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Species composition and interspecific association of plants in primary succession of Mount Merapi, Indonesia

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ABSTRACT

Sutomo, Faradila D, Putri LSE (2011) Species composition and interspecific association of plants in primary succession of Mount Merapi, Indonesia. Biodiversitas 12: 212-217. Primary succession refers to the establishment of plant species and subsequent changes in composition following major disturbance such as volcanic activity. The study of succession may assist in recognizing the possible effects of species interactions (i.e. facilitation or inhibition). The barren landscapes created by volcanic disturbance on Mount Merapi, Java, Indonesia, provide excellent opportunities to study primary succession. Fifty-six species belonging to 26 families were recorded in the five nuées ardentes deposits. The highest number of species belonged to the Asteraceae, then Poaceae, followed by Fabaceae and Rubiaceae. In Mount Merapi primary succession, the ecosystem may be developing with time as indicated by the increase in the number of species associations. The number of positive associations was generally higher than the number of negative associations, except in the 2001 deposit where it was equal. Native and alien invasive species had different patterns of interspecific associations. This research demonstrates that in primary succession sites on Mount Merapi, positive interspecific association increased as time progressed, which may support the view that facilitation is more prominent in a severely disturbed habitat as compared to competition.

Key words: primary succession, interspecific association, interaction, facilitation, pioneer, Mount Merapi.

INTRODUCTION

Volcanoes has shape many of the Earth landscapes (Dale et al. 2005a). More than half of the active terrestrial volcanoes encircle the Pacific Ocean and are known as the 'ring of fire'. Hence, there are many parallel situations in the world where volcanic activity has become a major disturbance such as in Hawaii (Mount Mauna Loa), New Zealand (Mount Ruapehu), USA (Mount St. Helens), and Indonesia (Mount Krakatau). Indonesia is particularly unique because of a series of active volcanoes which stand in line from the Sumatran Island to Java Island. With 130 active volcanoes lies on its region, Indonesia has become the most volcanic country on Earth (Weill 2004).

Primary succession refers to establishment of plant species and their changes in composition following major disturbance such as volcanic disturbance (Walker and del Moral 2003). One type of volcanic disturbance is *nuées ardentes* or pyroclastic flows. *Nuèes ardentes* are hot turbulent gas and fragmented material resulting from a collapsed lava dome that rapidly moves down the volcanic slope (Dale et al. 2005b). The accumulation of this material is called a *nuées ardentes* deposit and it may be up to 10 m thick (Franklin et al. 1985). Volcanic eruptions are strongly linked to depositions of volcanic materials avalanche to form "un-vegetated" barren areas which started primary succession. Primary succession commence on a barren substrate that does not have any biological legacies and does not support any organism (Walker and del Moral 2003). Vegetation establishment on volcanic deposits has been documented in many parts of the world such as in USA, Italy and Japan and their rates have been shown to vary (Eggler 1959; Tsuyuzaki 1991; Aplet et al. 1998; Dale et al. 2005c). For example, plant establishment and spread on the debris-avalanche deposit were slow during the first years after eruption of Mt St Helens in USA (Dale et al. 2005c).

Species interactions are of central importance in the study of succession. The study of succession may assist in recognizing the possible effects of species interactions (i.e. facilitation or inhibition) (Connell and Slatyer 1977; Walker et al. 2007). Facilitation promotes establishment and in the context of succession, facilitation can be defined as any role of plants that influences a change in species composition to the next stage (Walker and del Moral 2003). Previous studies have shown that in a severely disturbed habitat, the role of facilitation will be more prominent for species change and restoration, whereas competition tends to be significant in a more productive and established habitat (Callaway and Walker 1997; Walker et al. 2007). The barren landscapes created by volcanic disturbance provide excellent opportunities to examined the role of pioneer species in facilitating or inhibiting later species in succession (Morris and Wood 1989; Walker and del Moral 2003). However, initial interactions occurring during primary succession that drive the subsequent community composition remain studied in only a few locations (Connell and Slatyer 1977; Bellingham et al. 2001).

The *nuées ardentes* deposits found in Mount Merapi are relatively young, with the last known eruptions occurring between 1994 and 2006. Here we examine whether or not early interaction patterns among species can be identified by examining their interspecific association and test the hypothesis that positive association will more apparent compared with negative association over time.

MATERIALS AND METHODS

Study sites

Merapi is one of the most active volcanoes in Indonesia which is located 30 km North of Yogyakarta Province in Java Island at 7º35' S and 110º24' E (Figure 1). Climatologically, based on Schmidt and Fergusson's climate classification, the Merapi area is classified as a type B, tropical monsoon area, which is characterized by high intensity of rainfall in the wet season (November-April) and then the dry season (April-October). Its annual precipitation varies from 1,500-2,500 mm. The variation of rainfall on Merapi slope is influenced by *orographic* precipitation. Like in many other tropical monsoon areas, there are minor temperature and humidity variations. Merapi's relative humidity varies from 70-90% with daily average temperatures varying from 19-30° C (Forest Office of Yogyakarta 1999).

The research sites were located in the southwest flank forests of Mount Merapi within Merapi National Park. These sites are the most prone to and most often affected by volcanic disturbance due to the *nuées ardentes* that tend to flow down the hills in this direction. Using chronosequence (space for time substitution) method, we

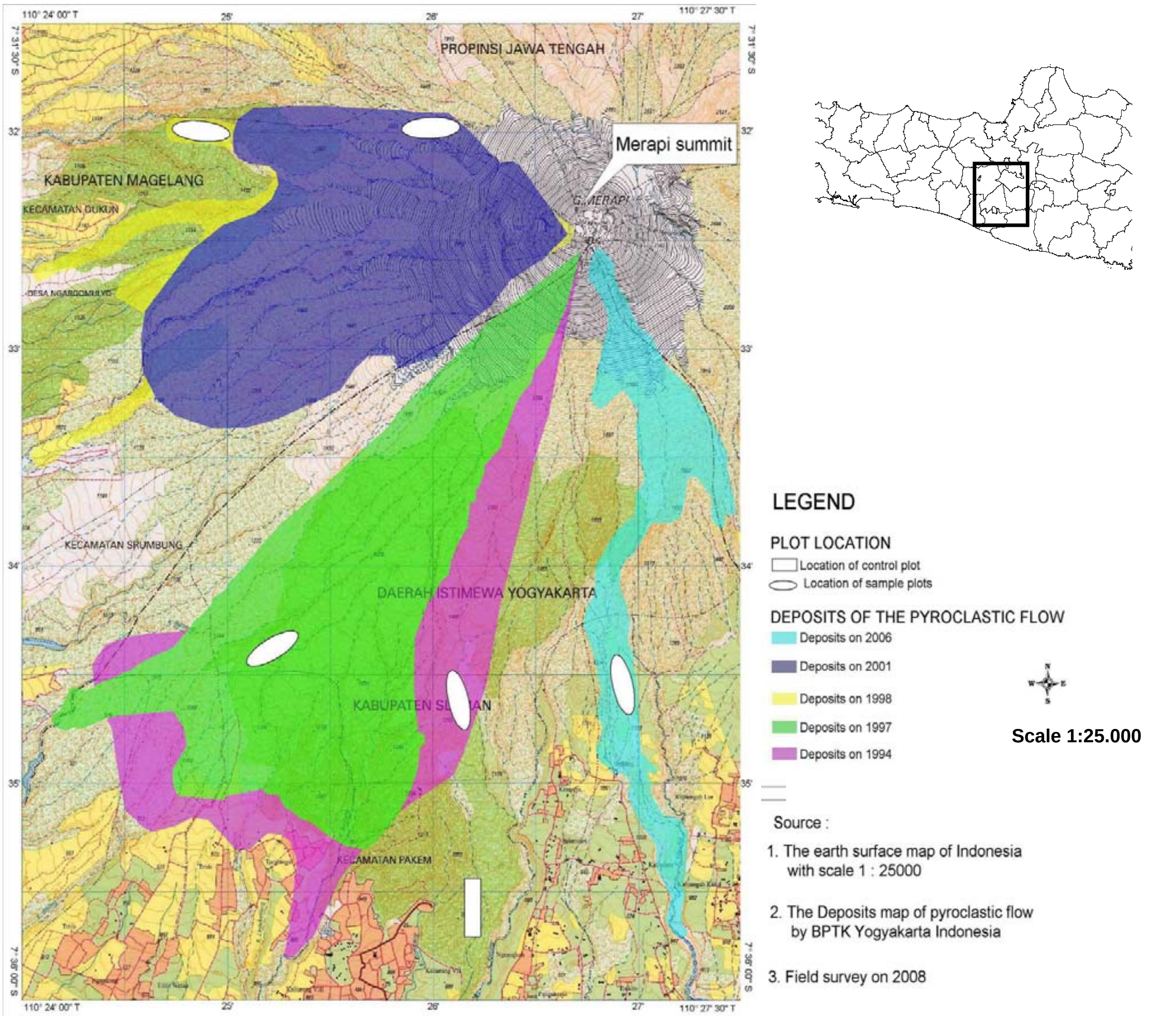

Figure 1. Map of Mt. Merapi National Park's eruption deposits. Circular symbols refer to the position of sampling sites in each deposit. The rectangle refers to the site position of an undisturbed forest in Kaliurang, Yogyakarta.

chose five areas that were affected by *nuées ardentes* deposits between 1994 and 2006 (Figure 1). The five deposit sites were located in a lower montane zone (Montagnini and Jordan 2005). The 1994 sampling site or the late primary succession site is located in an area surrounding the Kuning River, at an altitude of ± 1,180 m. In this late primary successional site the vegetation is generally composed of *Eupatorium odoratum* (Asteraceae) and *Imperata cylindrica* (Poaceae).

Sampling

Vegetation on the five *nuées ardentes* deposits was sampled in 2008. We sampled ten 250 m^2 circular plots in each deposit (50 plots in total), assigned at random to grid cells on a map Dale et al. 2005c). Each plot was located in the field with reference to a compass and a handheld Global Positioning System GPS (Garmin E-Trex Legend). We measured plant abundance as density, a count of the numbers of individuals of a species within the quadrate (Kent and Coker 1992; Endo et al. 2008). We noted both local plant name and scientific name (when known). Whenever there was any doubt about species name, a herbarium sample was made. Drying and sample identification were done in Laboratory of Dendrology, Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta. Vascular plant nomenclature is based on Backer and Bakhuizen van den Brink (1963). Although homogeneity of the sites was taken into account when choosing sample sites, differences in site conditions were likely to occur. Hence, for each circular plot, site attributes (altitude and slope) were measured. Altitude was measured using a GPS and referenced against 1:25,000 topographic maps. A clinometer (*Suunto* PM-5) was used to determine the slope (in degrees) (Le Brocque 1995).

Data analysis

Species composition

Plant community composition between deposits was described by Curtis and McIntosh's Importance Value Index or IVI (1950).

IVI = RD+RF

IVI = Importance Value Index

RD = Relative Density

Relative Density of A species =

$$\frac{\text{Number of individual of A species}}{\text{Total number individual of all species}} \times 100\%$$

RF = Relative Frequency

Relative Frequency of A species =

$$\frac{\text{Frequency value of A species}}{\text{Total frequency value of all species}} \times 100\%$$

Interspecific association

Interspecific association between species was measured using the chi-square (χ^2) test of the species presence/ absence data on a 2 × 2 contingency table (Ludwig and Reynolds 1988; Kent and Coker 1992; Supriyadi and Marsono 2001).

		Species B		
		Present	Absent	∑
Species A	Present	a	b	a+b
	Absent	c	d	c+d
	∑	a+c	b+d	N = a+b+c+d

a = the number of sampling unit (SU) where both species occur

b = the number of SUs where species A occur but not B

c = the number of SUs where species B occur but not A

d = the total number of SUs

Then a chi square test statistic is employed to test the null hypotheses of independence in the 2 × 2 table:

$$x^2 = \frac{(ad - bc)^2 N}{(a+b)(a+c)(b+d)(c+d)}$$

The significance of the chi-square test statistic is determined by comparing it to the theoretical chi-square distribution (P = 0.05, df = 1) There are two type of association:

Positive, if x^2 test > x^2 theoretical and observed a > expected a, Where expected a = $\frac{(a+b)(a+c)}{N}$, that is the pair of species occurred together more often than expected.

Negative, if x^2 test > x^2 theoretical and observed a < expected a, that is to say that the pair of species occurred together less often than expected.

The strength level of the association was measured using the Ochiai index, which is equal to 0 at 'no association' and to 1 at 'complete/maximum association'(Kent and Coker 1992).

$$\text{Ochai Index} = \frac{a}{\sqrt{(a+b)}\sqrt{(a+c)}}$$

RESULTS AND DISCUSSION

Fifty-six species belonging to 26 families were recorded in the five *nuées ardentes* deposits which mostly comprise of species belonged to the Asteraceae (herbs), then Poaceae (grasses), followed by Fabaceae (N_2 fixing tree seedling) and Rubiaceae (shrub). Based on vegetation analysis with IVI computation, we found that each deposit has almost similar set of species composition except for the latest deposits sites namely 2006 and 2001 (Figure 2).

Some species such as *Anaphalis javanica*, *Eupatorium riparium* and *I. cylindrica* showed consistency of their appearance in almost all of the deposits (Figure 3). It is interesting to see that these species have fluctuated over time except for invasive pioneer *I. cylindrica* which was declining in IVI index. This phenomenon may reflect that the abundance and domination of *I. cylindrica* decreasing as the community developed over time. The presence of other pioneer species such as *A. javanica* and invasive species such as *E. riparium* may have suppressed the domination of *I. cylindrica* in more developed sites.

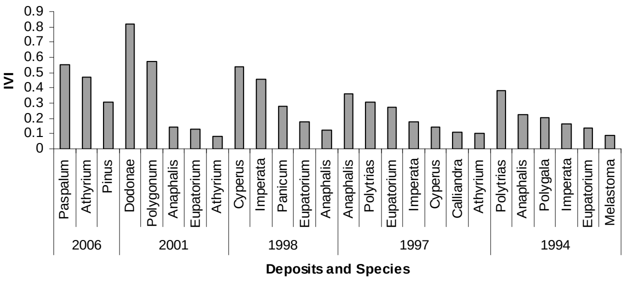

Figure 2. Dominant species based on Importance Value Index in each deposits of primary succession on Mount Merapi

Figure 3. Changes in IVI of some pioneer species of interest in each deposits of primary succession on Mount Merapi.

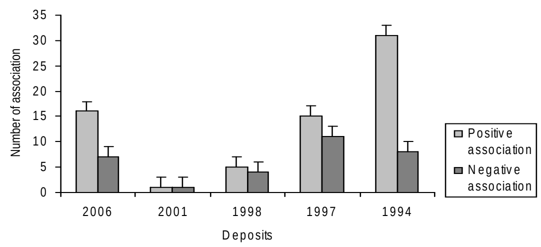

Figure 4. Interspecific association of species in each deposit at primary succession sites of different age.

The number of positive associations was generally higher than the number of negative associations, except in the 2001 deposit, where it was equal (Figure 4). Positive associations were highest in 1994, lowest in 2001 and 1998 and intermediate value in 2006 and 1997 deposits. Generally, the number of negative associations for each deposit was less than positive associations. Less variability occurred in the negative associations. Negative associations were lowest in 2001 and 1998, but almost similar for 2006, 1997 and 1994 deposits.

Native and invasive species had different patterns of interspecific associations (Table 2). Among the native species, *A. javanica* possessed the highest number of negative associations with other species, followed by *Pinus merkusii*. In contrast, *Calliandra calothyrsus* had the highest number of positive interspecific association compare to *Athyrium macrocarpum. A. macrocarpum* had the most tendencies to co-occur (or to absent together) with *Polygala paniculata* as shown by their strongest positive association. Among the invasive species however, *I. cylindrica* is very aggressive and may become dominant in the site as indicated by the absence of other co-occurring species in all deposit sites. *E. riparium* was more likely to occur together with *Melastoma affine,* whereas the presence of *Calliandra calothyrsus* is more likely with *Cyperus rotundus* (Table 2).

The nitrogen fixing legume, *C. calothyrsus* showed the highest number of positive associations with other species, mostly grasses such as *C. rotundus* and *Eleusine indica*. Native from Mexico, this species is now widely introduced in many tropical regions. *C. calothyrsus* is able to grow on a wide range of soils types, including the moderately acidic volcanic origin soils that are a common feature in the Southeast Asia (Palmer et al. 1994). This species is now naturalized in Asia including Indonesia (Palmer et al. 1994)

The mistflower (*E. riparium*) had a higher number of positive associations as compared to negative associations (Table 2). This species is also the dominant groundcover species in Kaliurang, an intact forest on the southern slope of Mount Merapi (Sutomo 2004). This species may have indirectly facilitated co-occurring species such as *Gnaphalium japonicum* and *M. affine* by assisting in stabilizing and preventing erosion on the deposit site (Heyne 1987). However, over domination by this invasive species could be a problem itself. *Eupatorium* is native to South America, and this unpalatable and highly competitive species has become a problem elsewhere, such as in Nepal (Kunwar 2003).

Cogon grass (*Imperata cylindrica*) did not exhibit any association with other species in any deposits (Table 2). *I. cylindrica is* an aggressive alien invader that has a long record of colonizing cleared lands in Indonesia (A. Hamblin, personal communication, 28 May 2009). *I. cylindrica* domination in Mount Merapi *nuées ardentes* deposits is presumably due to its wide-spread rhizomes and its wind-dispersed seeds (Jonathan and Hariadi 1999). *I. cylindrica* may have contributed indirectly to the increase in the number of species colonizing the deposits, especially in the early stages, by altering the soil properties (Walker and del Moral 2003; Collins and Jose 2009).

Species changes are do not only occurring in response to changes in physical environment, but can also be the result of interaction with another species, thus species interactions are also an important indicating factor in succession and ecosystem development (Walker and del Moral 2003; Muller 2005). Species co-occurrence observations may be seen as the first attempt to detect species interaction (i.e. facilitation and inhibition) and niche processes that structure a community (Walker and del Moral 2003; Widyatmoko and Burgman 2006).

While the general explanation of why two species are positively associated is because they favor the same environmental conditions, this explanation is not always as apparent as might first appear and may be over-simplistic (Kent and Coker 1992; Belyea and Lancaster 1999; Ruprecht et al. 2007). There are other factors such as plant species strategies, competition and interaction that also need to be considered (Belyea and Lancaster 1999; Dukat 2006). Facilitation may have a more vital role in species change and restoration in a severely disturbed habitat, whereas competition will tend to be important in a more productive and established habitat (Callaway and Walker 1997; Walker et al. 2007). Furthermore, one of the most important questions in plant community assembly rules may be generated from this observation: "which combination of species occurs together and why?" (Bond and Wilgen 1996).

In primary succession on Mount Merapi, the primary succession ecosystem may be developing to later stages with time as indicated by the increase in the number of species associations. Differences in the number of occurrences of positive associations with the negative associations were also recorded. Generally positive association was more apparent as compared with negative association as time progressed. This observation might support the view that in a severely disturbed habitat where primary succession is occurring, the role of facilitation will have a stronger role in species change as compared to competition (Callaway and Walker 1997). Primary succession on Mount St. Helen was reported to be very slow due to isolated and physically stressful habitat however, facilitation by nitrogen fixing species such as *Lupinus lepidus* may have also occurs (del Moral and Wood 1993). Positive interaction in plant communities is more common than negative interaction in high-elevation ecosystems (Callaway 1998; Endo et al. 2008). However, there has been accumulating evidence that stated facilitation is the dominant form of interaction in many ecosystems (Callaway 2007).

Plant association has also been found in other volcanic sites across the globe. Early associations comprised of *Honckenya peploides,* a low-growing, sand-binding pioneer, lyme grass, *Elymus arenarius,* and the lungwort, *Mertensia maritima,* have contributed to the development of a relatively unstable ecosystem on Surtsey, a volcanic island in Iceland 30 years after eruption (Thornton 2007). On the volcanic island of Krakatau in Indonesia, the beach-creepers *Ipomoea pes-caprae* and *Canavalia rosea*, and the grasses *I. cylindrica* (*alang-alang*) or *Saccharum spontaneum* (*glagah*), have been found to form association related to the slowly growing sand dunes community on the island (Thornton 2007). Furthermore, on a volcanic desert of Mount Fuji, Japan, a dwarf pioneer shrub *Salix reinii* was clumped together and positively associated with the tree seedling *Larix kaempferi* and has shown its role as nurse-plant in primary succession (Endo et al. 2008).

Table 2. Association tests using chi-squared test statistic (χ^2) between discriminating native and invasive pioneer species.

Species	Paired species	Result of chi-squared test	Type of association	Ochiai Index
Anaphalis javanica	*Debregeasia longifolia*	Associated	-	0
	Humata repens	Associated	-	0
	Rubus fraxinifolius	Associated	-	0
Athyrium macrocarpum	*Polygala paniculata*	Associated	+	1
	Polygonum chinense	Associated	-	0.4
Calliandra calothyrsus	*Crassocephalum crepidioides*	Associated	+	0.84
	Cyperus rotundus	Associated	+	1
	Polygala paniculata	Associated	+	0.84
	Panicum reptans	Associated	-	0.4
	Eleusine indica	Associated	+	0.77
	Polytoca bracteata	Associated	+	0.70
	Polytrias amaura	Associated	-	0.4
*Eupatorium riparium**	*Gnaphalium japonicum*	Associated	+	0.84
	Stachytarpheta jamaicensis	Associated	-	0
	Melastoma affine	Associated	+	1
*Imperata cylindrica**	*n.a.*	Not associated	*n.a.*	*n.a.*
Pinus merkusii	*Polygala paniculata*	Associated	-	0.28
	Shuteria vestita	Associated	-	0

Note: Association is significant at 0.05 levels. Values of the Ochiai Index (strength of association) are equal to 0 at 'no association' and to 1 at 'complete/maximum association'. An asterisk (*) indicates an invasive species.

CONCLUSION

This research has demonstrated that in Mount Merapi primary succession sites, positive interspecific association increased as time progressed, which supports already establish view that facilitation is more prominent in a severely disturbed habitat as compared to competition. This result could have important value for restoration programs, which could concentrate on re-planting subsequent species that have positive association with native pioneer species, perhaps preferably focusing on legume species to enhance the barren substrates.

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