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Response of terrestrial mammals to various types of disturbance in the Gunung Merapi National Park, Indonesia

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Abstract. *Sulaksono N, Pudyatmoko S, Soemardi, Wardhana W, Hadiyan Y, Nurvianto S. 2022. Response of terrestrial mammals to various types of disturbance in the Gunung Merapi National Park, Indonesia. Biodiversitas 23: 1635-1647.* Human disturbance in the form of sand mining and grass harvesting activities in the area of Mount Merapi is an important component of the ecological process alongside the eruption. The group of terrestrial mammals (TM) is one of the essential elements that are affected by this disturbance. Therefore, the objectives of this study were to determine the response of the TM in various types of habitats in areas affected by eruption disturbances >20 years (ERL), eruption < 20 years (ERE), mining (MIN), grazing (GRA), and non-disturbance areas (NDA) in Gunung Merapi National Park (GMNP). Camera traps were used to identify the abundance of each TM. Vegetation data were also used to represent habitat conditions and were taken on a plot of 0.04 Ha. The analysis results showed that the highest abundance of TM is at the NDA site (14.4), while the lowest is at the MIN site (2.08). The site with the highest level of TM diversity is ERL (1.97) and the lowest is NDA (1.52). Furthermore, there is a significant difference in TM abundance between the MIN and ERL sites, which indicates that each disturbance reacts differently to the site. Based on the results, mining disturbances negatively influenced the abundance of TM in GMNP, therefore, managers need to regulate mining activities and make efforts to restore the affected areas.

Keywords: Abundance, camera trap, human disturbance, sand mining, volcano

INTRODUCTION

Mammals play an important role in the ecosystem (Lacher et al. 2019), where some act as engineers who shape and modify their structure and composition to increase habitat heterogeneity (Sinclair 2003). This role is also carried out by small and medium mammals that live in soil holes/burrows (Davies et al. 2019), while some act as carriers of nutrients (macronutrients), minerals, and biomass in nutrient-poor areas. They also have a role as population control (Roemer et al. 2009), moreover, the presence of abundant elk (*Cervus elaphus* Linnaeus, 1758) that suppresses plant growth can be controlled by the reintroduction of its predator, namely Gray wolf (*Canis lupus* Linnaeus, 1758) (Ripple and Beschta 2012). In the Brazilian Amazon (South America), it's reported that terrestrial mammals have important rules as seed dispersers (Arévalo-Sandi et al. 2018) that assist the recovery process by bringing seeds to be damaged or degraded areas (Lindsell et al. 2015). Therefore, the presence of mammals can be used as an ecosystem indicator (Cheyne et al. 2016).

The global population of mammals is currently declining, where some species have become extinct (Pavoine et al. 2019) due to human disturbances such as hunting, land conversion, and over-exploitation of forests (Crooks et al. 2011; Haddad et al. 2015). Meanwhile, the types of mammals that have a high risk of extinction are the medium and large ones (Pavoine et al. 2019) because they require a larger space to live. This has occurred on Javan tiger (*Panthera tigris sondaica* Temminck, 1844) and Bali tiger (*Panthera tigris balica* Schwarz, 1912) which are now extinct (Xue et al. 2015). On the other hand, some mammals could survive, live and adapt in the remaining habitats, most of which are protected areas (Maharadatunkamsi et al. 2020).

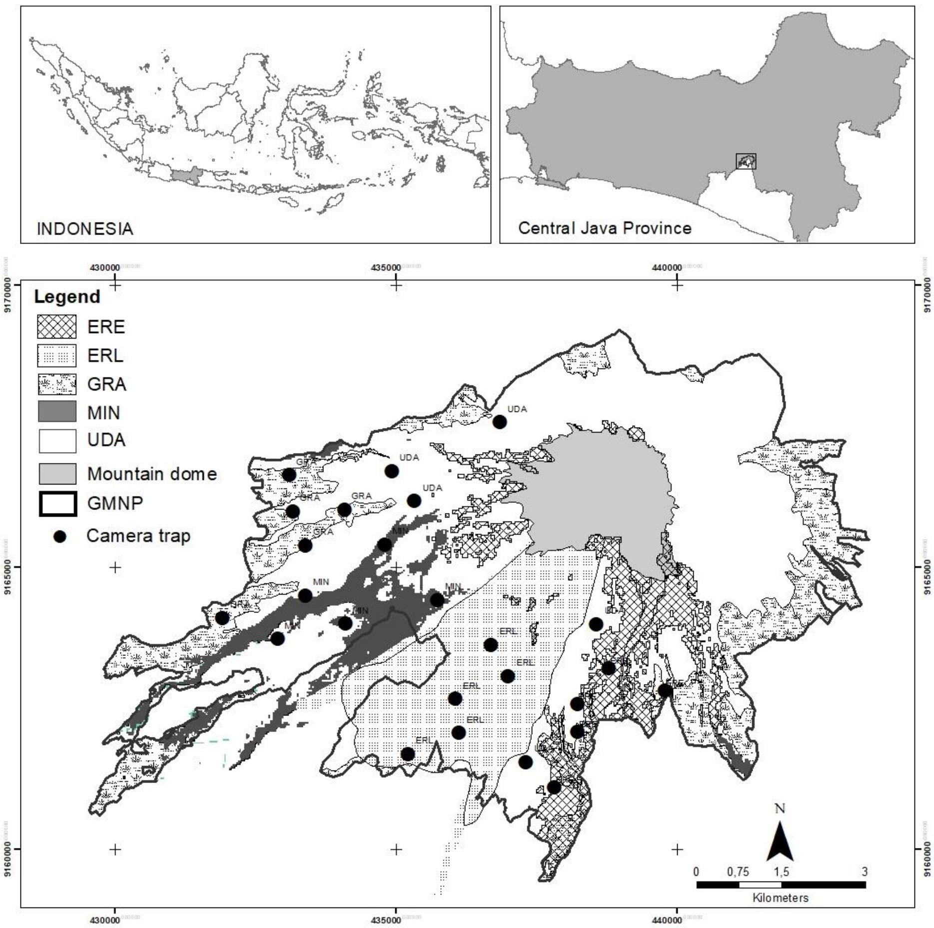
In Indonesia, the protected areas are mountainous and home to various types of native, endemic flora, and fauna still preserved (Noroozi et al. 2018; Silveira et al. 2019). Although only 25% of the total land area is on the earth, 85% of the amphibians, mammals, and birds in the world live in mountainous areas (Rahbek et al. 2019). These areas are under threat of damage caused by natural disturbances such as eruptions (Whittaker et al. 1989; Crisafulli et al. 2005, 2015; Dale et al. 2005), climate change (Palomo 2017), invasive alien species (Alexander et al. 2016) and humans such as land conversion (Ross et al. 2017), tourism activities (Niu and Cheng 2019), or fires (Hu and Zhou 2014; Cromartie et al. 2020). Moreover, natural and human disturbances also occur in the Gunung Merapi National Park (GMNP) area, which includes natural eruption disturbances (Marhaento and Faida 2016), and human activities such as mining (Sulaksono 2015), grazing, and taking firewood (Umaya et al. 2020a). These disturbances occur because GMNP is located on Mount Merapi, the most active volcano in the country and surrounded by densely populated settlements (Umaya et al. 2020b), making the GMNP ecosystem unique and different. Furthermore, disturbances are not only sourced from human activities, but also from volcanic activity that occurs periodically.

Both the natural and human sources of disturbance influence ecological processes (Crisafulli et al. 2005; Henríquez et al. 2015) that triggers ecosystem changes at the level of genetic diversity (Davies et al. 2016), species diversity (Fakhry et al. 2018), community (Danneyrolles et al. 2018), population, or landscape (Schroeder et al. 2011; Keane 2017). Similarly, eruption disturbances damage the plant and mammal communities that inhabit the Mount Merapi ecosystem (Sutomo et al. 2011; Gunawan et al. 2013). However, there is no study on mammals in the Merapi volcanic ecosystem and its existence, which is dynamic and vulnerable to changes due to disturbances. This makes it necessary to understand the response of the mammal community to various disturbances and identify the condition of the Mount Merapi ecosystem. The data on the presence of mammals and their response to the environment is important because they are observed from the level of animal presence, species richness, and abundance of animals in the disturbed area (Magurran and McGill 2011; Oberosler et al. 2017; Zungu et al. 2020). Therefore, the objectives of this study were to identify the response of the terrestrial mammals community to various disturbances in GMNP. The results are important for managers to identify ecological disturbances from the start and formulate their mitigation. Since disturbances are identified after major changes in habitat and animal communities have occurred, recovery requires large resources and a long time.

MATERIALS AND METHODS

Study area

This study was conducted in the protected area of GMNP (7º 35' S and 110º 24' E), which is administratively located on the border of Central Java Province (Magelang, Boyolali, and Klaten) and Yogyakarta (Sleman Regency), Indonesia. The GMNP area is surrounded by 30 villages that consist of 71 hamlets. The distance from residential areas to conservation areas varies between 50 m - 1 km and is limited by gardens, rice fields, or community forests.



Figures 1. Situation map of Gunung Merapi National Park, Indonesia. Notes : ERE: areas affected by eruptions < 20 years, ERL: areas affected by eruptions > 20 years, GRA: grazing areas, MIN: areas affected by mining activities, NDA: non-disturbance areas

Table 1. Site type, symbol, number of camera traps in each site type, and the total day's number of camera trap installation

Site type	Symbol	NOC	NON
This site was affected by the 1994 and 1997 eruptions but is now also used as grass areas	ERL	5	360
This site was affected by the 2006 and 2010 eruptions and is also used as a grass area	ERE	5	317
Sites of former sand mining and areas where sand extraction activities are carried out.	MIN	5	305
The site is used for grazing activities by the surrounding community.	GRA	5	350
Non-disturbance area	NDA	5	353
		25	1685

Note: NOC: number of camera traps on each site; NON: number of nights

Based on the classification of Schmidt and Ferguson, the climate type in the study area is type C or slightly wet with a Q value of 33.3-66% (BTNGM 2018a). Furthermore, the rainfall in the last 20 years varies with the lowest at 2,092 mm/year and the highest more than 3,000 mm/year of 4,395 mm/year. There are small variations in temperature and humidity throughout the year in other tropical rain areas. The relative humidity at Mount Merapi varies from 70%-90%, with a daily average temperature of 19-30°C (BTNGM 2018b).

Mount Merapi has a unique and unpredictable type of eruption (Surono et al. 2012) that repeatedly occurred with a Volcanic Explosivity Index (VEI) between 1-4 (Voight et al. 2000). The largest eruptions with VEI 4 were recorded in 1872-1873 and 2010 (Voight et al. 2000; Jenkins et al. 2013). Meanwhile, the eruptions with VEI 1-3 are frequent and repeated with durations that vary between 2-15 years. Previous studies showed that natural disturbances from eruptions affected the life of native flora and fauna of Merapi (Gunawan et al. 2013; Marhaento and Kurnia 2015), which also poses a threat of extinction to their existence in Java (Marhaento and Faida 2016).

Based on its activities, Mount Merapi is classified as type A, which has erupted since 1600 (Wittiri 2014). This eruption is unique and different from other types of volcanic eruptions in the world, making it classified separately as the Merapi type (Bronto 2013; Wittiri 2014).

Procedures

The data were collected at 4 sites affected by disturbance and 1 site not affected by disturbance. Meanwhile, the disturbed areas consist of areas affected by eruptions > 20 years (ERL; affected areas in 1994 and 1997), areas affected by eruptions < 20 years (ERE; 2006 and 2010), grazing areas (GRA), areas affected by mining activities (MIN) and non-disturbance areas (NDA) (Table 1). These sites were determined based on the results of field surveys, interviews, analysis of Landsat images, eruption maps from the Geological Disaster Technology Research and Development Agency (BPPTKG), and GMNP grass area maps (BPPTKG 2006; BTNGM 2018a). The variables measured to describe site conditions were the history and type of disturbance, as well as an intervention at each site.

The samples used are terrestrial mammals with the criteria of body weight > 1 kg (Francis 2008; Maharadatunkamsi et al. 2020). Subsequently, a total of 5 units of animal data were taken with camera traps for each disturbance location with a minimum distance of 500 m between the cameras (Hedwig et al. 2018). The camera trap used was the Bushnell Cam HD 119876 type and was installed 30-50 cm above ground surface for a minimum of 60 days/camera from July to October 2020. The cameras were activated for 24 hours and installed in a path that allows animals to pass, while figure capturing was set at 2-second intervals with 3 shots being taken (Pudyatmoko 2017). However, the installation of camera traps is not carried out on a grid 3 km away from the summit due to disaster mitigation reasons.

Vegetation data were taken from measuring plots that cover an area of 0.04 ha with a total of 5 plots/camera traps, making a total of 125 plots. The measuring plots were placed in cardinal positions, namely north, east, south, and west with a plot of 50 m from the camera trap point. It was made into a circle with an area of 0.04 Ha and the procedure was carried out at Noon (1981). The plants are divided into 8 classes, namely class S (3 ≤ diameter breast high (dbh) < 8 cm), A (8 ≤ dbh < 15 cm), C (23 ≤ dbh < 38 cm), D (38 ≤ dbh < 53 cm), E (53 ≤ dbh < 69 cm), and (F 69 ≤ dbh < 84 cm (Noon 1981).

Modeling was carried out using the Generalized Linear Model (GLM) to evaluate the effect of human and natural disturbances on the diversity of mammal species. In this process, the first step is to define variables that have an effect on species diversity, which include 1) binary value of the area affected by eruption > 20 years (ERL), 2) binary value of the area affected by eruption < 20 years (ERE), 3) binary value of the area affected by sand mining activities (MIN); 4) binary value of the area affected by grass-harvesting activities (GRA), 5) binary value of the nondisturbance area (NDA), 6) distance to the settlement (D_SET), 7) distance to mining area (D_MIN), 8) distance to grass area (D_GRA), 9) distance to the dome of the mountain (D_DOM), 10) distance to the area affected by eruption > 20 years (D_ERL); and 11) distance to the area affected by eruption < 20 years (D_ERE).

Data analysis

All figures of mammals were identified to the species level and tagged using the open-source DigiKam version 7.1.0. The species that were captured repeatedly within 30 minutes were detected as single individuals (O'Brien et al. 2003). Subsequently, the encounter of each species was counted at each station using the open-source software R with the CamtrapR package (Niedballa et al. 2016), and the stages of camera trap data management are complete according to (Niedballa et al. 2016).

The diversity analysis was carried out using the Shannon-Wiener diversity index (H'), while the dominance index used the Simpson index (D). Diversity and dominance indices were measured using the Paleontological statistical software PAST 3.22 (Hammer et al. 2001). Statistical analysis Mann-Whitney U test was used to compare the diversity of flora species and the abundance of TM in the study area. The Relative Abundance Index (RAI) of the mammalian class at each site was expressed using the formula by (Liu et al. 2013; Pudyatmoko 2017), namely: RAI = $\frac{A}{N}$ x 100, where RAI = Relative Abundance Index, A = Total number of species detected in all camera traps, N = The number of days of all camera traps. Relative abundance was measured for the mammals' level in each habitat type and a comparative test was carried out to identify the differences between sites.

The Generalized Linear Model (GLM) analysis with Gaussian distribution was used to determine the effect of predictor variables on species diversity (Santos-Filho et al. 2008; Sudibyo et al. 2018). This analysis used the GLM function with statistical software "R" version 4.1.2 under the "stats" package according to Dunn and Smyth (2018). Various models were built based on the combination of predictor variables using the dredge function in the "MuMIN" R package (Einoder et al. 2018; Barton and Barton 2020). Moreover, the best model was selected using criteria with an AICc value < 2 (Burnham and Anderson 2002). Out of these models, further tests were carried out with an analysis of the deviance table to obtain the best model (Schabetsberger et al. 2009; Burnham et al. 2011).

RESULTS AND DISCUSSION

Site characteristic

Each site has a different history of disturbance (Table 2), where those at the ERL and ERE sites are eruption and grass harvesting activities. For example, in 1994 and 1997, the ERL site was affected by eruptions, while the ERE was affected in 2006 and 2010. As a result, the Volcanic Explosive Index (VEI) at the ERE site is IV and the largest VEI index in the last 100 years, while the VEI index at the ERL site is II. Apart from being affected by the eruption, these sites are also grassed areas by the surrounding community.

The MIN site is an area affected by mining activities and a former mining area affected by fires in 2015 and 2019. Meanwhile, the GRA site is a traditional zone of GMNP, which is used for grazing activities for local communities, and is affected by a disturbance in grass activities. Generally, it is located in border areas and adjacent to residential areas and is not affected by human or natural disturbances is the NDA site. The management interventions were carried out are at the ERL and ERE sites in the form of planting by area managers or the community.

In Table 3, the measurement results of the vegetation that compose each site are presented. The NDA site has the most vegetation species, including 32 species in class S, 26 in class A, 21 in class B, 8 in class C, 10 in class D, and 3 species in class E, where the lowest number of species is MIN. For the number of individuals, GRA sites in classes S and A had the highest number of sites compared to others, while classes B, C, D, and E, NDA sites had the largest. The site with the least number of individuals is the MIN site, even in classes D and E, there are no individuals/plants.

The site with the highest diversity value is NDA in class S, A, and B, while in class C, the highest diversity is in the GRA site and the one with the lowest diversity value is the MIN site. Furthermore, the site with the highest species richness index value is the NDA for classes S and B, while the GRA site has the highest diversity value for class C.

The results of the comparison test on the number of species using the Mann-Whitney U test (Table 4) showed that the ERD, ERS, and GRA sites were not significantly different from the NDA site, while the MIN and NDA sites had a significant difference with a significance value of $P < 0.05$ ($P = 0.03638$). However, based on the diversity comparison using the Mann-Whitney U test (Table 5), the MIN is significantly different from the NDA with a significance value of $P < 0.05$ ($P = 0.04495$), while ERD, ERS, and GRA were not significantly different from the NDA.

Table 2. The results of the identification of site characteristics based on the disturbance type (anthropogenic and natural disturbances): Areas affected by the eruptions in 1994 and 1997 (ERL), areas affected by the 2006 and 2010 eruptions (ERE), areas affected by mining activities (MIN), areas affected by grazing activities (GRA), and undisturbed area (NDA)

Disturbance Variable	ERL	ERE	MIN	GRA	NDA
Anthropogenic disturbance					
1. Grazing	Y	Y	N	Y	N
2. Mining	N	N	Y	N	N
3. Fire	N	N	Y	N	N
Natural disturbance					
1. Pyroclastic flow	Y	Y	N	N	N
2. Time	1994, 1997	2006, 2010			
3. Max Volcanic Explosive Index	II	IV			
Rehabilitation program					
1. by government	Y	Y	N	Y	N
2. by community	Y	Y	N	N	N

Note: Y: Yes; N: NO

Table 3. The measurements results of species richness and Shannon diversity index in-plant classes S (3 dbh < 8 cm), A (8 dbh < 15 cm), C (23 dbh < 38 cm), D (38 dbh < 53 cm), E (53 dbh < 69 cm) and (F 69 dbh < 84 cm) at the ERL site (area affected by the 1994 and 1997 eruptions), ERE (area affected by the 2006 and 2010 eruptions), MIN (area affected by mining activities), GRA (area affected by grass activity), and NDA (non-disturbance areas)

Site	ERL	ERE	MIN	GRA	NDA
Species number					
S	15	16	8	20	32
A	9	13	7	18	26
B	7	12	5	17	21
C	5	6	5	9	8
D	5	2	0	0	10
E	0	0	0	1	3
Diversity (H')					
S	2.185	2.210	1.656	2.436	3.063
A	1.934	2.212	1.504	2.541	2.716
B	1.597	2.086	1.479	2.648	2.633
C	1.220	1.735	1.561	1.987	1.609
D	1.044	0.451	0.000	0.000	2.019
E	0.000	0.000	0.000	0.000	1.011

Table 4. Significance (P-values) for pair-wise comparisons of the number of species in each habitat type using Mann Whitney U test

	ERE	MIN	GRA	NDA
ERL	0.747	0.410	0.376	0.127
ERE		0.293	0.521	0.229
MIN			0.169	0.036*
GRA				0.298

Note: *Significance P < 0.05

Table 5. Significance (P-values) for pair-wise comparisons of the plant diversity in each habitat type using Mann Whitney U test

	ERE	MIN	GRA	NDA
ERL	0.748	0.572	0.375	0.128
ERE		0.170	0.572	0.298
MIN			0.221	0.044*
GRA				0.377

Note: *Significance P < 0.05

Terrestrial mammals (TM)

The number of days for installation of 25 camera traps is 1,685 days and 698 images of mammals are obtained. Meanwhile, the 9 species of terrestrial mammals were recorded on camera consisted of the order : 1) Artiodactyla that consist of Indian muntjak (*Muntiacus muntjak* Zimmermann, 1780), Wild boar (*Sus scrofa* Linnaeus, 1758); 2) Carnivore that consist of Leopard cat (*Prionailurus bengalensis* Kerr, 1792), Javan mongoose (*Herpestes javanicus* É.Geoffroy Saint-Hilaire, 1818), Javan ferret badger (*Melogale orientalis* Horsfield, 1821), Asian palm civet (*Paradoxurus hermaphroditus* Pallas, 1777), Small Indian civet (*Viverricula indica* É.Geoffroy Saint-Hilaire, 1803); 3) Pholidota that consist of Malayan pangolin (*Manis javanica* Desmarest, 1822); and 4) Rodentia that consist of Sunda porcupine (*Hystrix javanica* F.Cuvier, 1823). Based on the IUCN Redlist, 1 species have a Critically Endangered (CR) status, namely *M. javanica*, while the other has a Least Concern (LC) status. According to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P 106 on Species of Protected Plants and Animals, there are 4 species of animals that have protected status, namely *M. muntjak, P. bengalensis, M. javanica, and H. javanica*.

The mammal species discovered in the ERL, ERS, MIN, GRA, and NDA sites were *M. muntjak, H. javanicus, M. orientalis, P. hermaphroditus,* and *V. indica.* Meanwhile, only *M. javanica* was in the ERL, GRA, and NDA (Table 7) and *H. javanica* was also the only species discovered in the ERL, ERS, GRA, and NDA sites. The 3 species with the highest Relative Abundance Index (RAI) include *M. muntjak* (RAI 6.57), *H. javanica* (RAI 7.90), and *P. hermaphroditus* (RAI 5.35), while those with the lowest RAI were *H. javanicus* (RAI 0.56), *M. javanica* (RAI 0.66), and *S. scrofa* (RAI 0.87).

It was shown that the ERE and NDA sites had the highest number of species (9), ERE had the lowest number of species (6), and the MIN and GRA had 7 species. The index measurement results showed that the ERE site had the highest H' value of 1.97 and NDA had the lowest H' value of 1.52. The site that had a high dominance level was NDA with a D value of 0.28, while ERE had a low dominance level with a D value of 0.15 (Table 7). Based on the RAI TM comparison test using the Mann-Whitney U test (Table 8), ERL had a significant difference with ERE (P = 0.033) and MIN (P = 0.023) but had no significant difference with GRA and NDA.

Table 6. Terrestrial Mammals species were recorded on camera trap in GMNP and its conservation status

Species	English	RAI	Conservation Status	
			RI	IUCN
Artiodactyla				
Muntiacus muntjak (Zimmermann, 1780)	Indian muntjac	6.57	*	LC
Sus scrofa (Linnaeus, 1758)	Wild boar	0.87		LC
Carnivore				
Prionailurus bengalensis (Kerr, 1792)	Leopard cat	2.65	*	LC
Herpestes javanicus (É.Geoffroy Saint-Hilaire, 1818)	Javan mongoose	0.56		LC
Melogale orientalis (Horsfield, 1821)	Javan ferret badger	1.99		LC
Paradoxurus hermaphroditus (Pallas, 1777)	Asian palm civet	5.36		LC
Viverricula indica (É.Geoffroy Saint-Hilaire, 1803)	Small Indian civet	2.91		LC
Pholidota				
Manis javanica (Desmarest, 1822)	Malayan pangolin	0.66	*	CR
Rodentia				
Hystrix javanica (F.Cuvier, 1823)	Sunda porcupine	7.90	*	LC

Note: Primary Data (2020 - 2021), IUCN (2018), CITES (2018), and Minister of Environment and Forestry Regulation (2020). Notes: RI: Minister of Environment and Forestry Regulation Number P 106 on Species of Protected Plants and Animals; IUCN: VU: Vulnerable; CR: Critically Endangered; LS: Least Concern

Table 7. Relative Abundance Index (RAI) and number of mammals in each habitat type

Species	ERL		ERE		MIN		GRA		NDA	
	NOP	RAI	NOP	RAI	NOP	RAI	NOP	RAI	NOP	RAI
Mammals										
Sus scrofa	5	0.3	-	-	4	0.24	3	0.18	2	0.12
Herpestes javanicus	2	0.12	4	0.24	1	0.06	1	0.06	1	0.06
Muntiacus muntjak	15	0.89	8	0.47	2	0.12	5	0.3	79	4.69
Prionailurus bengalensis	17	1.01	-	-	4	0.24	6	0.36	16	0.95
Hystrix javanica	17	1.01	6	0.36	-	-	12	0.71	96	5.7
Melogale orientalis	11	0.65	9	0.53	2	0.12	4	0.24	6	0.36
Paradoxurus hermaphroditus	23	1.36	7	0.42	9	0.53	17	1.01	31	1.84
Viverricula malaccensis	29	1.72	3	0.18	13	0.77	-	-	4	0.24
Manis javanica	1	0.06	-	-	-	-	2	0.12	8	0.47
Sum	120	7.12	37	2.2	35	2.08	50	2.98	243	14.43
Total days/night	360		317		305		350		353	
Species number	9		6		7		8		9	
Shannon diversity (H')	1.97		1.79		1.72		1.84		1.5	
Dominance	0.15		0.16		0.21		0.19		0.28	

Note: NOP: Number of Photos; RAI: relative abundance index (%)

Based on the GLM analysis on 8,192 pairs of models, it was discovered that there were 13 best models with criteria Δ AICc < 2 (Table 9). Out of the 13 models, the 3 best models with the smallest AICc values were selected, such as models with a rating of 1, 2, and 3 for further testing by observing the deviance value (Schabetsberger et al. 2009; Burnham et al. 2011). The analysis obtained 1 best model with a residual deviance value and small P-value criteria, namely the D_SET + MIN model (Table 9). These results indicate that the D_SET + MIN model is most suitable to explain the diversity of mammal species in GMNP. A total of 2 variables make up this model, such as the distance from the settlement (D_SET) and the area affected by sand mining activities (MIN). Furthermore, Figure 1 shows the relationship between the two variables with the diversity of mammal species. The D_SET variable has a positive estimate value, which indicates that the closer to the settlement, the lower the diversity of mammal species, and the farther from the settlement, the higher the diversity of mammal species. This is in contrast to the MIN predictor with a negative estimate value, which indicates that the closer to the mining-affected area, the lower the diversity of mammal species (Figure 1B).

Table 8. Significance (P-values) for pair-wise comparisons of RAI (relative abundance index) of terrestrial mammals in each habitat type using Mann Whitney U test

	ERE	MIN	GRA	NDA
ERL	0.033*	0.023*	0.101	0.929
ERE		0.893	0.789	0.101
MIN			0.449	0.056
GRA				0.156

Note: *Significance P < 0.05.

Table 9. AICc (corrected Akaike Information Criterion) model selection based on candidate set of model for predicting diversity of terrestrial mammals at Gunung Merapi National Park, Indonesia

Models	df	Model Rank	logLik	AICc	Delta	Weight
D_SET + MIN	4	1	-12.000	33.990	0.000	0.140
MIN	3	2	-13.430	34.000	0.000	0.140
D_ERL+D_MIN+ERL	5	3	-10.810	34.780	0.790	0.100
D_DOM+D_ERE+MIN	5	4	-10.840	34.850	0.850	0.090
ERE+MIN	4	5	-12.420	34.850	0.850	0.090
(Null)	2	6	-15.400	35.350	1.360	0.070
D_ERE+D_SET+MIN	5	7	-11.110	35.380	1.390	0.070
D_GRA	3	8	-14.200	35.540	1.540	0.070
D_ERE+MIN	4	9	-12.840	35.670	1.680	0.060
D_ERL+ERL+MIN	5	10	-11.280	35.730	1.730	0.060
D_ERL+ERL+MIN	4	11	-12.890	35.790	1.790	0.060
D_GRA+D_SET+MIN	5	12	-11.350	35.870	1.870	0.060

Table 10. Analysis of deviance table to fit the best model. D_SET: distance to the settlement area, MIN: area affected by mining activities, D_ERL: distance to the area affected by the eruption > 20 years, D_MIN: distance to the area affected by mining activities, and ERL: area affected by eruption > 20 years

Model	Resid. Df	Resid.Dev	Df	Deviance	Pr(>Chi)	Sig
NULL	24	5.019				
D_SET + MIN	22	3.822	2	1.198	0.027	*
MIN	23	4.285	-1	-0.463	0.094	.
D_ERL+D_MIN+ERL	21	3.476	2	0.809	0.087	.

Note: Significance codes: P value < 0.05 '*', < 0.1 '.'

Disturbance character

The identification results of ERE, ERL, MIN, GRA, and NDA showed that 5 sites have different characteristics. ERL and ERE are sites affected by natural eruption disturbances, while MIN and GRA are affected by human disturbances such as mining and grazing activities. The eruption disturbances have the widest impact compared to human-caused disturbances. This is shown in the 2006 and 2010 eruptions which caused more than 1,000 hectares of damage (Rahayu et al. 2014; Marhaento and Kurnia 2015; Marhaento and Faida 2016) in less than 2 months. Although grazing and mining disturbances have low severity, they have a high disturbance intensity. This is because mining is carried out almost every day since it is a source of livelihood for local people to fulfill their daily needs (Umaya et al. 2020a). Based on the data collection results conducted by the GMNP Office, the number of people who depend on mining activities is 1122 people (BTNGM 2018a; Nurwati et al. 2020). The intensity of mining activities carried out reduces the rate of recovery, which is different from eruption disturbances that occurred for 2-10 years (Voight et al. 2000; Surono et al. 2012; Charbonnier et al. 2013). Therefore, the ecosystem has a longer interval to recover compared to disturbances from mining and grazing.

MIN site has the lowest diversity index and several plant species compared to others (Figure 2). The comparison test results showed that the plant diversity and the number of species in the MIN site are significantly different from the plant diversity at the NDA site (Table 4). This is different from ERE, ERL, and GRA have no significant difference with ERL, ERE, GRA, and NDA (Table 5). The species richness and the low value of plant diversity in MIN of the ecosystem at the site have not yet recovered. Mining activities have also caused the loss of vegetation, sand, and soil, replaced with gravel as waste from mining activities, making the natural succession process at the MIN site last longer. Meanwhile, the largest mining activity occurred before 2009 and stopped after a joint operation by the GMNP Office (Umaya et al. 2020b), and the damage caused by the activities is still visible. The young secondary forest has not yet been formed in this area but is still dominated by litter and weeds. The number of species and the level of plant diversity at MIN in classes S, A, B, C, and D is still very low compared to other sites (Figure 2), which showed that the ecosystem recovery process in mining-affected areas takes a long time. This is different from ERE with higher species richness and plant diversity than MIN. Similarly, ERE was also affected by eruption disturbances in 2006 and 2010, and currently has a higher species richness and plant diversity than MIN (Table 3), which indicated that ERE has a higher level of resilience than the MIN.

The low level of diversity and number of species at the MIN site are responded to by the low presence and abundance of TM animals at the site. Meanwhile, the abundance of mammals at the MIN site was the lowest compared to other sites. Based on the comparison test results with the Mann Whitney U test, the abundance of terrestrial mammals at the MIN site was significantly different from the ERE and not different from the GRA, ERE, and NDA sites. This strengthened the previous results, where the level of damage due to sand mining disturbances was the greatest compared to areas affected by other disturbances. The MIN site consists of river flows used for mining activities, namely the White and Bebeng River flows, Srumbung Sub-District, Magelang Regency. Since sand mining activities have damaged the river flow, the function of the corridor is disrupted. There are at least 4 functions of the corridor, namely as a habitat for certain species, a place to carry out activities and movement of species, protection, and provision of resources (Gokyer 2013).

Figure 1. Graph of the relationship between species diversity of terrestrial mammals and the area affected by mining (a) and distance to settlement (b)

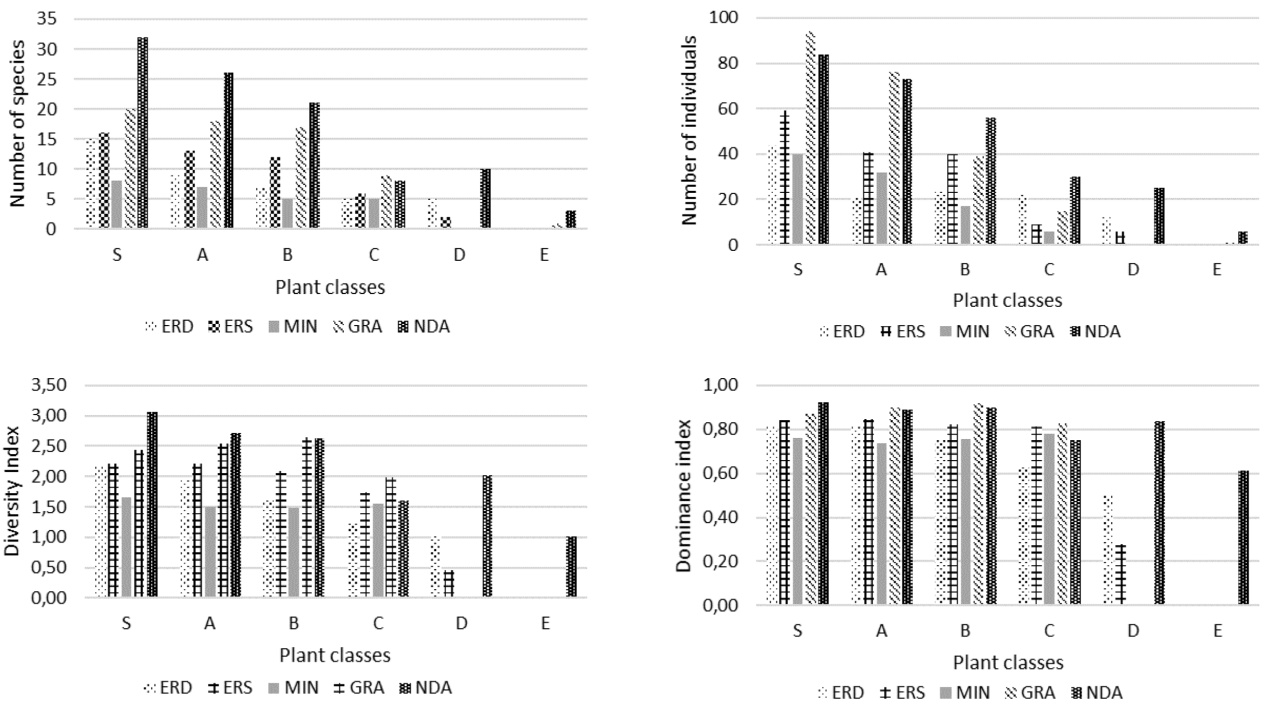


Figure 2. Graph for number of species, number of individuals, Shannon's Diversity Index, and Dominance Index of vegetation. Plant classes S (3 dbh < 8 cm), A (8 dbh < 15 cm), C (23 dbh < 38 cm), D (38 dbh < 53 cm), E (53 dbh < 69 cm) and (F 69 dbh < 84 cm)

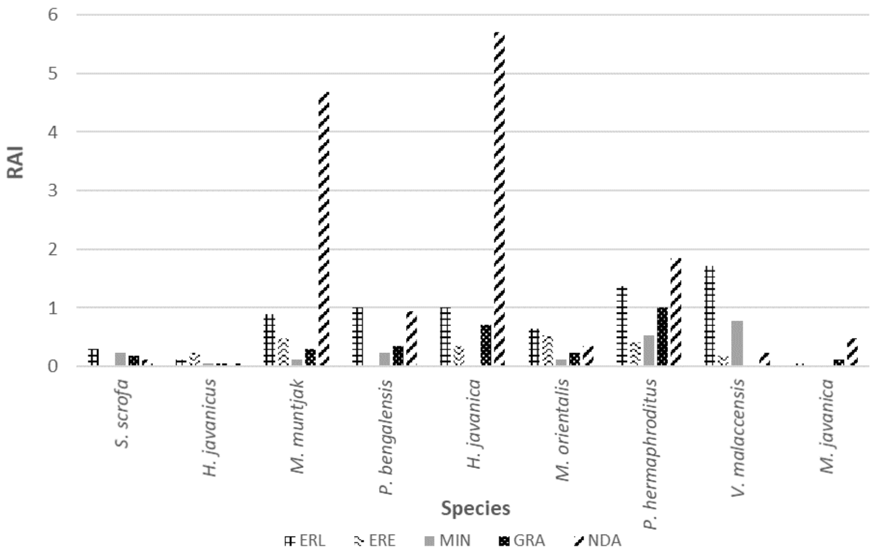


Figure 3. Relative Abundance Index (RAI) of terrestrial mammals for each site (ERL, ERE, MIN, GRA, and NDA)

There are no significant differences between the plants that make up the ERE and ERL sites because they have sufficient time to recover and colonize the site. The long interval of disturbance period and the minimum number of human disturbances also increased the recovery process. According to (Collins and Glenn 1997), the level of diversity and species richness is expected to increase as the frequency of disturbances decreases and the interval of disturbances increases. The site affected by the 1994 eruption has not fully recovered and was affected again in 1997 (Voight et al. 2000). However, it was not affected by the eruption after the 1997 eruption, making it possible to carry out the recovery process (Sutomo et al. 2015). The disturbance interval allows other species to enter and carry out the colonization process. Therefore, the number and diversity of species will be higher and at a certain point, the richness and diversity of species are expected to experience a decline. This occurs when the disturbance is less frequent and the occurrence interval is getting longer. During the period, the rehabilitation intervention by the manager accelerated the recovery of the ecosystem.

Animal species response

In this study, camera traps were used to capture figures of 9 species of terrestrial mammals, where *H. javanica* and *M. muntjak* were the animals with the highest RAI values of 7.9 and 6.57, while *H. javanicus* and *M. javanica* had the lowest RAI values of 0.56 and 0.66, respectively. Although *H. javanica* has the highest RAI value, only ERL, ERE, GRA, and NDA sites captured its presence. Furthermore, it was not discovered at the MIN site, while *M. muntjak*, which was present at all sites because deer have a wider home range than *H. javanica*. *Muntiacus muntjak* can also adapt to various patches of different habitats that are disturbed by nature or humans. The presence of *M. muntjak* in disturbed areas could be due to just passing through, such as corridors, or for protection from predators (Ouboter et al. 2021). *Muntiacus muntjak* was also discovered at the GRA because the site provided an abundant source of feed. Regular grass harvesting activities are followed by the growth of young grass, which is a source of food for *M. muntjak*.

Hystrix javanica which is only present on the ERL, ERE, GRA, NDA sites was not in the MIN site that is composed of mining waste such as coarse sand and rocks. This activity causes the loss of vegetation, soil, and topsoil for site preparation and is replaced by open areas (Yang et al. 2018). This has made the MIN site have a rough and hard texture, which becomes inhabitable for *H. javanica* that requires loose soil to make a large hole, however, it can be inhabited by 6-8 porcupines (Farida 2015).

This study also discovered the presence of *M. javanica* which is classified as Critically Endangered (CR) according to the IUCN Red List and included in the category of protected animals. This is a new record of its discovery in the Mount Merapi ecosystem. *Manis javanica* was found at sites not affected by disturbance (NDA), grass activity sites (GRA), and sites affected by eruptions for more than 20 years (ERL). However, it was not in mining-affected sites (MIN) and eruption-affected sites less than 20 years old (ERE). This result is in line with those of Lim and Ng (2008) and Anasari et al. (2021), where *M. javanica* was discovered in several types of habitats such as near settlements, plantations/agriculture, and secondary forests. This is because the sites were close to food sources such as ants, termites, and other small insects. Furthermore, *M. javanica* is a nocturnal animal that is active at night, unlike grazing activity that is active from morning to evening. This time difference allows it to live and carry out activities around the grass area and community. It was also not discovered at the MIN site because it is composed of gravel and coarse sand as waste from mining activities. This is in line with (Kuswanda and Setyawati 2016), which stated that *M. javanica* prefers areas with soft soil texture to make burrows for resting or foraging easily. This further strengthens the importance of the Mount Merapi ecosystem as a home for animals and plants of Java that are threatened with extinction.

Figure 4. Types of terrestrial mammals recorded on camera traps in the GMNP, Java, Indonesia: A. *Muntiacus muntjac*, B. *Sus scrofa*, C. *Prionailurus bengalensis*, D. *Hystrix javanica*, E. *Paradoxurus hermaphroditus*, F. *Viverricula indica*, G. *Melogale orientalis*, H. *Herpestes javanicus*, I. *Manis javanica*

The GLM analysis results showed that the species diversity in the GMNP area is influenced by the presence of mining activity (MIN) and the distance from the settlement (D_SET). This indicated that the area affected by mining disturbance is the main component influencing the low diversity of land mammal species in the Gunung Merapi National Park area. This is in line with previous studies on the impact of development on biodiversity, where mining activities have a high level of disturbance compared to others such as grass picking and eruptions (Espinosa-Reyes et al. 2014; Ardente et al. 2016; Belay et al. 2020; Koehnken et al. 2020). Based on Figure 1, it was discovered that the closer the value to 1, the lower the diversity of mammal species and vice versa, which indicated that mining activities have an impact on low vegetation and mammals.

Mount Merapi ecosystem

The diversity index of each site has a different value, where the ERL site has the highest value. This showed that mammals have started to appear and colonize the area. Although the number of species and the RAI value of mammals at the NDA site has a high value, its diversity value is the lowest due to the presence of several dominant species such as *M. muntjak* and *H. javanica* (Figure 3). The abundance of these species in the Mount Merapi ecosystem is due to the abundance of food, the absence of predators in the ecosystem. In this study, the *Panthera pardus melas* (G.Cuvier, 1809) that supposed to be a predator for *M. muntjak* and *H. javanica* was not found. This is in line with the concept of the Intermediate Disturbance Hypothesis (IDH) which stated that ecosystems with a large and a small level of disturbance have a low diversity value, while those with moderate disturbances have a high or optimal level of diversity (Connell 1978). Therefore, it can be stated that the mammal diversity in the ERL site is at an optimal point after more than 20 years of recovery. This value is expected to decrease when several species have started to dominate in the same pattern as the NDA site.

Similarly, the MIN site has a low mammal diversity value and a low mammalian RAI value, which showed that the site is still damaged and has not been restored. This condition makes only a few mammals present and lives in the area. Currently, there are still mining activities that can cause the unsuccessful colonization process by animals in a short time. Only organisms with high resistance and rapid colonization can survive in areas with high frequency and intensity of disturbance, which reduces diversity and species richness (Connell 1978).

The volcano ecosystem cannot be separated from the presence of natural and human disturbances that have received different responses at each site (Calderon et al. 2012; Sutomo et al. 2015). Mining disturbances are responded to by the low number of species and the level of plant diversity. This shows that the response of site recovery to mining disturbances is significantly low, therefore, there is a need for serious concern by managers. Furthermore, mining activities trigger habitat fragmentation and become a barrier to the movement of mammals where there is no arrangement. Mining activities also affected the low level of diversity of plant and mammal species. In contrast to ERE and ERL, where the site condition has begun to recover and TM animals have started to appear and colonize. This is similar to the GRA site that has a diversity level and the number of plant species that are not significantly different from the ERL and NDA sites. This showed that the condition of the GRA site tends to be stable and the presence of grasses does not interfere with the presence of TM animals that have adapted to grazing activities by sharing niches of time and space. Although the NDA site is not affected by disturbances, the ecological condition of the ecosystem at the site is still not healthy. The abundance and high dominance of one species (*M. muntak* and *H. javanica*), and the absence of predators can be indicators of the unhealthy ecosystem in the area. This had also occurred in Yellowstone National Park, where the absence of *C. lupus* caused an abundance of *C. elaphus* and inhibited the development of native plants (Ripple and Beschta 2012).

This study showed that the GMNP is an important habitat for native mammals in Java Island. It was also discovered that mammals respond differently to each site affected by eruption disturbances and humans. This variety of responses can be used as a basis and consideration to formulate management strategies, specifically at sites affected by mining activities. The results also discovered a new record of the existence of terrestrial mammals that were previously 5 species (Gunawan et al. 2013) into 9 species, where one had the status of Critical Endangered based on the IUCN Red list, namely *M. javanica*. Meanwhile, further studies are needed on the daily behavior and determination of mammalian habitats, specifically protected animals, as an effort for preservation. Monitoring of mammals regularly and continuously is also needed to be carried out to detect the development and dynamics of the Merapi volcano ecosystem, which is rapidly changing and full of uncertainty.

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