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DOMINANCE, ASSOCIATION AND DISTRIBUTION PATTERN OF TREE SPECIES IN BURNT FOREST IN EAST KALIMANTAN

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ABSTRACT

Repeated forest fires remarkably impact species composition. Pioneer species colonize the burnt forest and widely develop up to 30 years after a fire but late-succession species regenerate gradually or even disappear owing to direct impact of fires or other ecological consequences related to fires. Hence, forest restoration through assisted natural regeneration needs some information about the state of post-fire species composition. To better evaluate tree species composition after repeated fires, the species dominance as an indicator of species composition was used in this research, with additional information on the species association and distribution patterns. A 1.8-hectare plot, divided into 180 subplots with size of 10 x 10 m, was established in a secondary forest in Samboja Research Forest, East Kalimantan. The sample plot was burnt in 1982/1983 and 1997/1998. All trees above 10 cm DBH were measured and leaf specimens were collected for species identification at the Herbarium Bogoriense, Cibinong, West Java. For comparison, the 1981 data from the Indonesian Institute of Science were used. Analysis of the Importance Value Index used the species dominance data. A 2 x 2 matrix based on the presence-absence of species for each subplot was used to analyse the association index among species. Variance and average value ratio of certain species present in each subplot were expressed in a dispersion index. A chi-square was used to test the significance between the association and dispersion index. Thirteen years after a second fire, pioneer species of *Macaranga gigantea* were most dominant, followed by *Vernonia arborea*, a sub-climax species. This indicated that the forest was in an early succession process. *Pholidocarpus majadun* was consistently dominant before and after the fire. A total of 38 pairs of species were significantly positively associated and 4801 pairs negatively associated. About 60% of species association, both negatively and positively, were among the 'native species' (species that existed before the fire events) and 'non-native species' (new comer species that regenerated after the fire) in the plot sample. A non-native species, *Vernonia arborea*, associated negatively with the non-native species *Tabernaemontana sphaerocarpa*, and native species, *Oncosperma horridum, Palaquium dasyphyllum* and *Endiandra rubescens*. The distribution pattern of four native species, *Artocarpus anisophyllus*, *Cananga odorata*, *Croton laevifolius* and *Macaranga gigantea,* changed after repeated fires, from uniform to clumped.

Keywords: association, distribution pattern, dominance, East Kalimantan, forest fire

INTRODUCTION

Samboja Research Forest is a remnant, lowland, mixed, Dipterocarp forest ecosystem in East Kalimantan, Indonesia, in which the commercial and high-quality timber species grow, such as meranti (*Shorea* sp.) and ulin (*Eusideroxylon zwageri*) (Delmy 2001). Fifty-five (55) species of Dipterocarpaceae were preiously growing in the area (Kartawinata *et al.* 2008). However, the forest was disturbed by major fires during the dry seasons of 1982/1983 and 1997/1998, leading to a decline in its tree species richness, from 254 to 148 species in 1.65 hectares (Simbolon 2005). Fires dramatically increased the canopy openness and light penetration owing to drastic declines in aboveground biomass immediately after the fires (Slik *et al.* 2008). The high light environment was associated with an abundance of light-

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demanding, light wood, large-leaved, small-seed and long-seed dormancy species which are typically characteristics of early succession tree species (Slik *et al.* 2010; Swaine & Whitmore 1988).

Dominant pioneer species mostly occurred in the first decade of forest succession and then followed by climax species commonly characterized by the shade-tolerant species (Slik *et al.* 2008). Species interactions during the succession process are of central importance in the ecology of a species because a number of biotic and abiotic factors influence the species interaction. In addition, inter-specific association plays a role in controlling species' diversity and composition (Ludwig & Reynolds 1988; Condit *et al.* 2002). Positive association will support the forest regeneration process because species will develop together, but negative association may lead to forest regeneration failure owing to competition among species (Wright 2002). However, species have natural mechanisms to avoid competition both from other individual trees and from other species through developing spatial distribution patterns (Janzen 1970).

Restoration of degraded forest, instead of focusing only on preservation and protection of intact systems, has emerged as a conservation effort in the past few decades (Dobson *et al.* 1997). Traditional restoration efforts focusing on re-establishing abiotic conditions and relying on succession of biotic communities that remained resilient in degraded forest are faced with many challenges such as changes in landscape connectivity, loss of native species, shift in species dominance, trophic interaction and/or exotic invasion, and the effects of changes in the biogeochemical processes. Identifying the constraints is a critical step toward providing recommendations on addressing these challenges (Suding *et al.* 2004). A shift in species dominance due to repeated fires was the constraint faced in Samboja Research Forest (Simbolon 2005; Slik *et al.* 2008). Shifting dominance as a result of fire disturbances may affect the recovery interactions between existing species and future species composition. Understanding the condition of dominant species, species association between species and spatial distribution patterns is important in forest-restoration planning. The spatial distribution of species and inter-species association are fundamental information for understanding species structures and coexistence in communities (Li *et al.* 2014). However, inter-specific association (between species) and spatial distribution pattern of species in secondary growth after fire disturbances have been rarely studied.

The objectives of this research therefore, were (1) to analyze species' dominance affected by repeated fires; (2) to analyze associations between species and spatial distribution patterns after repeated fires; and (3) to provide recommendations for future restoration planning based on current conditions in ecosystem succession.

MATERIALS AND METHODS

Study Area

A permanent 1.8 ha. plot was established amidst the 3,504 hectares of Samboja Research Forest, Kutai Kertanegara and Penajam Paser Utara District, East Kalimantan, Indonesia with location coordinates of 0°59'23"–0°59'27" S and 116°57'31"–116°57'51" E (Fig. 1). The study site was a remnant lowland mixed Dipterocarp forest that was affected by repeated fires in 1982/1983 and 1997/1998.

Methods

The 1.8 hectare (120 x 150 m), divided into 180 subplots with size of 10 x 10 m, was established in the secondary forest of Samboja Research Forest in 2011. The plot was affected by major fires in 1982/1983 and 1997/1998. Trees above 10 cm diameter at breast height (DBH) were recorded from the sampling units of 10 x 10 m, with their DBH recorded and positions geo-mapped. Leaf specimens were collected for species identification at the Herbarium Bogoriense, Bogor, West Java, Indonesia. The collected data were then compared with those published by the Indonesian Institute of Sciences (IIS) in 1981 (Kartawinata *et al.* 2008) and in 2003 (Simbolon 2005).

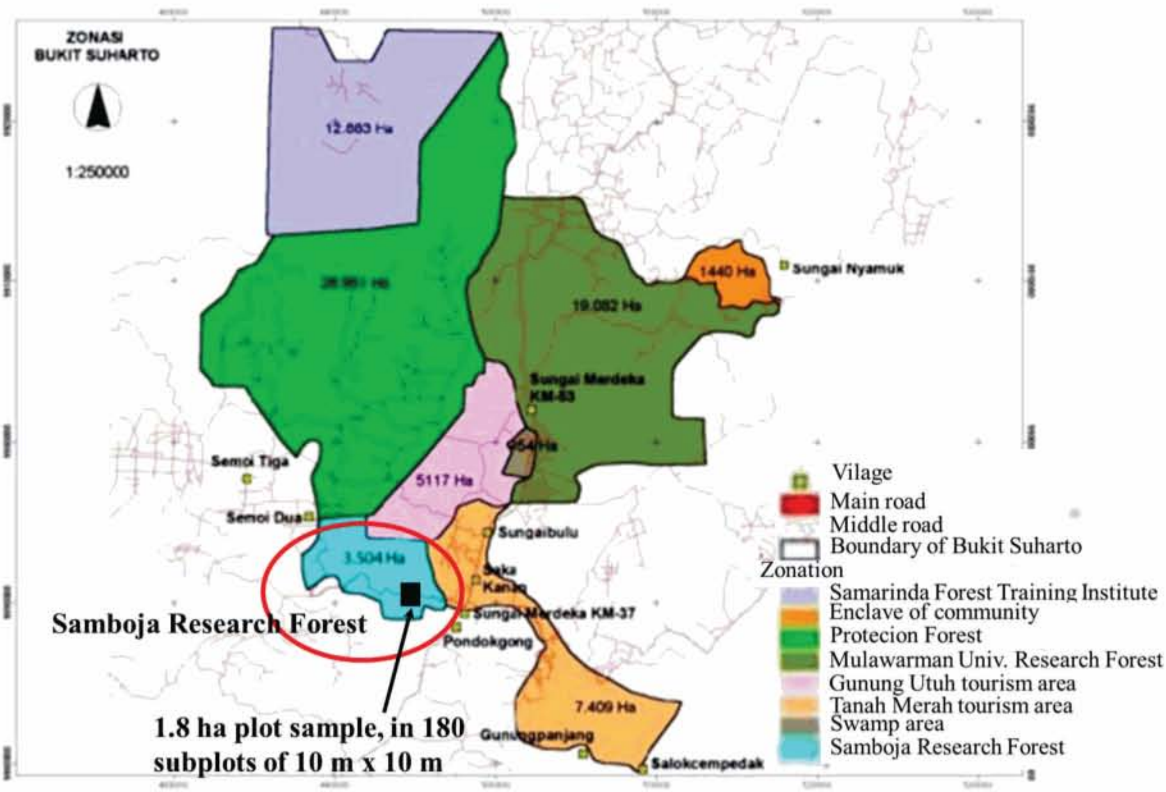

Figure 1 Samboja Research Forest, East Kalimantan, Indonesia
Source: Balitek KSDA Samboja – KHDTK Samboja

Data Analysis

The Importance Value Index (IVI) of each species was computed from the Relative Frequency, Relative Density and Relative Dominance of the species (Curtis 1959). Higher IVI value indicates more dominant species compared to others.

The association between species was analyzed by measuring the degree of association based solely on the presence or absence of species in the sampling units of 10 x 10 m subplots established in the sample plot (Ludwig & Reynolds 1988). Presence and absence of single species in the sampling unit was presented in binary data of 2 x 2 contingency (Table 1).

Table 1 Association index between two species

		Species B		
		Presence	Absence	
Species A	Presence	a	b	m = a+b
	Absence	b	d	n = c+d
		r = a*c	s = b*d	N= a*b*c*d

where:
a = number of subplots where both species, A and B, are present.
b = number of subplots where species A is present, but species B is absent.
c = number of subplots where species B is present, but species A is absent.
d = number of subplots where both species, A and B, are absent.
N= number of subplots.

Expected value of a species associated with other species was calculated using:

$$E\,(a) = \frac{(a + b)\,(a + c)}{N}$$

and association index (AI) is a - E(a).

Chi-square test was used to test the significance of the association, using Yates correction factor:

$$\chi_i^2 = \frac{N\lceil |(ad) - (bc)| - (^N/_2)\rceil^2}{mnrs}$$

Degree of freedom for association index is (r-1)(c-1).

R statistic software was used in this data analysis. There were two types of association:

1. Positive, if a > E(a), that is, the pair of species occurred together more often than expected if independent.
2. Negative, if a < E(a), that is, the pair of species occurred together less often than expected if independent.

Index of dispersion (ID) used to express the species distribution pattern based on the variation to mean ratio (Ludwig & Reynolds 1988), was computed as:

$$ID = \frac{\sigma^2}{\mu}$$

where: σ^2 is the variance and μ is the mean

The three types of dispersion index are namely; (1) random, if $\sigma^2 = \mu$, (2) clumped, if $\sigma^2 > \mu$ and (3) uniform, if $\sigma^2 < \mu$.

Chi-square statistics used to test significantly different ID, was computed as:

$$\chi^2 = \frac{(\Sigma_{i=1}^{N}\ (x_i) - \mu)^2)}{\mu}$$

Degree of freedom (db) is N-1.

RESULTS AND DISCUSSION

Species Dominance

The five most dominant species observed in the sample plots of the 10.5 hectare undisturbed ulin and Dipterocarp forest in Samboja Research Forest in 1981 were *Shorea laevis*, *Pholidocarpus majadun*, *Diospyros borneensis*, *Eusideroxylon zwageri* and *Scapium macropopdum* (Kartawinata *et al.* 2008). During the 1981 observation, three most dominant species were found in the smaller plot of 1.8 ha of undisturbed *Pholidocarpus majadum, Diospyros borneensis* and *Eusideroxylon zwageri.* Further analysis was focused on the smaller sample plots in the 1.8 ha.

Five years after the second fire of 1997/1998, three most dominant species based on stem basal area were found in the smaller plots, namely; *Pholidocarpus majadun, Eusideroxylon zwageri* and *Dipterocarpus cornutus* (Simbolon 2005). These three species had individual trees that survived the repeated fires. The surviving individual trees were recognised from tree mapping analysis through comparing coordinate position and stem diameter of 1981 and 2011 data. Large surviving trees having > 40 cm diameter of *Eusideroxylon zwageri* and *Dipterocarpus cornutus,* as well as the palm species, *Pholidocarpus majadun*, having 20 – 30 cm diameter contributed both high basal area and IVI. Other species that started to establish during the period had contributed to small IVI. The burnt area was dominated by trees having < 5 cm diameter and 10 – 15 cm tree diameter (Simbolon 2005).

Thirteen years after the second fire (2011 observation), the three most dominant species dramatically changed from the climax species of *Eusideroxylon zwageri* and *Dipterocarpus cornutus* to pioneer species of *Macaranga gigantea* and sub-climax species of *Vernonia arborea. Pholidocarpus majadun* was consistently in the third place (Table 1).

The ten most dominant species were mostly pioneer, except *Eusideroxylon zwageri* and *Dipterocarpus cornutus.* This clearly indicated that 13 years after a fire disturbance, pioneer species colonized the open area. However, surviving species continued to grow among the pioneer species. The surviving individuals of *Pholidocarpus majadun* provided high levels of seed for the regeneration process. This endemic palm in Kalimantan, mostly growing in swamp forest in the study area, was unaffected by the fires (Simbolon 2005). Moreover, mortality of this palm was relatively low, reaching 10% in the burnt forest, probably due to the physiological characteristics of its stem vascular structure (van Nieuwstadt & Shiel 2005).

Table 1 Species with the 10 highest IVI at 13 years after the second fire (2011 observation)

No.	Family	Species	Local name	Importance Value Index
1	Euphorbiaceae	*Macaranga gigantea*	Merkubung	35.29
2	Asteraceae	*Vernonia arborea*	Merambung	30.54
3	Arecaceae	*Pholidocarpus majadum*	Liran	12.98
4	Moraceae	*Artocarpus anisophyllus*	Mentawa	12.27
5	Rutaceae	*Melicope glabra*	Sampang/terutup	12.19
6	Euphorbiaceae	*Croton laevifolius*	Lasa-lasa/belanti	7.46
7	Lauraceae	*Eusideroxylon zwageri*	Ulin	7.20
8	Verbenaceae	*Peronema canescens*	Sungkai	6.71
9	Annonaceae	*Cananga odorata*	Kenanga	5.73
10	Dipterocarpaceae	*Dipterocarpus cornutus*	Keruing gajah	5.62

Eusideroxylon zwageri is another surviving species that had a slight decrease in IVI from 9.3 before to 7.2 after the fire. *E. zwageri* has the capacity to re-sprout from damaged trees after fire (Delmy 2001), even from stumps and roots (van Nieuwstadt & Shiel 2005). This species is categorized as heavy wood, ranging 0.88 – 1.19 g/cm^3, on average 1.04 g/cm^3 (Martawijaya *et al.* 1992). Heavy wood species (> 0.8 g/cm^3) have the capacity to survive fire (van Nieuwstadt & Sheil 2005; Brando *et al.* 2012). High density wood produces some extractive material, such as cellulose, hemicelluloses, and lignin, and other properties, that reduce the fire distribution index and ignition time (Brando *et al.* 2012).

Before fire, *Macaranga gigantea* was a minor species in the permanent plot of Samboja Research Forest (Kartawinata *et al.* 2008). After repeated fires, the number of trees increased rapidly from 35 in 2003 (Simbolon 2005) to 167 in 2011. Three years after the fire, *Macaranga gigantea* was the most dominant species in the twice-burned forest, (Slik *et al.* 2008) and was consistently dominant at 5, 7 and 13 years. This species was regularly found as one of the most dominant species after 10 – 20 years in regenerating forest (Silk *et al.* 2008). However, in Samboja Research Forest, *M. gigantea* was the most dominant species three years after the fire. The level of disturbance after the fire might have affected the early establishment of *Macaranga gigantea*. *Macaranga* is an early succession genus that prefers a frequently disturbed habitat that is characteristic of a highly-disturbed forest (Slik *et al.* 2003).

M. gigantea traits of being a pioneer and light demanding species are suitable for growth in burnt forest where high exposure to sunlight occurs. Its typically orthodox seeds are able to lie dormant in the soil and germinate as soon as the forest canopy opens up (Suita & Nurhasybi 2009; Susanto *et al.* 2016).

Vernonia arborea, a sub-climax species (Desitarani *et al.* 2015), was not found in the sample plot before the fire events but developed rapidly and became the second dominant species in 2011. However, this species was found in an undisturbed forest located at 1 – 2 km from the sample plot (Krisnawati *et al.* 2011, Atmoko *et al.* 2015). The small seeds of *V. arborea* can be dispersed by wind. Moreover, this species was a co-dominant in the once-burned forest of Sungai Wein but not in the twice-burned Samboja (Slik *et al.* 2008b). Increasing Al^{3+} after fires probably affected *V. arborea* colonization in burnt areas. A study in Samboja Lestari, East Kalimantan documented that Al+ content in the soil significantly increased four years after a fire and *V. arborea* was associated with high Al^{3+} content (Yasir *et al.* 2010). High Al^{3+} content in the soil becomes a limiting factor of root growth (Mossor-Pietraszewska 2001) for common species, but not for *V. arborea* which is adapted to high Al^{3+}. In Samboja, the *V. arborea* population developed widely after 2003 (five years after the second fire).

The occurrence of pioneer and sub-climax species as the most dominant, together with establishing climax species in the burned forest has indicated that the succession process was in a competition phase (Clement 1916). In order to address restoration management goals, the assisted natural regeneration and species enrichment activities can be applied in the forest succession phase (Elliot *et al.* 2013; Lamb & Gilmour 2006). Assisted natural regeneration should focus on species priorities and enrichment, particularly for sub-climax and climax species, to improve the forest function and therefore, conserve biodiversity.

Species Association

Thirteen years after the second fire, an analysis of the 191 established species in the sample plots of secondary forest showed that 18,336 pairs of species pairing with themselves, consisted of 1,220 (7%) pairs with positive association, 17,115 (93%) pairs with negative association and a pair of species as neutral. Chi-square test found 38 pairs with significantly positive association and 4,801 pairs with negative association. This positive association rarely occurred but negative association was common, particularly, among 'non-native' species (Kuebbing & Nunez 2015). Non-native and native species in this research refers to the existence of species before and after the fires. Non-native species were found in the plot only after the fires but native species were found before and after the fires.

However, positive association is important in establishing management priorities (Kuebbing & Nunez 2015). It is critical in community structure or habitat modification, in which one individual or species alters the condition of the local environment, often making a stressful habitat more hospitable to other individuals or species (Stachowicz 2001). Furthermore, positive association between species in mutual interaction will enhance each other's survival probabilities (Ludwig & Reynolds 1988). Positive interactions between different species are of particular interest because of their potential to 'cascade' throughout the community, with a major effect on the ecosystem structure and function (Stachowicz 2001).

Some 53% positive association and 60% negative association in the sample plot occurred between species that existed before the fire ('native') and newcomer species that regenerated after the fire ('non-native'). In this research, the negative association occurred more frequently between 'native' and 'non-native' rather than among 'non-native'. The more frequent occurring association among the 'non-native' species indicated that 'non-native' species indirectly provide environmental support (Flory & Bauer 2014). Improving performance of the 'non-native' species after fires is associated with natural resources availability or changes in disturbance regime (Daehler 2003). However, light competition as an indirect impact of fire disturbance was an important factor affecting interaction among individual trees or species (Kunstler *et al.* 2012).

Vernonia arborea, a 'non-native' species, was positively associated with one 'native' species *Anthocephalus chinensis* but negatively associated with other 'native' species, *Oncosperma horridum, Palaquium dasyphyllum, Ediandra rubescens* and 'non-native' species, *Tabernaemontana sphaerocarpa* (Table 2). *A. chinensis,* a surviving individual tree provided a suitable environment for sub-climax species of *V. arborea* seedlings. *Anthocephalus chinensis* grows in the swampy area of the plot unaffected by fires (Simbolon 2005).

V. arborea generally grew in the upper elevations of the sample plot. Only a few individual trees grew on the swamp area close to *Anthocephalus chinensis*. As a sub-climax species, *V. arborea* probably took advantage of *A. chinensis*' canopy for shade during early regeneration. Negative association between *V. arborea* with *Tabernaemontana sphaerocarpa, Oncosperma horridum, Palaquium dasyphyllum* and *Endiandra rubescens* was probably because of different habitat requirements. *Tabernaemontana sphaerocarpa, Oncosperma horridum, Palaquium dasyphyllum* and *Endiandra rubescens* grew on lower elevations, in the swampy part of the sample plot.

Table 2 Ten species' pairs with highest Yates Chi-square value

Pair of species		A	Ea	df	Yates χ^2 correction	Critical value	Association type
Knema latericia	*Neonauclea calycina*	2	0.07	15	32.24	25.00	+
Calophyllum soulattri	*Diospyros pilosanthera*	2	0.08	8	25.59	15.51	+
Anthocephalus chinensis	*Vernonia arborea*	4	2.92	12	24.31	21.03	+
Knema cinerea	*Polyalthia rumphii*	2	0.09	3	23.80	7.82	+
Polyalthia rumphii	*Syzygium brachyrachis*	2	0.09	3	23.80	7.82	+
Tabernaemontana sphaerocarpa	*Vernonia arborea*	0	0.83	2	1861.84	5.99	-
Tabernaemontana havilandii	*Vitex pinnata*	0	0.01	2	129.56	3.84	-
Oncosperma horridum	*Vernonia arborea*	0	0.83	2	127.65	3.84	-
Palaquium dasyphyllum	*Vernonia arborea*	2	2.50	2	91.47	25.00	-
Endiandra rubescens	*Vernonia arborea*	0	0.83	2	68.78	3.84	-

Notes: A= number of subplots where both species, A and B, are present; Ea= Expected value of a species associated with other species.

V. arborea generally grew in the upper elevations of the sample plot. Only a few individual trees grew on the swamp area close to *Anthocephalus chinensis*. As a sub-climax species, *V. arborea* probably took advantage of *A. chinensis*' canopy for shade during early regeneration. Negative association between *V. arborea* with *Tabernaemontana sphaerocarpa, Oncosperma horridum, Palaquium dasyphyllum* and *Endiandra rubescens* was probably because of different habitat requirements. *Tabernaemontana sphaerocarpa, Oncosperma horridum, Palaquium dasyphyllum* and *Endiandra rubescens* grew on lower elevations, in the swampy part of the sample plot.

Species Distribution Pattern

In the 1981 observation, the species distribution in the 1.8-hectare sample plot of undisturbed forest was a balance between uniform (48%), where the distance between neighbouring individuals is maximised due to competition of resources, and random (52%) where the spacing between individual is unpredictable, usually occurring in the habitat with consistent environmental condition. Repeated fires affected the species' distribution pattern. Analysis of 191 species in the 1.8 hectare secondary growth forest indicated that 69 species (36%) were distributed randomly, 28 species (14%) were clumped and 95 species (50%) were uniformly distributed. Clumped dispersion of species was found in the secondary growth forest after repeated fires. Further statistical testing using the Chi-square found six species with significantly distributed clumped (Table 3).

The changing distribution pattern of *Artocarpus anisophyllus, Cananga odorata, Croton laevifolius* and *Macaranga gigantea* from uniform to clumped, after repeated fires, was due to various factors, such as tree survival in the cooler site and their stem size (Davis *et al.* 2005). The survivor trees in the cooler site functioned as seed sources when most trees were killed, while their small stem size tended to clump. The nature of its fruits and seeds had also affected their distribution pattern after the fire. *Artocarpus anisophyllus* has a compound fruit. It contains many 1.7 x 1.0 cm seeds that are difficult to disperse without a dispersal agent, such as a big mammal. The swampy area was suitable for *Cananga odorata* and *Croton laevifolius*. Swampy area depletion and droughts after the fires became a limiting factor for *C. odorata* and *C. laevifolius* growing in the sample plot. *Macaranga gigantea*, a minor species and distributed uniformly, changed dramatically to dominant and clumped. After biomass burning, open areas were associated with pioneer species, such as *M. gigantea*, due to high light availability as an energy source during the colonization process. Clumped pattern of *Peronema canescens* might affect the planting of this species in a forest rehabilitation program. During the forest rehabilitation activities in Samboja Researh Forest in 1990s *P. canescens* was one of the species planted in the area for fire breaks and boundary area signs to community land. Then, it has spread out after the repeated forest fire.

Table 3 Dispersion index of six species in the 1.8-hectare secondary forest after repeated fires in Samboja Research Forest

Species name	Variance	Average	Dispersion Index	χ^2	df	Critical value
Artocarpus anisophyllus	1.97	0.37	5.28	348.74	66	85.98
Cananga odorata	0.21	0.13	1.66	36.61	22	32.67
Croton laevifolius	0.31	0.18	1.77	54.86	31	44.98
Macaranga gigantea	1.37	0.93	1.48	245.95	166	197.06
Peronema canescens	0.33	0.18	1.80	57.48	32	46.19
Vernonia arborea	1.29	0.75	1.73	231.32	134	162.01

CONCLUSION

The dominance of *Macaranga gigantea* indicated a high level of forest disturbance in that part of Samboja Research Forest affected by two fire events. Co-dominance of *Vernonia arborea* indicated the changing environmental conditions, such as increasing Al^{3+}, which was limiting to the species growth. Occurrence of pioneer, sub-climax and climax species indicated that the forest succession was in a competition phase. Assisted natural regeneration and species enrichment would be possible restoration activities for biodiversity conservation. Improving non-native species performance in the twice-burned area might occur due to changing natural resources availability and disturbance regime after a fire. Lastly, the changing environmental conditions, species characteristics and human activities affected the distribution pattern of species.

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