasion in MMNP. It was assumed that the eruption of Mount Merapi with the pyroclastic flow has positive correlation with the abundance population of *A. decurrens* in Mount Merapi. The autecology study was performed to explain the characteristic, dynamic population of individual species, life cycle and ecological factors, including physical, biological and environmental factors.

MATERIALS AND METHODS

Study Site

The research was conducted from March to December 2014. The research was conducted in Mount Merapi National Park (MMNP). The research location was divided into two sites. The first site was Cangkringan located at 7°35.771” – 110°26.375” (954 m asl). This site was affected by pyroclastic flow during the eruption in 2010. The second site was Selo located at 7°30.843” – 100°27.188” (1,044 m asl). This site was not affected by the pyroclastic flow. The study at each site was conducted at three different altitude zones i.e. high zone (1,400 – 1,700 m asl), middle zone (1,100 – 1,400 m asl) and lower zone (800 – 1,100 m asl).

Sampling Design and Data Analysis

Vegetation analysis was performed using a systematic sampling with transect line along 100 m for each zone in the two study sites. Each transect line consisted of 10 quadrats of 10 x 10 m (for tree species), 10 quadrats of 5 x 5 m (for sapling species) and 10 quadrats of 2 x 2 m (for herb species) (Cropper 1993; Krebs 2002). Height and diameter data of *A. decurrens* trees were collected at each site. These data were collected from 15 trees that were inside the 10 quadrat plots of 10 × 10 m. Environmental data collected at each site were soil physical and chemical properties, air temperature, humidity, light intensity and wind speed.

Importance Value Index (IVI) was calculated to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance were summed up together (Kent & Paddy 1992). Species diversity was determined using Shannon-Wiener Diversity Index (H), while species dominance was determined using Simpson's Dominance Index (D).

Shannon-Wiener Diversity Index (H) is an index that is commonly used to characterize species diversity in a community. Shannon-

Wiener Diversity Index (H) accounts for both abundance and evenness of the existing species, as is shown in this formula:

$$H = -\sum Pi \, InPi;$$

$$Pi = \frac{ni}{N}$$

where:
H = Shannon-Wiener Diversity Index
Pi = proportion of species
n_i = number of species
N = number of quadrat

Simpson's Dominance Index (D) is a simple mathematical measure that characterizes species diversity in a community. The proportion of species (ni) relative to the total number of species (N) is calculated and squared. The squared proportions for all the species are summed, and the reciprocal is taken:

$$D = \sum_{i=1}^{s} \left[\frac{ni}{N}\right]$$

where:
D = Simpson's Dominance Index
n_i = number of species
N = number of quadrat

The Simpson's index ranges:

1. If D = 0 – 0.5 this means that none species were dominant
2. If D = 0.5 – 1 this means that there is a dominant species

Evenness Index (E) can be calculated by dividing H by H_{max} (where $H_{max} = \ln S$). Equitability assumes a value between 0 and 1 with 1 being complete evenness.

$$E = \frac{H}{InS}$$

where:
E = Evenness Index
H = Shannon-Wiener value
S = total number of species in the community

Plant distribution pattern was analyzed using Morisita Index of Dispersion (Ið), as is shown by this formula:

$$Ið = n \left(\frac{\sum Xi^2 - \sum Xi}{\sum Xi^2 - \sum Xi}\right)$$

where:
Ið = Morisita Index of Dispersion
N = sample size
$\sum Xi$ = sum of the quadrat count
$\sum Xi^2$ = sum of the quadrat count from the total of species in the community

The deviation from random expectation can be tested using critical values of the Chi-square distribution with n-1 degrees of freedom. Confidence interval around 1 can be calculated by the uniform (Mu) and clumped (Mc) indices (Krebs 2002).

$$Mu = \frac{x^2 0.0975 - n + \sum xi}{\sum xi - 1}$$

$$Mc = \frac{x^2 0.025 - n + \sum xi}{\sum xi - 1}$$

where:
$x^2 0.0975$ = value of chi-square from the table with (n-1), degree of freedom that has 97.5 % of the area to right
$x^2 0.0025$ = value of chi-square from the table with (n-1), degree of freedom that has 2.5 % of the area to right
xi = number of individual of species in a set of quadrat
n = number of quadrat

Standardized Morisita Index was calculated using the following four formulas:

When $Ið \geq Mc \geq 1.0$ $Ip = 0.5 + 0.5 \left(\frac{Ið - Mc}{n - Mc}\right)$

When $Mc > Ið \geq 1.0$ $Ip = 0.5 \left(\frac{Ið - Mc}{n - Mc}\right)$

When $1.0 > Ið > Mu$ $Ip = -0.5 \left(\frac{Ið - 1}{Mu - 1}\right)$

When $1.0 > Mu > Ið$ $Ip = -0.5 + 0.5 \left(\frac{Ið - 1}{Mu - 1}\right)$

Standardized Morisita Index of Dispersion (Ip) ranges from -1.0 to +1.0 with 95% confidence limit at +0.5. Ip = 0 means that the plants are in random dispersion, Ip > 0 means that the plants are in clumped dispersion and Ip < 0 means that the plants are in uniform dispersion.

Correlation between environmental factors and abundance of *A. decurrens* was analyzed using Canonical Correspondence Analysis (CCA) of the PAST V2. Software (Legendre & Legendre 1998; Hammer *et al.* 2005). Distribution and association between *A. decurrens* and other species in the community were determined using species ordination of the Non-Metric Multidimensional Scaling and calculated using PRIMER v5. Software (Clarke & Gorley 2015).

Table 1 Vegetation observed at Cangkringan site that were affected by pyroclastic flow

No.	Species	Family	Importance Value Index			Morisita Index		
			Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Herbs								
1	*Centella asiatica*	Apiaceae	14.46	19.46	13.59	C	C	C
2	*Ageratum conyzoides* L.*	Asteraceae	4.59	7.88	11.88	C	C	C
3	*Bidens biternata*	Asteraceae	10.64	6.32	8.85	C	C	U
4	*Emilia sonchifolia*	Asteraceae	4.30	10.92	7.11	C	C	C
5	*Eupatorium odoratum**	Asteraceae	8.54	1.18	7.00	C	C	C
6	*Eupatorium inulifolium**	Asteraceae	5.46	13.70	4.37	C	C	C
7	*Eupatorium triplinerve**	Asteraceae	4.20	5.39	3.35	C	C	C
8	*Gynura crepidioides*	Asteraceae	1.35	7.60	4.83	C	-	C
9	*Mimosa pudica**	Asteraceae	10.14	3.64	8.23	C	C	C
10	*Pennisetum macrostachyum**	Asteraceae	6.85	4.77	5.68	C	C	C
11	*Polygala paniculata**	Asteraceae	11.87	1.28	10.11	C	C	C
12	*Sida rhombifolia*	Asteraceae	1.07	5.29	0.86	C	C	C
13	*Stachytarpheta jamaicensis*	Asteraceae	2.51	2.46	2.04	C	C	C
14	*Wedelia trilobata**	Asteraceae	9.84	3.45	8.23	C	C	U
15	*Impatiens platypetala*	Balsaminaceae	6.97	10.92	6.14	C	R	C
16	*Cyperus rotundus**	Cyperaceae	3.86	3.73	3.14	C	C	C
17	*Erigeron sumatrensis* Retz	Gleicheniaceae	10.33	-	8.39	C	-	U
18	*Melastoma malabathricum**	Melastomaceae	1.97	-	6.76	C	C	C
19	*Selaginella kraussiana*	Mimosaceae	3.93	-	3.11	R	C	R
20	*Synedrella nodiflora*	Oxalidaceae	10.07	-	8.26	C	U	C
21	*Imperata cylindrica**	Poaceae	31.19	59.85	26.59	C	-	C
22	*Tithonia diversifolia**	Poaceae	1.07	1.09	0.86	C	C	C
23	*Tridax procumbens*	Poaceae	3.15	2.08	11.24	C	C	C
24	*Gleichenia longissima*	Polygalaceae	5.39	3.73	4.40	C	-	C
25	*Oxalis corniculata**	Silaginellaceae	7.13	4.67	5.93	C	C	C
26	*Lantana camara**	Verbenaceae	5.48	6.53	4.48	C	C	C
27	*Rubus chrysophyllus* Miq.	Verbenaceae	1.97	1.99	1.56	C	C	C
Sapling								
1	*Acacia decurrens**	Fabaceae	80.84	81.84	84.00	C	C	C
2	*Erythrina variegata*	Fabaceae	57.82	-	35.05	C	-	C
3	*Paraserianthes falcataria*	Fabaceae	23.19	-	79.62	C	-	U
4	*Schima wallichii*	Theaceae	-	59.82	-	-	C	-
Pole								
1	*Acacia decurrens**	Fabaceae	157.68	158.68	146.09	R	C	C
2	*Erythrina variegata*	Fabaceae	28.93	30.93	21.30	C	C	C
3	*Paraserianthes falcataria*	Fabaceae	9.64	12.64	32.61	C	C	C

Notes: - = not found in the site; C = Clump; R = Random; U = Uniform
* = invasive plant based on information from Global IAS Database (www.issg.org)

RESULTS AND DISCUSSION

Species composition of the vegetation at Cangkringan and Selo sites in terms of Importance Value Index (IVI) and Morisita Index of Dispersion for herbs, sapling and tree for each altitude zone are shown in Table 1 and 2. Vegetation at Cangkringan site was dominated by herbs species of *Imperata cylindrica*, *Centella asiatica, Impatiens balsamina* and by sapling and tree species of *A. decurrens* (Table 1).

Vegetation at Selo site was dominated by species of *C. asiatica*, *Eupatorium odoratum*, *Eupatorium riparium*, *Pennisetum purpureum*, *Pogonatum* sp., and by sapling and tree species of *A. decurrens*, *Vaccinium varingiaefolium* and *Albizia lophantha* (Table 2).

Table 2 Vegetation observed at Selo site that were not affected by pyroclastic flow

No.	Species	Family	Importance Value Index			Morisita Index		
			Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Herbs								
1	*Centella asiatica*	Apiaceae	34.16	20.43	5.18	R	C	C
2	*Foeniculum vulgare*	Apiaceae	5.05	0.0	0.00	C	-	-
3	*Anaphalis javanica*	Asteraceae	6.32	10.50	16.21	U	C	C
4	*Anaphalis longifolia*	Asteraceae	3.79	11.31	9.96	U	C	C
5	*Lactuca sativa*	Asteraceae	4.25	6.07	19.20	C	C	C
6	*Athyrium* sp.	Athyriaceae	7.34	6.07	6.62	C	C	C
7	*Impatiens platypetala*	Balsaminaceae	12.16	12.16	0.00	C	C	-
8	*Erigeron sumatrensis* Retz*	Compositae	5.51	9.84	0.00	C	C	-
9	*Indigofera cassioides*	Fabaceae	4.40	1.97	0.00	C	C	-
10	*Eupatorium odoratum**	Malvaceae	5.93	9.03	27.02	C	C	R
11	*Eupatorium riparium**	Malvaceae	21.34	9.36	8.49	C	C	C
12	*Melastoma malabathricum* *	Melastomaceae	5.97	3.44	5.15	C	C	C
13	*Oxalis corniculata*	Oxalidaceae	12.38	59.80	0.00	C	C	-
14	*Pennisetum purpureum**	Poaceae	42.09	25.40	50.56	C	R	R
15	*Pogonatum* sp.	Poaceae	10.70	0.0	31.00	C	-	C
16	*Brugmansia candida*	Solanaceae	4.10	0.0	0.00	C	-	-
17	*Lantana camara**	Verbenaceae	7.08	5.90	11.43	C	C	C
18	*Rubus chrysophyllus* Miq.	Verbenaceae	2.83	3.44	4.78	C	C	C
19	*Rubus plicatus*	Verbenaceae	4.55	5.24	7.72	C	C	R
Sapling								
1	*Acacia decurrens**	Fabaceae	33.67	42.51	58.67	R	R	R
2	*Vaccinium varingiaefolium*	Ericaceae	39.29	64.64	104.53	C	C	M
3	*Albizia lophantha**	Fabaceae	37.90	30.38	36.00	C	C	M
4	*Erythrina lithosperma*	Fabaceae	27.29	30.95	0.00	C	U	-
5	*Toona sureni*	Meliaceae	16.52	8.13	0.00	C	C	-
6	*Cinchona succirubra*	Rubiaceae	22.90	11.69	0.00	C	C	-
7	*Dodonaea viscosa*	Sapindaceae	14.52	12.69	0.00	A	-	-
8	*Schima wallichii*	Theaceae	21.90	42.51	0.00	C	C	-
Pole								
1	*Casuarina junghuhniana*	Casuarinaceae	17.44	18.44	23.81	C	C	C
2	*Cupressus montana*	Cupressaceae	13.04	15.04	10.48	C	C	C
3	*Vaccinium varingiaefolium*	Ericaceae	19.60	22.60	47.86	C	C	C
4	*Acacia decurrens**	Fabaceae	41.94	45.94	107.38	C	C	R
5	*Albizia lophantha*	Fabaceae	37.77	42.77	11.19	C	C	C
6	*Erythrina lithosperma*	Fabaceae	18.39	24.39	0.00	C	C	-
7	*Toona sureni*	Meliaceae	6.52	0.00	0.00	C	-	-
8	*Myrica javanica*	Myricaceae	8.06	0.00	0.00	C	-	-
9	*Cinchona succirubra*	Rubiaceae	9.01	13.52	0.00	C	C	-
10	*Dodonaea viscosa*	Sapindaceae	4.98	0.00	0.00	C	-	-
11	*Schima wallichii*	Theaceae	24.69	16.06	0.00	C	R	-

Notes: – = not found in the site; C = Clump; R = Random; U = Uniform
* = invasive plant based on information from Global IAS Database (www.issg.org)

Herbs at Cangkringan site were dominated by Asteraceae family, while at Selo site were dominated by Asteraceae and Verbenaceae families. The domination of Asteraceae family occurred because this family can well adapt to the mountain slope conditions. This family also has role in ecosystem functions, such as preventing erosion and enriching soil organic matter

(Kumolo & Utami 2011). They are often classified as weed on agricultural land. One species member i.e. *E. odoratum* was reported by Sunaryo *et al.* (2012) and Uji (2010) for invading several locations in the Mount Salak and Mount Gede Pangrango National Park. Based on database from Invasive Species Specialist Group (ISSG 2015), numbers of herbs and tree species in the two study sites were listed as Invasive Alien Plant Species (IAPS). Only few numbers of native plants were found after the eruption. Native plants can adapt to a very low frequency of disturbance and take a long time to recover into the same population size as before the disturbance (Smith & Tunison 1992). *A. decurrens* is the most dominant and has high risk to the environment in Mount Merapi National Park. This species densely covered the vegetation at Cangkringan site.

Morisita Index of Dispersion showed that the *A. decurrens* was dispersed into clumped pattern (Table 1 & 2). In natural ecosystem, plant distribution or dispersion was correlated with environmental condition and competition with other species in the community. Random dispersion of plant in the community is rarely found in the tropic ecosystem (Call & Nilsen 2003). Clump distribution of the plant was also caused by high seed reproduction of mature plants which seeds fall surrounding the parent plant. Environmental factors such as climate, wind, soil nutrients may influence plant distribution.

Clump distribution of plant species affected species diversity and evenness of plant community (Soerianegara & Indrawan 1998). The results showed that at Cangkringan site population of *A. decurrens* was clump distribution (Table 1) with lower diversity index compared to the index at Selo site (Table 3).

A. decurrens at Selo site was randomly distributed (Table 2). Species diversity in a plant community was affected by density of the individual species, the larger number of the species and the spread of each species. At Cangkringan site the evenness index showed that the herbs were more stable than the pole or tree plant due to the invasion of *A. decurrens* which densely distributed in clumps. Simpson's Dominance Index (D) showed that some species dominated plant community both at Cangkringan and Selo sites. Pole and tree vegetations at Cangkringan site had low dominance indices than those at Selo site. Smaller dominance index indicated that there was a species spread and dominated the coverage of an area (Krebs 2002).

Table 3 Shannon-Wiener Diversity Index (H), Evenness Index (E) and Simpson's Dominance Index (D) of vegetations at Cangkringan and Selo sites

Location	Zone	Vegetation Category	H	E	D
Cangkringan	1	Herb	2.80	0.84	0.91
		Sapling	1.39	0.86	0.73
		Pole	0.39	0.35	0.19
	2	Herb	2.80	0.88	0.72
		Sapling	0.55	0.79	0.86
		Pole	0.17	0.15	0.87
	3	Herb	2.89	0.87	0.92
		Sapling	1.00	1.44	0.60
		Pole	0.15	0.14	0.96
Selo	1	Herb	2.15	0.65	0.82
		Sapling	2.66	1.65	0.85
		Pole	2.02	1.84	0.53
	2	Herb	1.89	0.57	0.75
		Sapling	1.84	1.14	0.37
		Pole	2.02	1.84	0.76
	3	Herb	1.95	0.59	0.80
		Sapling	0.98	0.61	0.44
		Pole	0.99	0.90	0.52

Invasion of *A. decurrens,* forming monoculture thickets, may reduce the abundance of native plant species. Few native species found at the Cangkringan site was highly invaded by *A. decurrens*. Reduction of species diversity may be caused by competition for soil nutrients between native species and IAPS. Other possible cause was the ability of *A. decurrens* (Legume family) to increase soil nitrogen content (nitrogen fixing). Changes in vegetation composition and loss of diversity are considered to negatively affect wildlife through quality and quantity of ecosystem services (Mc. Donald *et al.* 2012).

Autecology

Perhutani (State Forest Enterprise) introduced *A. decurrens* into MMNP around 1980s, before the region was declared as a conservation area. *A. decurrens* was used as divider between plantation area with agriculture land. Over time, *Acacia* was widespread in several regions around the national park. Significant high number of *A. decurrens* population was recorded in 2011, a few months after the eruption of Mount Merapi which occurred from October to November 2010. *Acacia* has hard and thick seed coat to remain dormant in certain circumstances. Also, the seed structure makes it possible for *Acacia* to germinate under unsuitable condition caused by major disturbances. Invasive species tend to have generalist pollination, mass seed production, efficient seed dispersal and persistent seed bank which can endure heat caused by fire or disturbance that triggered seed germination (Gibson *et al.* 2011). This study indicated that the pyroclastic flow broke the dormancy of seed stored in the soil (soil seed bank). *Acacia* invasion in MMNP was caused by major disturbances resulted from Mount Merapi eruption. The invasion occurred in several areas impacted by the pyroclastic flow. The pyroclastic flow contained materials that can stimulate biological production in the impacted environment. The materials can be used as fertilizer and contain many elements that can increase soil fertility.

There is positive correlation between *A. decurrens* invasion and Mount Merapi eruption, accompanied by pyroclastic flow. Fire is one of natural disturbances and important processes for maintaining species diversity in forest ecosystem (Walker & del Moral 2003). Non-native plant species with an established seed bank tend to respond positively to post-fire conditions, such as increased soil temperatures, increased light levels, reduced competitions and increased available nitrogen (Wagner & Fraterrigo 2015). *A. decurrens* is known for their high flammability and has tendency to quickly recover from disturbance compared to native species (Brooks *et al.* 2004).

High population of *A. decurrens* at Cangkringan site was an example showing correlation between area impacted by pyroclastic flow and *Acacia* invasion in the area. Selo site had low population of *Acacia* because Selo site was not impacted by pyroclastic flow (Table 1 & 2). Invasive species responded quicker to disturbance than non-invasive species (Gibson *et al.* 2011). Invasive alien plant species can widely spread, have high growth rate and have high tolerance to physical conditions such as fire, flood, drought and other natural disturbances. These physical conditions are the major factors for alien plant species to invade a new area (Velde *et al.* 2006). There are four factors influencing the success of species invasion i.e. disturbances occurred in ecosystem (fire or natural disaster), ability to compete, availability of resources and pressure of propagules (Moser *et al.* 2009). Species invasion is the result of interactions between habitat suitability and pressure of propagules (Rejmànek *et al.* 2005). Changes in environmental conditions may affect the level of species invasion. Changes in environmental conditions interfere with the balance of competition between native plants and foreign plants. Among changes in the environment are limited metabolism, high temperature and presence of toxin (Alpert *et al.* 2000).

Cluster analysis showed that *A. decurrens* has positive correlation only with herbs. High numbers of correlation were observed between *A. decurrens* and *C. asiatica*, *E. riparium*, *Impatiens platypetala* and *Pennisetum purpureum* (Fig.1). Negative correlations occurred between *A. decurrens* and native species. The results also showed that at Cangkringan site there was a decrease in the number of native tree species due to high numbers of *A. decurrens* (Fig. 2).

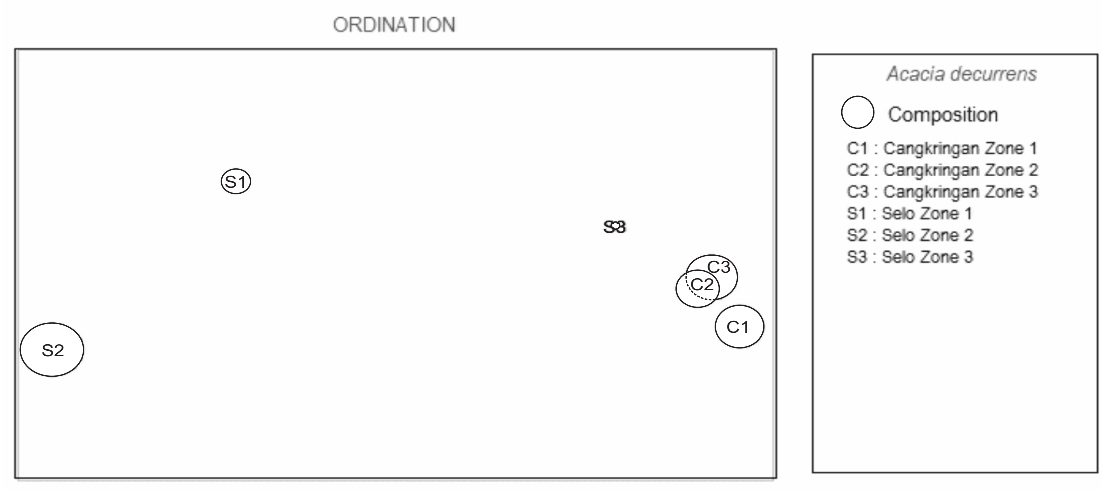

Figure 1 NMDS ordination result (2D stress = 0.01, measured from relationship between actual dissimilarities and distances) which shows species composition difference in each sample plot and change in abundance of *A. decurrens*

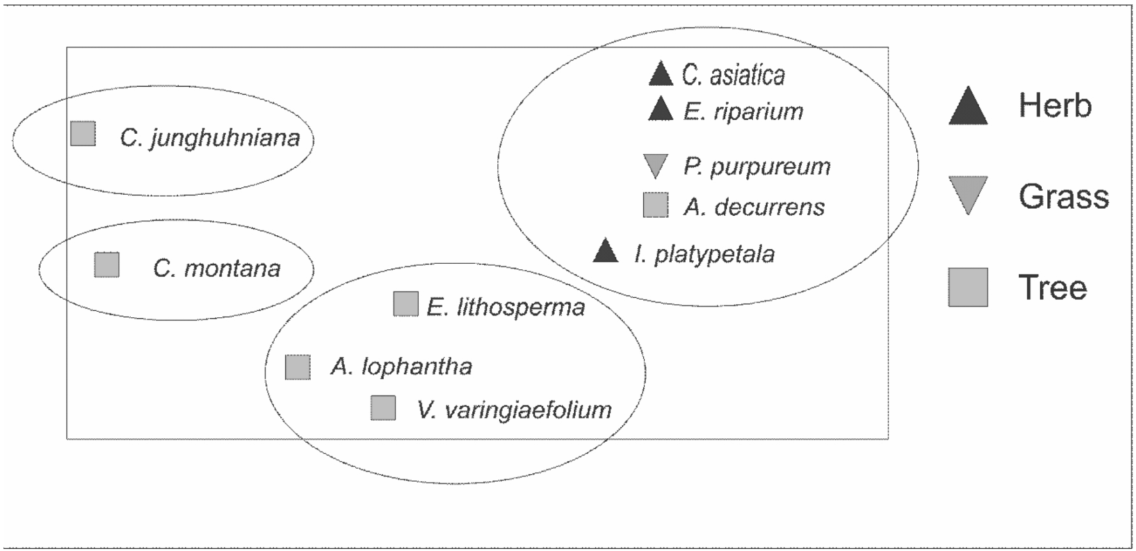

Figure 2 NMDS ordination result (2D stress = 0.11, measured from relationship between actual dissimilarities and distances) which shows association clusters of plant community including *A. decurrens* at sampling locations

Being tree and woody species, *A. decurrens* is a competitor to other tree species. The dominance of *A. decurrens* presents an extreme challenge for the native plant communities because the rapid canopies growth of A. *decurrens* hindered other plants from obtaining light.

It is very important to understand that invasion process varies along biotic and abiotic gradients within a local environment. Abiotic variable is the most important factor to study the plant autecology (Swamy *et al.* 2000). The study of abiotic gradient analysis showed that the invasion of *A. decurrens* correlated with available light and weather temperature (Fig. 3).

Changes in available light, wind speed, humidity, temperature and soil moisture induced by fragmentation of forest ecosystems often add to competitive advantages of invasive species over native species (Emily *et al.* 2004). Mount Merapi eruption has burned down all of the native vegetation and transform it into the open area. As the open area, automatically the light density was increased light intensity and also the increase of the temperature after the eruption.

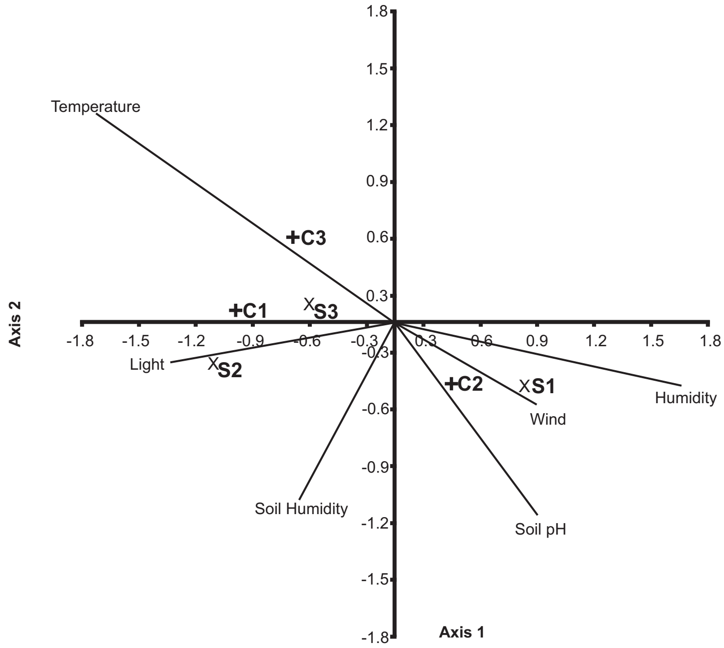

Figure 3 The influence of environmental factors in the two study sites towards *A. decurrens* population using Canonical Correspondence Analysis (CCA)
Notes: C = Cangkringan; S = Selo; 1 = Zone 1; 2 = Zone 2; 3 = Zone 3

The increase of temperature and the light density was triggered the seed bank to germinate. IAPS can endure extreme temperature which makes them competitor to the native vegetation (Hellmann *et al.* 2008; Ordonez *et al.* 2010; Van Kleunen *et al.* 2010). Song *et al.* (2010) studied the effect of extreme high temperatures for the invasive *Wedelia trilobata*, and found out that in the extreme high temperature condition, *W. trilobata* experienced less inhibition of relative growth rate (RGR) and biomass production than the native plant *Wedelia chinensis*.

Our study compared diameter and height of *A. decurrens* located in area affected by pyroclastic flow (Cangkringan) and those located in area not affected by pyroclastic flow (Selo). Diameter of *A. decurrens* at Cangkringan site was lower than that at Selo site. Inverse effect observed for the height of *A. decurrens* (Fig. 4 & 5). Tree height or diameter was also affected by species composition of understory (Suryanto *et al.* 2010). IAPS also produce large amount of litter under the canopies, which may influence understory species (Williams & Wardle 2007). Results of this

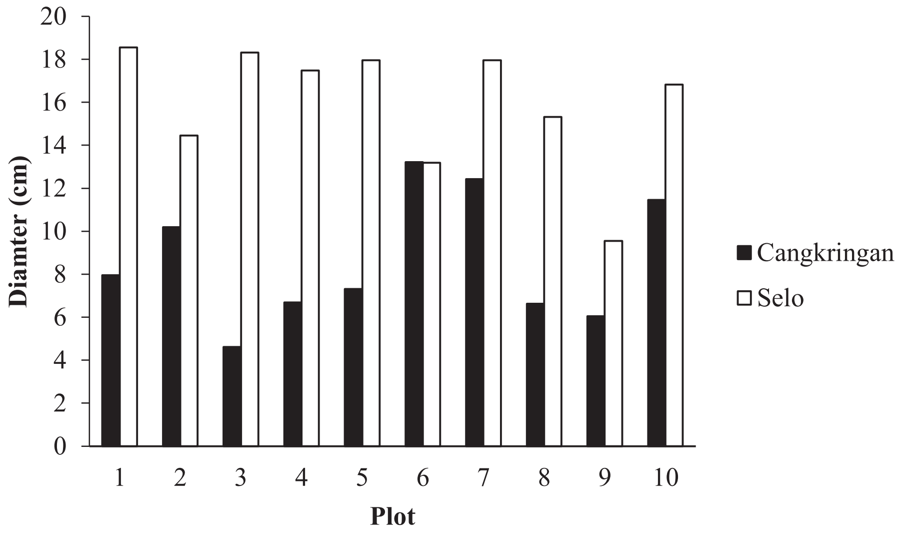

Figure 4 Diameter of *A. decurrens* at Cangkringan site (invaded) and Selo site (uninvaded)

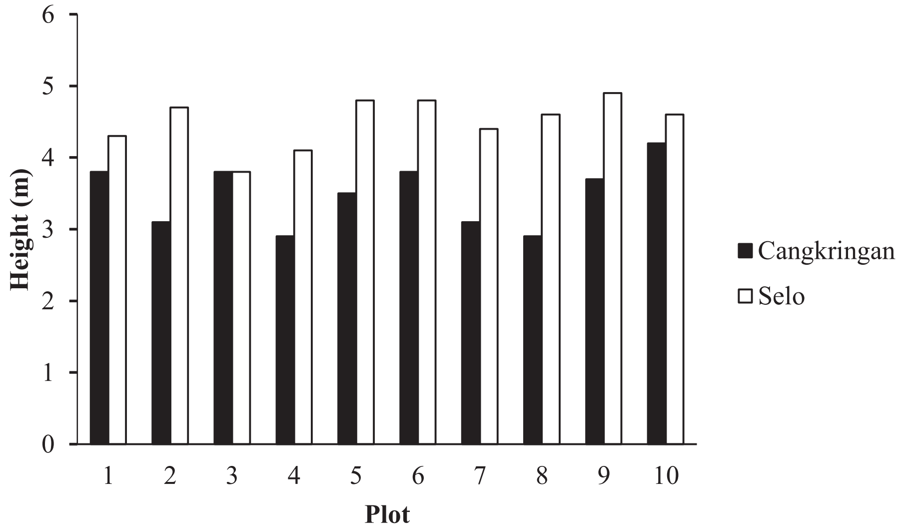

Figure 5 Height of *A. decurrens* at Cangkringan site (invaded) and Selo site (uninvaded)

study revealed that there were different sizes of diameters as well as dissimilarity in native understory plant composition between those located at Cangkringan site (invaded by *A. decurrens*) and those located at Selo site (not invaded by *A. decurrens*). Dense population at Cangkringan (invaded site) would lead to intraspecific competition in obtaining resources from the environment.

A. decurrens invaded from low elevation to higher elevation; therefore, it was adapted to the climate of Mount Merapi. The management of MMNP has to be aware of the invasive ability of *A. decurrens* in order to control the spreading of this plant species. Among effective treatments to eradicate *A. decurrens* population are cut stump method, herbicide treatment and seed production decrease.

We suggest conducting a study for determining the most feasible and most economical management strategy to eradicate this invasive species. Among characteristics of *A. decurrens* are having mass seed production, seed germination triggered by high temperature, high potential to spread and ability to produce root sucker. In managing the invasion, it is not immediately apparent whether the eradication method used will be cost effective or not. Therefore, it is very important to have a good understanding of the invaded site, the invasive plant species characteristics, the biological impacts and the management strategy to control invasive plant species (Moore *et al.* 2011).

CONCLUSIONS

Mount Merapi eruption triggered the spread of *A. decurrens* in MMNP. The Importance Value Index showed that the invasion of *A. decurrens* was more dominant in Cangkringan site (affected by the eruption) than in Selo site (not affected by the eruption). NMDS ordination showed the differences in the composition and abundance of *A. decurrens* between Cangkringan site and Selo site. *A. decurrens* showed a clump dispersal pattern at Cangkringan Site and a random dispersal patterns at Selo site. Environmental factors positively correlated with the abundance of *A. decurrens* were temperature and light intensity.

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