Research Article

Post-eruption species dynamic of Gunung Merapi National Park, Java, Indonesia

Priyono Suryanto[1,2], Mohd Zaki Hamzah[2]*, Mohamad Azani Alias[2] and Azmy Mohamed[2]

[1]*Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia.*

[2]*Faculty of Forestry, Universiti Putra Malaysia, Selangor, Malaysia, 43400 UPM Serdang, Selangor, Malaysia. *email: zakihamzah@ymail.com*

ABSTRACT. A comprehensive study was carry out in Gunung Merapi National Park, Indonesia, to elucidate the species succession of the area within a three year period after the 2006 eruption. For this study, the selected area was divided into five plots, namely P1, P2, P3, P4 and P5, each sized 50 x 20 m. Data collection was carried out for 18 months from May 2008, the close monitoring on species diversity, growth, recruitment, mortality and survival. Species diversity increased significantly (about 2 to 3 times) from census 1 in all the plots. The highest increase of richness was recorded in P5 (3.300±0.198 to 9.517±0.133), while the lowest was in P1 (1.907±0.458 to 3.824±0.841). Species heterogeneity within plots increased significantly. Similarly, evenness values in four plots, namely P1, P2, P3 and P4, increased significantly. There was an inverse-proportional pattern of relationship between the density and recruitment following the linear function of R^2, which was about 0.029 to 0.438. The density and mortality were directly proportionate to the quadratic function of R^2, which was about 0.807 to 0.936, with a p-value of <0.05. The initial result of this study can be used as basic reference for forest rehabilitation strategies on post eruption and supporting GMNP recreation especially the Merapi lava tour.

Keywords: succession, eruption, species diversity, species dynamic

INTRODUCTION

Mount Merapi was established as a national park (Gunung Merapi National Park) as part of government efforts to facilitate sustainable management of natural resources and biodiversity of ecosystems, in addition to potential development of nature tourism in Yogyakarta province, Indonesia (Ministry of Forestry-Indonesia, 2004). Mount Merapi gets serious attention because of its active stratovolcano (Lavigne *et al.,* 2000). The last major eruption of Mount Merapi occured in 2006, and it consisted of gaseous clouds that rapidly travelled 7 km down the southern slope of Merapi along the Gendol River (Charbonnier & Gertisser, 2008).

One of the effects of the Mount Merapi eruption was ecological damage to ecosystems, forcing them to restart with the primary succession (Walker & del Moral, 2003). The development of succession can be seen from the status of sere as a succession product (Kimmnis, 1997), and its assessment can be carried out by conducting species diversity and dynamic assessment. The diversity was composed of two components, i.e. the number

Received 1 March 2010. Revision accepted 26 April 2010

of species and the evenness of their frequency distribution (Purvis & Hector, 2000; Magurran, 2004).

In addition, the dynamics of species recruitment, mortality and survival of species during the early successional stage is of paramount importance. Generally, the limiting factor in the process of forest regeneration is seedling establishment, determined by the distribution of adult population (Rey & Alcantara, 2000). The understanding of possible seedling establishment as an effort to link the past and future of this forest is indeed crucial (Arrieta & Suarez, 2005). Hence, the recruitment of new tree seedlings is a critical event after disturbance (Coates, 2002).

Generally, the natural disturbance regime is referred to as the best model for managing forests (Seymour *et al*., 2002), of which feature-vegetation as useful indicators for sustainable forest management must be identified (Robets, 2007). Initial information in the Merapi succession can be used as a basis for consideration of forest rehabilitation strategy. Hence, the objectives of this study were to describe species diversity and dynamic pattern on early succession of Mount Merapi's post-eruption.

MATERIALS AND METHODS

Study site

The study was conducted at Southern Gunung Merapi National Park (GMNP), which is situated in the Sleman district, Yogyakarta, Indonesia (Figure 1). GMNP, which covers an area of about 6,410 ha, is located on an elevation ranging from 600 to 2967 m asl. The climate of the area is categorized as wet tropic, with the climate of C with Q 33.3-66% based on the Schmidt and Fergusson classification. The annual rainfall is about 875 mm year^{-1} to about 2527 mm year^{-1}, with November to May as wet months, and June to October as dry months (Ministry of Forestry, Indonesia, 2004).

Permanent sample plot

We established five phytosociological relevés or permanent sample plots (labelled P1, P2, P3, P4 and P5), each with a size of 50 x 20 m established on two distinct locations, i.e. P1 (at elevation of 1210 m above sea level) and P2 (1220 m) were placed on the west bank of Gendol River, while P3 (1250 m), P4 (1260 m) and P5 (1300 m) were placed on the east bank of the river. Each plot was divided into 25 quadrats (each with a size of 2 x 2 m). At the beginning of the study (May 2008), all of the trees were recorded, tagged and identified (census 1). In addition, total height, diameter at breast height (DBH) and distribution of individual trees in each quadrat were also recorded. After six months (November 2008), census 2 followed by census 3 (May 2009) were conducted to record mortality (M) and recruitment (R). Approximately 18 months after census 1, census 4 (November 2009) was conducted which include the recording of all dead trees, recruitment, height and diameter.

Analysis

All data from the study plot was collected and analyzed using a descriptive quantitative approach. The calculation covered species diversity (richness, heterogeneity and evenness), diameter, height, and population dynamics (recuitment, mortality and survival). Species diversity among the plots was analyzed with ANOVA and DMRT for species richness, heterogeneity and evenness (Krebs, 1989). Species richness was calculated using the Jacknife Estimation Method, while heterogeneity and evenness were calculated with the Shannon-Wiener method (Heltse & Forrester, 1983).

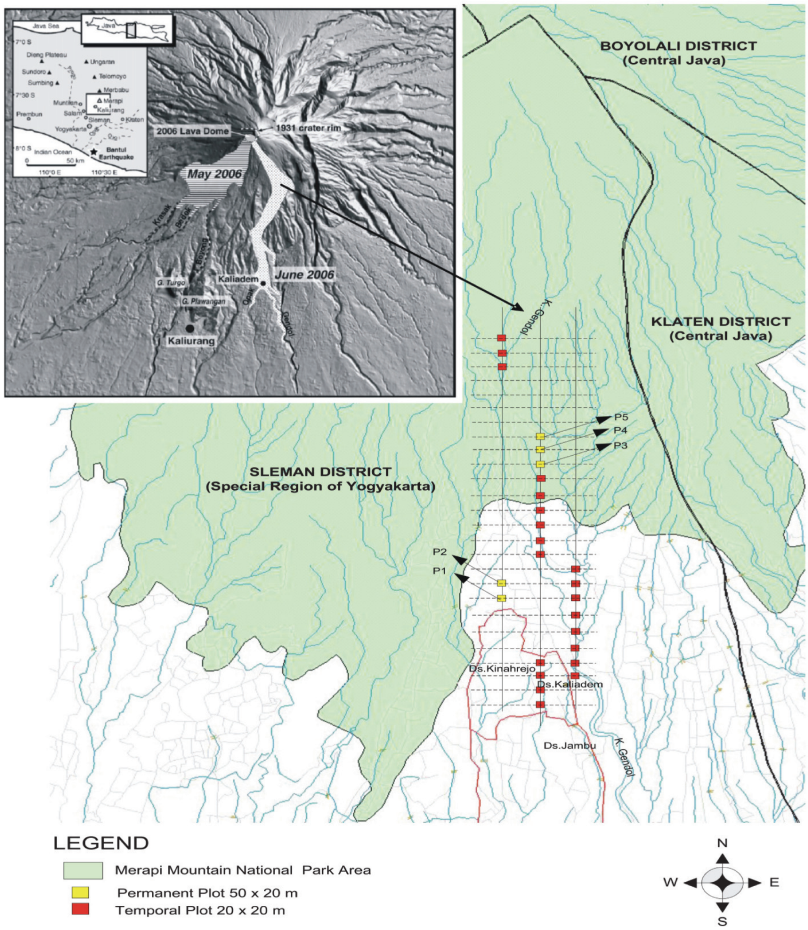

Figure 1. Gunung Merapi National Park, Java, Indonesia (Modified from Charbonnier & Gertisser, 2008).

Relative rate change (RRC) is a relative change value from first census (Breugel *et al*., 2006). RRC in this study are height, diameter, density, recruitment, mortality and survival. RRC of each structural variable Xi was calculated over the two study years as the difference between the variable in the last (Xf) and the first census (Xi) as a proportion of Xi and corrected for the actual census period in days (t).

$$RRC_{(X)} = \left(\frac{x_f}{x_i}\right)^{\frac{365}{t}} - 1$$

Similarity recruitment, mortality and survival among the plots done by mapping species with multidimensional scaling (MDS) technique that used scale measurement Euclidiance Distance. Data input is individual abundance based on recruitment, mortality and survival transformed in standardized value (Waite, 2000).

RESULTS

Diversity of the species dynamic

Species richness after the three-year post eruption of Mount Merapi was of the same magnitude in the five plots, which increased significantly about 2 to 3 times from census 1. The highest increase of richness was found in P5 - from 3.300±0.198 to 9.517±0.133, while the lowest was discovered in P1 - from 1.907±0.458 to 3.824±0.841 (Table 1). Based on heterogeneity, almost all the plots increased. In addition, similar results were found for the evenness in P1, P2, P3 and P4, which increased significantly. However, in P5, the change had no significant difference (Table 1). On the other hand, the evenness in P1 and P2 was lower, which means that the plots had dominant species, i.e. *Acacia decurrens*. Having mentioned that, the dominant species found in P3 and P4 were *Pinus merkusii* and *A. decurrens*, while in P5, it was dominated by *Acacia villosa, P. merkusii* and *Schima wallichii*.

The density (individuals/ha) in P1 decreased from 72907.87±9478.02 to 56251.37±9562.73. Similar with P1, the trend densities in P3 and P4 decreased from 10663.20±639.79 to 9036.21±542.17 and 7922.38±475.34 to 7553.27±377.66, respectively. In contrast, two plots, i.e. P2 and P5, had increased in their density from 4441.33±532.96 to 5153.05±618.37 and from 5061.52±860.46 to 5072.02±811.52, respectively. Based on the CI, the level significance of 95% revealed that the density in P1 changed significantly (Figure 2).

Characteristics of recruitment, mortality and survival of species

Species mapping based on the recruitment, mortality and survival showed that the dominant

Table 1. The dynamics of species richness, heterogeneity and evenness for every plot.

Plot	Richness		Heterogeneity		Evenness	
	2008	2009	2008	2009	2008	2009
P1	1.907±0.458	3.824±0.841	0.029±0.007	0.137±0.033	0.041±0.010	0.243±0.066
P2	2.140±0.043	4.262±0.502	0.084±0.003	0.252±0.045	0.101±0.002	0.469±0.110
P3	2.300±0.014	4.863±0.229	0.131±0.101	0.915±0.105	0.150±0.101	0.660±0.104
P4	2.500±0.225	5.259±0.473	0.277±0.125	0.873±0.179	0.252±0.123	0.542±0.149
P5	3.300±0.198	9.517±0.133	0.598±0.110	1.663±0.117	0.626±0.108	0.669±0.107

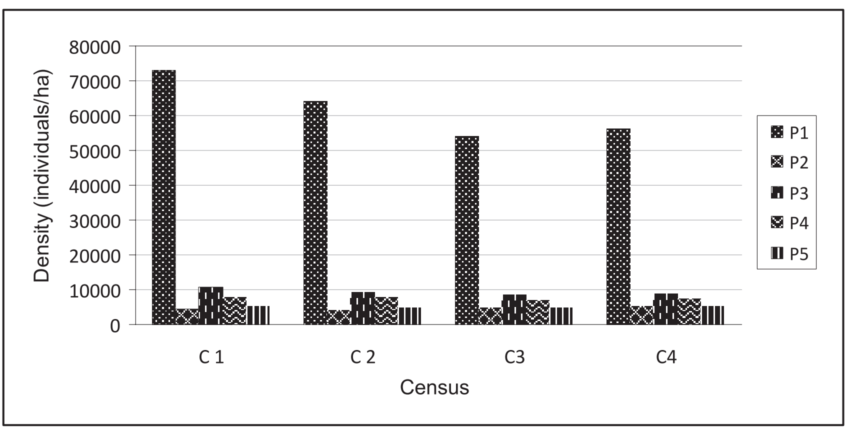

Figure 2. Density on census 1, 2, 3 and 4 for every plot.

species at every plot was strongly dynamic. This means that the dominant species was more dynamic than the non-dominant one in each plot. The trend of species recruitment and mortality found in P1 and P2 was *A. decurrens*, while in P3 ad P4, the species recruitment and mortality were *A. decurrens* and *P. merkusii.* As in P5, the trend of species mortality was dominated by *P. merkusii* and *A. villosa*, while the recruitment species was dominated by *S. wallichii* and *A. villosa*. On species survival, it revealed that species recruitment in all the plots had not yet extinct, and apparently, the number of individual survival of each species followed the first census number.

The population dynamics (i.e. density, mortality, recruitment and survival) in all the plots showed a similar trend (Figure 3a, b, c, d and e). The patterns of relationship between the density and recruitment in each plot was inversely proportionate, following the linear function of R^2, which was about 0.029 to 0.438. The relationship between P1 and P5, giving the p-value >0.05, was significant, whereas the relationship in the other plots was not significantly different.

Within all the plots, the relationship between the density and mortality was directly proportional, following the quadratic function of R^2, which was about 0.807 to 0.936 and p-value < 0.05. Similar with the density and mortality relationship, the relation between the density and survival was directly proportional, following the quadratic function of R^2, which was 0.935 to 0.960 and p-value < 0.05 (Figure 4).

DISCUSSION

Generally, the species diversity increased in all the plots with recruitment species found in each plot, followed by the proportional of evenness. The various experiments had repeatedly found positive relationships between plant species richness (Hooper *et al.,* 2005). The recruitment species found in all the plots were as follows: P1 - *Pinus merkusii*, P2 – *Psidium guajava*, P3 – *Schima wallichii*, P4 – *Erythrina hypaporus* and P5 – *Altingia excelsa*. Nonetheless, because each individual species was relatively small in number, it did not shift the dominant species in the early census. One of the diversity components was the species richness, while the other component was evenness, which was strongly influenced by the relative frequencies of the dominant species (Magurran, 2004; Kindt *et al*., 2006). Apparently, *Acacia decurrens* was the dominant species in P1, P2, P3 and P4. The pioneer species dominated the community during the first year of regeneration, leading to the forest composition (Chazdon, 2003; Peña-Claros, 2003).

This study highlighted the importance of the highest increase of richness in P5 due to the early situational disturbance triggered by the Merapi eruption, which was significantly different from other plots. The disturbance caused by the eruption could be categorised into two conditions. The first condition was caused by the spinning clouds of super-heated gases and mud-stream (as in P1, P2, P3 and P4), while the second one was only caused by the spinning clouds of super-heated gases as in P5 (Lavigne *et al*., 2000). The species richness and composition might vary considerably, depending on the forest type, intensity of land use, biophysical conditions, soil type and attributes, species availability and characteristics (Guariguata & Ostertag, 2001; Moran *et al.,* 2000; Zarin *et al.,* 2001; Pickett & Cadenasso, 2005).

Our results indicated that the early species dynamics after the Mount Merapi eruption were still limited in dominant species, such as *A. decurrens* and *P. merkusii* in their recruitment, mortality and survival. The characteristics of species that only occurred in the earliest

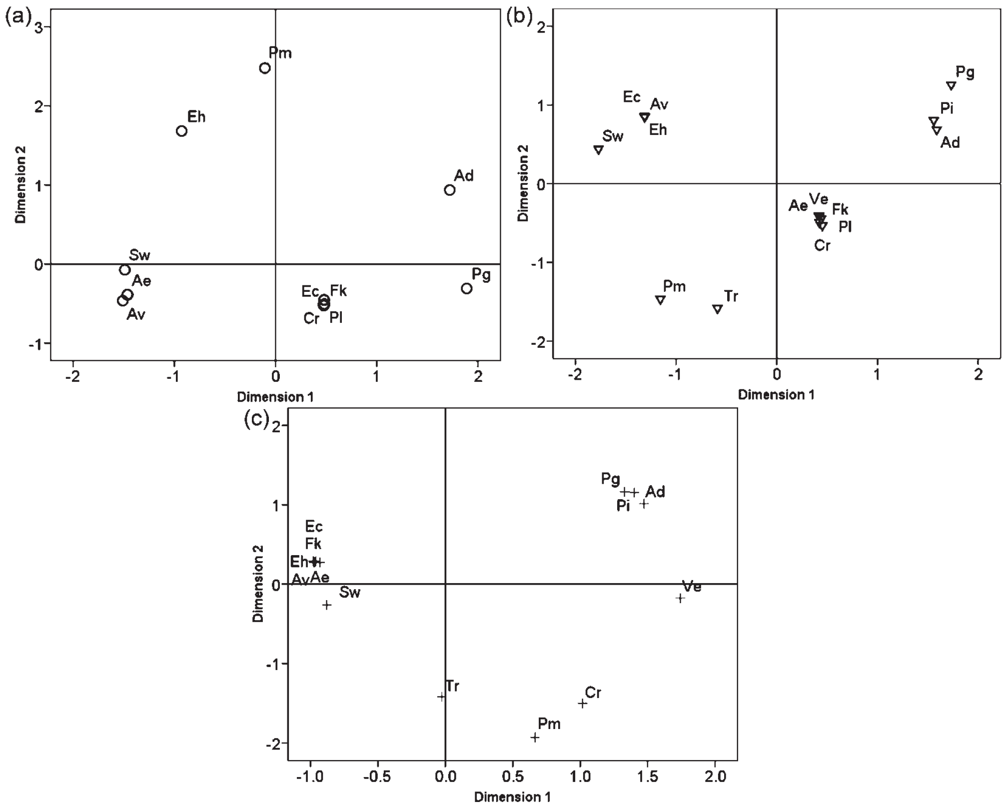

Figure 3. The pattern of recruitment (a), mortality (b) and survival (c) with Ad (*Acacia decurrens*), Pm (*Pinus merkusii*), Av (*Acacia villosa*), Cr (*Cincona rebbeca*), Eh (*Erythrina hypaporus*), Ec (*Euphorbia ciacembus*), Fk (*Ficus kubeba*), Pg (*Psidium guajava*), Pl (*Palotus* sp.), Pi (*Pillantus* sp.), Sw (*Schima wallichii*), Tr (*Trema* sp.), Ve (*Verbenaceae*), Ae (*Altingia excelsa*)

succession stages tended to have high rates of invasion because they produced very large numbers of reproductive propagules and had efficient means of dispersal (Kimmins, 1997). In this context, the limitation of recruitment was potentially one of the most important processes permitting the co-existence of a large number of ecologically similar species in a single community (Hurtt & Pacala, 1995).

The other factor was the limited forest stand as a source of seed bank. GMNP area was initially a forest production (i.e. monoculture stand) and it was then developed into a forest protection and finally established as a national park in 2004 (Ministry of Forestry-Indonesia, 2004). Based on the dominant species from lower to top zones in GMNP (the southern part), three limited species were found, i.e. *P. merkusii, A. decurrens* and *S. wallichii* (Suryanto *et al*., 2010). The seedling recruitment patterns depended on a number of factors, particularly the availability of seed producers, temporal patterns of seed production and germination conditions (Frey *et al*., 2007). The across-site variation in these patterns had been related to environmental factors such as soil characteristics (Donfack *et al.,* 1995; Chinea, 2002), distance to seed sources (Purata, 1986; Mesquita *et al.,* 2001)

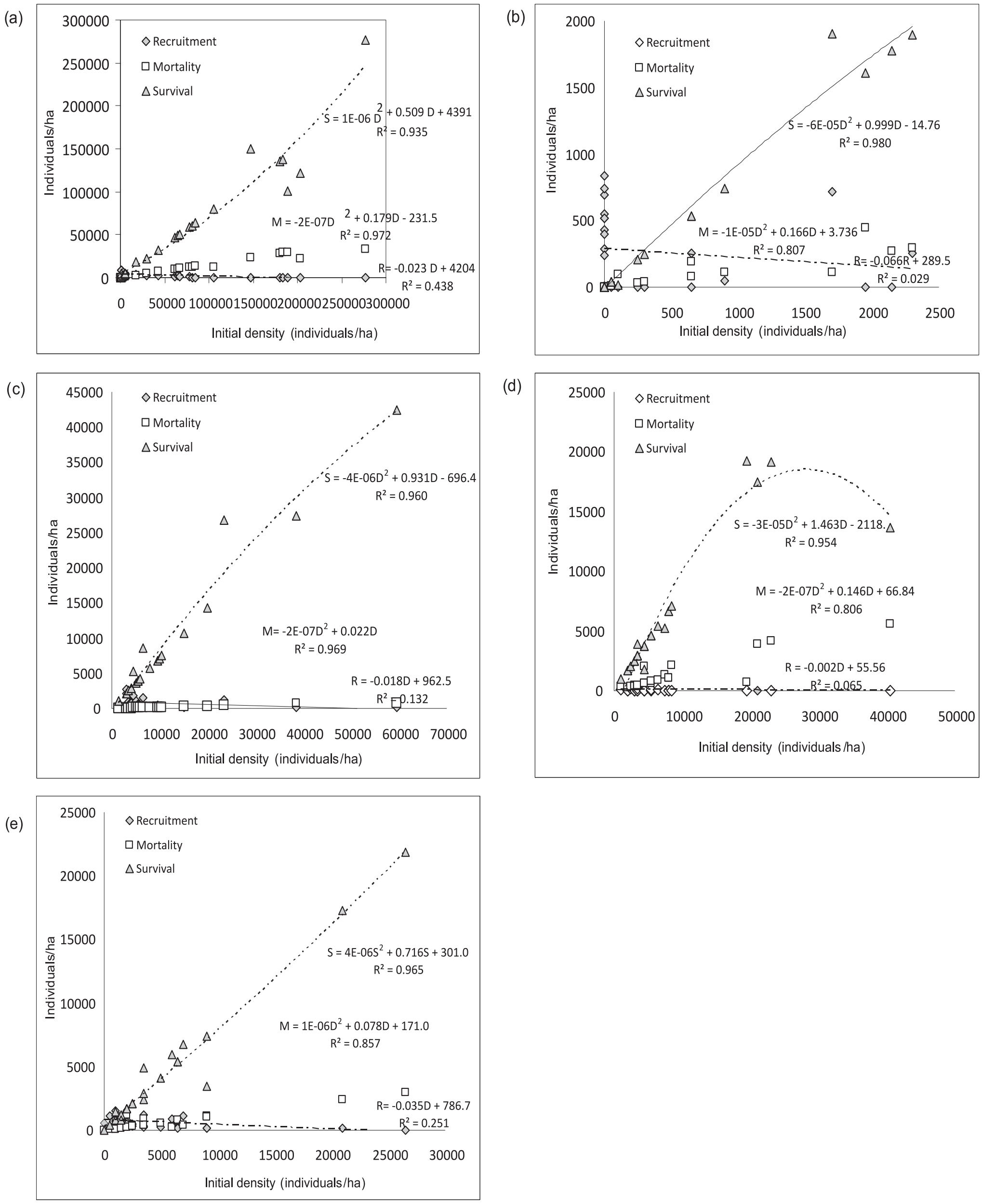

Figure 4. The relationship initial density, recruitment (R), mortality (M) and survival (S) at five different plots: P1(a), P2(b), P3(c), P4(d) and P5(e).

and characteristics of the dominant species (Mesquita *et al.,* 2001). Regeneration would largely depend on the seed rain from outside (Wijdeven & Kuzee, 2000; Cubina & Aide, 2001) or driven from outside the area (Walker & del Moral, 2003).

Our work also highlighted the dynamic population of the species, generally describing the higher density of the recruitment species, which had relatively smaller and higher densities, as well as higher species mortality. Besides that, the number of the survival species was equal with that of the individuals in the early census. The first year after germination was the determinant of recruitment, with very high mortality occurring during this period, followed by a subsequent higher survival in the following years (Rey & Alcantara, 2000). The absence of seedlings of a species from a site might result either from a lack of seeds or 'safe site' in which it could become established (Kimmins, 1997). In addition, tree mortality was affected by various factors involving very complicated processes such as environmental, physiological, pathological and entomological factors, as well as some random events (Yang *et al*., 2003).

Finally, the results of this study had been catalysed as a pioneer of the early stage of succession, which could serve as useful information for basis of reference for forest rehabilitation strategy on post eruption. It also supports GMNP recreation, especially the Merapi lava tour, with new information of early primary succession. The findings are very important for future consideration because they also serve as a scheme for policy makers and new compatible management of GMNP.

REFERENCES

Arrieta, S. & F. Suarez. 2005. Spatial patterns of seedling emergence and survival as a critical phase in holly (*Ilex aquifolium* L.) woodland recruitment in Central Spain. *Forest Ecology and Management* 205:267-282.

Breugel, M.v., M. Martínez-Ramos & F. Bongers. 2006. Community dynamics during early secondary succession in Mexican tropical rain forests. *Journal of Tropical Ecology* 22: 663-674.

Charbonnier, S.J. & R. Gertisser. 2008. Field observations and surface characteristics of pristine block-and-ash flow deposits from the 2006 eruption of Merapi Volcano, Java, Indonesia. *Journal of Volcanology and Geothermal Research* 177: 971-82.

Chazdon, R.L. 2003. Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics* 6: 51-71.

Chinea, J.D. 2002. Tropical forest succession on abandoned farms in the Humacao Municipality of Eastern Puerto Rico. *Forest Ecology and Management* 167:195-207.

Cubina, A. & T.M. Aide. 2001. The effect of distance from forest edge on seed rain and soil seed bank in a tropical pasture. *Biotropica* 33: 260-267.

Coates, K.D. (2002). Tree recruitment in gaps of various size, clearcuts and undisturbed mixed forest of interior British Columbia, Canada. *Forest Ecology and Management* 155:387-398.

Donfack, P., C. Floret & R. Pontanier. 1995. Secondary succession in abandoned fields of Dry Tropical Northern Cameroon. *Journal of Vegetation Science* 6: 499-508.

Frey, B.R., M.S. Ashton, J.J.McKenna, D. Ellum & A. Finkral. 2007. Topographic and temporal patterns in tree seedling establishment, growth, and survival among masting species of southern New England mixed-deciduous forests. *Forest Ecology and Management* 245: 54-63

Guariguata, M.R. & R. Ostertag. 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. *Forest ecology and management* 148: 185-206.

Heltse, J.F. & N.E. Forrester. 1983. Estimating species richness using the jacknife procedure. *Biometrics* 39: 1-11.

Hooper, D. U., F.S. Chapin, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setala, A.J. Symstad, J. Vandermeer & D.A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* 75:3-35.

Hurtt, G.C. & S.W. Pacala. 1995. The consequences of recruitment limitation: reconciling chance, history and competitive differences between plants. *Journal of Theoretical Biology* 176:1-12.

Kimmin, J.P. 1997. *Forest ecology a foundation for sustainable management*. Prentice Hall, Upper Saddle River, New Jersey.

Kindt, R., P.V. Damme & A.J. Simons. 2006. Tree diversity in Western Kenya: using profiles to characterise richness and evenness. *Biodiversity and Conservation* 15: 1253-1270.

Krebs, C.J. 1989. *Ecological methodology*.University of British Columbia-Harper Collins Publisher. Inc. New York.

Lavigne, F., J.C. Thouret, B. Voight, H. Suwa & A. Sumaryono. 2000. Lahars at Merapi volcano, Central Java: an overview. *Journal of Volcanology and Geothermal Research* 100: 423-456.

Magurran, A.E. 2004. *Measuring biological diversity*. Blackwell Publishing, Malden, MA, USA.

Mesquita, R., K. Ickes, G. Ganade & G.B. Williamson. 2001. Alternative successional pathways in the Amazon Basin. *Journal of Ecology* 89: 528-537.

Ministry of Forestry, Indonesia. 2004. Ministry of Forestry Decision Nomor SK.134/MENHUT-II/2004. Changing function forest conservation, sanctuary and natural park recreation merapi located at Magelang, Boyolali and Klaten District, Central Java Province and Sleman District, Yogyakarta Province to Merapi Mountain National Park. http://www.dephut.go.id.

Moran, E.F., E.S. Brondizio, J.M. Tucker, M.C. da Silva Forsberg, S. McCracken & I. Falesi. 2000. Effects of soil fertility and land-use on forest succession in Amazonia. *Forest Ecology and Management* 139: 93-108.

Peña-Claros, M. 2003. Changes in forest structure and species composition during secondary forest succession in the Bolivian Amazon. *Biotropica* 35: 450-461.

Pickett, S.T.A. & M.L. Cadenasso. 2005. Vegetation dynamics. In E. v. d. Maarel (Ed.). *Vegetation Ecology*, pp. 172-198. Blackwell Science Ltd, Oxford.

Purvis, A. & A. Hector. 2000. Getting the measure of biodiversity. *Nature* 405: 212-219.

Purata, S.E. 1986. Floristic and structural changes during old-field succession in the Mexican Tropics in relation to site history and species availability. *Journal of Tropical Ecology* 2: 257-276.

Rey, P.J. & J.M. Alcantara. 2000. Recruitment dynamics of a fleshy fruited plant (*Olea europaea*): connecting patterns of seed dispersal to seedling establishment. *J. Ecol.* 88, 622-633.

Roberts, M.R. 2007. A conceptual model to characterize disturbance severity in forest harvests. *Forest Ecology and Management* 242:58-64.

Seymour, R.S., A.S. White & P.G. de Maynadier. 2002). Natural disturbance regimes in northeastern Nort America-evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management*.155:357-367.

Suryanto, P., M.H. Zaki, M.A. Azani & M. Azmy. 2010. Species diversity of Gunung Merapi National Park, Java, Indonesia Following Eruption 2006. *Res. Environ.Life Sci*. 3 (1):1-6.

Waite, P. 2000. *Statistical ecology in practice*. Pearson Education Limited.

Walker, L.R. & R. del Moral. 2003. *Primary Succession and Ecosystem Rehabilitation*. Cambridge: Cambridge University Press.

Wijdeven, S.M.J. & M.E. Kuzee. 2000. Seed availability as a limiting factor in forest recovery processes in Costa Rica. *Restoration Ecology* 8: 414-424.

Yang, Y., J.T. Stephen, & H. Shongming. 2003. Modeling individual tree mortality for white spruce in Alberta. *Ecological Modelling* 163: 209-222.

Zarin, D.J., M.J. Ducey, J.M. Tucker & W.A. Salas. 2001. Potential biomass accumulation in Amazonian regrowth forests. *Ecosystems* 4: 658-668.