Journal of Tropical Biodiversity and Biotechnology
Volume 04, Issue 02 (2019): 54 — 61
DOI: 10.22146/jtbb.41008

Research Article

Changes in Vegetation on Mount Agung Volcano Bali Indonesia

Sutomo[1,2]*, Luthfi Wahab[2]

1) Research Centre for Plant Conservation and Botanic Garden-Indonesian Institute of Sciences (LIPI), Bali Botanical Garden, Candikuning, Baturiti, Bali, Indonesia.
2) AF GIS and Remote Sensing Consultant and Training, Karanggayam, Yogyakarta, Indonesia.

*Corresponding author, email: tommo.murdoch@gmail.com

Keywords:
Vegetation
Mt. Agung
Bali
LANDSAT
REMAP

Article history:
Submitted 16/11/2018
Revised 08/05/2019
Accepted 17/05/2019

ABSTRACT

Volcanic activity is a major natural disturbance that can catastrophically change an ecosystem over a short time scale. The eruption of Mt. Agung strato-volcano in 1963-1964 was considered among the most important volcanic event of the 20th century due to its effect on global climate. Studies on vegetation and landscape of Mt. Agung post-1970-1980 has been scarce. The current eruption of Mount Agung in June-July 2018, brought awareness of the importance urge to document the past and current landscape along with vegetation on Mt. Agung. Our study aimed to utilize remote sensing technique to explore the pattern of current (2017) land cover and vegetation density on Mt. Agung and estimate of vegetated areas and whether it has changed from the past. LANDSAT 8 images (www.earthexplorer.usgs.gov/) were used in this study. Supervised classification in ENVI was employed to obtain land use or land cover of the Mt. Agung area. Normalized Difference Vegetation Index (NDVI) was also calculated using the feature in the ARC GIS. Online web-based application, REMAP was used to obtain information on past and present condition of the crater of Mt. Agung to see whether there have been changes in vegetated areas around the crater using REMAP (www.remap-app.org). Results showed there are basically five main landcover that can be recognized namely forest (20758.23 ha), settlement (4058.37 ha), water area (41606.64 ha), open area (15335.64 ha) and farming (34554.78 ha). Our NDVI analysis also resulted in areas with have high density (78836.04 ha), medium density (15490.26 ha) and also no vegetation (31008.24 ha). Using web-based GIS application REMAP, we found that there has been an increase (approximately 1 km^2) in vegetation cover from the 1980s to 2016. The changes in vegetation near the crater of Mt. Agung is relatively slow when compared to another volcano such as Mt. Merapi. Remote sensing application has enabled us to obtain information on vegetation change relatively easily compared to conduct an extensive on-ground survey where more time and funding is needed.

INTRODUCTION

Volcanic activity is a major natural disturbance that can catastrophically change an ecosystem over a short time scale (2001). More than half of the active terrestrial volcanoes encircle the Pacific Ocean and are known as the 'ring of fire'. Indonesia is located on this chain of active volcanoes that stretched from west to east of the Archipelago (Sutomo 2013). With 130 active volcanoes lies in its region, Indonesia has become the most volcanic country on Earth (Weill 2004). One of the volcano in Indonesia which recently being on the center of attention is the Agung volcano in the Island of Bali. In September 29th, 2017 the volcano status was on the highest alert level due to its numerous volcanic activities. There has been debate and opinion that the volcano is surely set to erupt, then in 25th November 2017 Mt. Agung erupted.

The first ever recorded in history eruption of Mt. Agung was in 1843 (Dilmy 1965) and there is no complete report has been written following the eruption. The next catastrophic eruption was in 1963

-1964. The eruption of this strato-volcano in 1963-1964 is considered among the most important volcanic event of the 20th century due to its effect on global climate (Self and Rampino 2012). One year after 1963 of Mt. Agung eruption, almost 90% of the affected areas were still barren almost as if it had been cemented (Whitten *et al.* 1996). Few plant species that survive the eruption such as *Sambucus javanica*, *Eleusine indica,* and *Ageratum conyzoides* were found to be alive after a few months of the eruption (Dilmy 1965).

Change in land use and land cover has been a significant aspect of environmental management and conservation planning for many decades (Murray *et al.* 2017a). The role of remote sensing (RS) and geographical information systems (GIS) in ecology, especially in fire and vegetation management, has been recognized (Arno *et al.* 1977; Chuvieco and Congalton 1989; Keane *et al.* 2001; van Wilgen *et al.* 2000; Verlinden and Laamanen 2006). Van Etten (1998) used a GIS for predictive vegetation mapping using models that linked vegetation units to mapped environmental variables across the extensive remote areas of Hammersley Ranges in Australia.

Land cover maps permit the portrayal of the distribution of ecosystems and land cover types, assessments of biodiversity and identification of areas undergoing loss, fragmentation, and degradation (Haddad *et al.* 2015; Murray *et al.* 2017a). Studies on vegetation and landscape of Mt. Agung post 1970-1980 has been scarce. With the current eruption on Mount Agung in June-July 2018, it is of importance to document the past and current landscape along with is vegetation on Mt. Agung. Our study aimed to utilize remote sensing technique to explore the pattern of current (2017) land cover and vegetation density on Mt. Agung and estimate of vegetated areas and whether it has changed from the past.

Method

To obtain the current land cover and vegetation density on Mt. Agung and its surrounding, a satellite image for Mt. Agung (year 2017) was downloaded from LANDSAT 8 (www.earthexplorer.usgs.gov/). When selecting images to be download, we looked for images which were not covered by clouds or try to minimize the cloud cover percentage as much as possible with image quality level 9 (no errors detected, perfect scene). We then chose band 6, 5, and 3 and composite them into one image. After layer stacking, then cropping was done so that only Mt. Agung area was shown. This result then was load as RGB and used as the basis for classification. The classification was done using supervised classification, maximum likelihood approach with ENVI 4.5. Once classification finished, each class were converted to individual layer in a shapefile to be analyzed in ARCGIS 10.1.

We also use REMAP to obtain information on past and present condition of the crater of Mt. Agung to see whether there have been changes in vegetated areas around the crater. We use REMAP because it is difficult to find good past images from LANDSAT on Mt. Agung. Remap (https://remap-app.org) is an online mapping platform. Remap was developed to enable users to quickly map and report the status of ecosystems, contributing to a global effort to assess all ecosystems on Earth under the IUCN Red List of Ecosystems (Murray *et al.* 2017a). Remap uses the power of the Google Earth Engine, allowing users to directly access vast satellite data archives and state-of-the-art remote sensing methods. Remap handles the technical details of remote sensing so that users can focus on training, classifying and improving their maps (Murray *et al.* 2017b).

To obtain information on vegetation density, we used NDVI technique. NDVI is an index describing vegetation by showing the difference between near infrared (which is strongly reflected by vegetation) and red light (which is absorbed by vegetation). NDVI is correlated to vegetation biomass, vigour, and photosynthetic activity. This index exploits the reflectance patterns of ground elements in the red (R) and near-infrared (NIR) bands of the electromagnetic spectrum to distinguish green vegetation from its background soil brightness and is calculated as (NIR - R)/ (NIR + R). NDVI values range from -1 to 1, with positive values representing vegetated areas and negative values representing non-vegetated regions (Sankaran 2001). The NDVI ratio approach usually adopted for land cover change estimation in preference to the more commonly employed post-classification pixel-by-pixel comparison method (Lillesand *et al.* 2008) since it also permits the identification of areas where changes in the vegetative cover have been significant, but insufficient to cause change in class membership (Sankaran 2001). In our study, NDVI was generated using NDVI feature in ARC-MAP (ARC GIS 10.1) image analysis toolbar. Band 2, 3, 4, and 5 were chosen for Landsat 8 (OLI)image as input images in ARC-MAP which represent the blue, green, red and near-infrared (NIR) bands. By choosing image analysis tab, all the bands layers were composite into one and then the RGB channels were adjusted to just using only the NIR, red and green bands. Scientific output box was chosen on the NDVI tab in ARC-MAP so that instead of displaying the wavelength, it will give the value of +1 to -1 in the NDVI result. Once NDVI images generated, colour scheme was applied for easier interpretation.

In addition, to obtain information regarding plant species that were occurred on Mt. Agung and its surrounding from past to present, we conducted a literature study into the database belongs to plant registration division of Bali Botanical Garden. The database holds the information on the past flora exploration (1970's) up to 2000 (Arinasa 2017).

Results and Discussion

Our result on landcover classification using Landsat 8 image and processed with ENVI is presented in figure 1. There are basically five main landcover that can be recognized namely forest (20758.23 ha), settlement (4058.37 ha), water area (41606.64 ha), open area (15335.64 ha) and farming (34554.78 ha). Our NDVI analysis also resulted in areas with have high density (78836.04 ha), medium density (15490.26 ha) and also no vegetation (31008.24 ha) (Figure 2). Most of the unvegetated areas located on the northern part of the mountain. This could indicate the direction of the eruption.

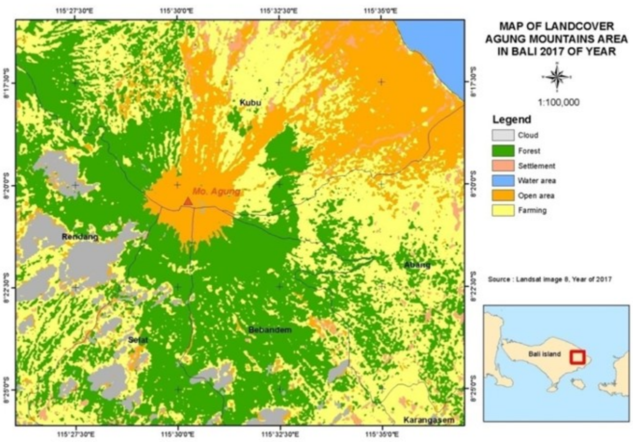

Figure 1. Landuse map of Mount Agung in Bali, using Landsat image 8 (2017).

Unlike eruption on Mt. Merapi, where the direction of pyroclastic flows mostly moved from the crater to the south flank of the mountain (Sutomo 2010), Mount Agung flows of eruption materials tends to move to the north. On 4th June 2006, the "*Geger boyo*" flank in Kaliadem (Sleman District, Yogyakarta Province) collapsed and *nuées ardentes* occurred until 14th June. The flows moved down the slope through Gendol River (Kaliadem area) and destroyed all vegetation and buildings in its path (Sutomo 2010). Offcourse the Agung Mountain has a different type of eruption with Merapi. Merapi type eruption is unique where it usually in a form of a pyroclastic flows or *nuees ardentes* that originated from a collapsed lava dome at the summit (Bardintzeff 1984), whereas Agung is more of an explosive volcanic type of eruption. The February 1963 to January 1964 eruption of Gunung Agung, Indonesia's largest and most devastating eruption of the twentieth century, was a multi-phase explosive and effusive event that produced both basaltic andesite tephra and andesite lava (Self and Rampino 2012). Perhaps due to this direction of eruption and lava deposit, we can see from the produced map (Figure 2), the northern part of the mountain are mostly seen as no vegetation or medium density vegetation. However, these results could also mean that on the northern part of the Island are probably populated by human which dwell up until along the north coastline.

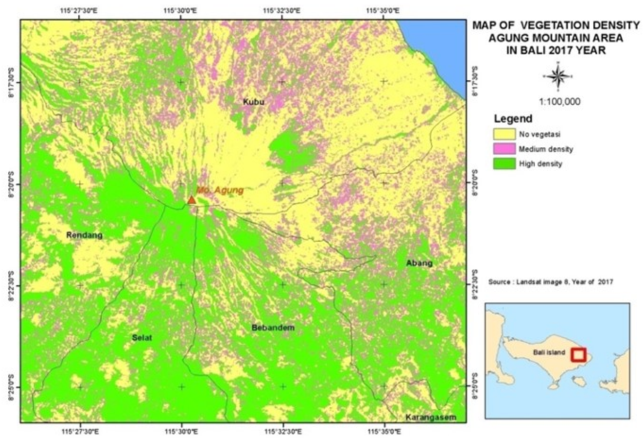

Figure 2. Vegetation density on Mount Agung and surrounding, using Landsat image 8 (2017).

Another approach to see the changes in vegetation cover following the eruption is to focus on the area surrounding the crater of Mt. Agung. Therefore, using web-based GIS application REMAP, we found that there has been an increase (approximately 1 km^2) in vegetation cover from the 1980s to 2016 (Figure 3). Remote sensing has also been applied to study vegetation succession on Mount Merapi. Yuniasih (2017) used NDVI approach to compare vegetation density in two locations of affected by 2010 eruption of Mt. Merapi and one that was not affected by the eruption. The study found that the location that was affected by pyroclastic flows of Merapi eruption have almost similar NDVI with location which was not affected, indicating the existence of the successional process.

It can be inferred from the results (Figure 3) that the rate of vegetation succession on Mt. Agung is slow compared with Mt. Merapi. In the first decade of primary succession, plant re-colonization on Mt. Merapi *nuées ardentes* deposits was rapid, with fifty-six species belonging to 26 families recorded. The highest number of species belonged to the Asteraceae, then Poaceae, followed by Fabaceae and Rubiaceae. The number of species presents varied as

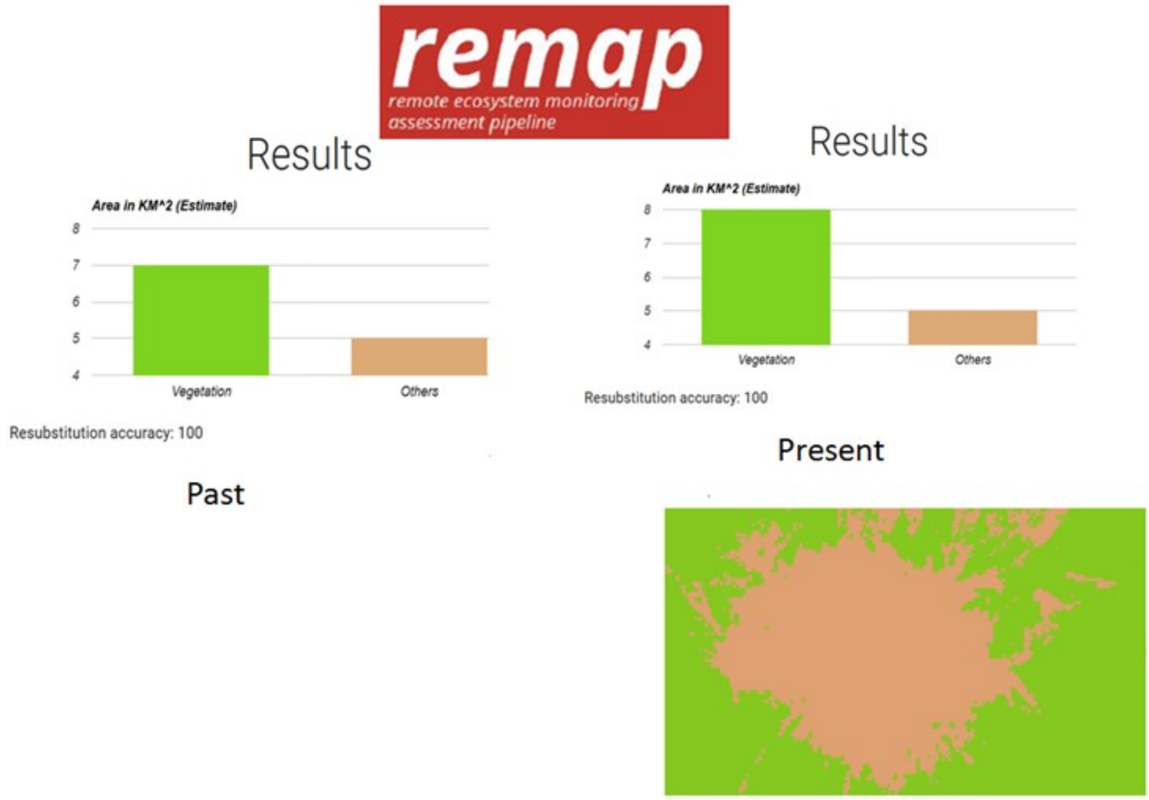

Figure 3. Vegetated areas changes on the surrounding summit (near the crater) of Mount Agung Bali using remap. Past refers to 1980's and present refers to 2016.

the deposit aged, with a rising trend of species richness and diversity over time (Sutomo *et al.* 2011). Unfortunately, studies on vegetation of Mt. Agung post 1970-1980 has been scarce. However, Dilmy (1965), reported that a few months after the 1963 eruption three species of plants were found in the Besakih vicinity on the slope of Mt. Agung namely *Sambucus javanica, Eleusine indica,* and *Ageratum conyzoides*, while all other plants were dead. Antos and Zobel (2005) report that the majority of types of herbs can penetrate to deposits of 4.5 cm or less, but at a depth of more than 15 cm most layers of herbs will die and cannot penetrate. One year later in 1964, Dilmy reported that there were 83 species consists of grasses, herbs, shrubs, and trees were found growing at the elevation of 900 to 1250 m above sea level. Pioneer tree species that Dilmy (1965) found one-year fater the eruption among others were *Albizzia procera, Albizzia montana, Engelhardia spicata, Ficus benjamina, Ficusseptica, Ficus ampelas,* and *Melia azedarach*.

According to Dilmy (1965), these plants were found along dikes and water courses in moist places. This highlight the importance of microsites or safe sites which facilitate pioneer plants to grow. There has been abundance research on safe sites and their importance for seedling recruitment and establishment on a disturbed areas (Eriksson and Ehrlén 1992; Jumpponen *et al.* 1999; Moral and Wood 1993; Tsuyuzaki *et al.* 1997). Sutomo and Hasanbahri (2008) studied pine species (*Pinus merkusii)* recovery in Kaliadem forest of Mt. Merapi which was affected by the 2006 eruption. Needles and stem branches of the pine that fall on the surface of the sediment serves as mulch and helps provide it nutrients needed for pine seedlings to grow. In addition, the morphology of the rocky deposits protects pine seedlings from herbivory by animals. Thus recovery of Pinus in Kaliadem forests already have a good source of seedlings 'capital'.

Another approach that we can use to obtain a description of what plant species constitute on the Mt. Agung areas is by studying expedition records from a nearby botanical garden. "Eka Karya" Bali Botanical Garden-Indonesian Institute of Sciences (LIPI) as a plant conservation unit has conducted series of plant expedition from the 1970s up to 2000s to explore plants species including general taxa and also specific such as an orchid. A summary of the results is displayed in table 1. Among these results, there are seven species that similar to the species that were reported by Dilmy one year after the 1963 eruption namely *Pteridium aquilinum*, *Musa* sp., *Clerodendron serratum*, *Homalomena* sp., *Hibiscus rosa -sinensis*, *Vernoneaarborea*, and *Litsea* sp.

The duration of a succession process will depend on many things but among them is how severe the damage is and how much area is affected, whether there is a biological legacy (such as the source of seeds/location in the location and

Table 1. List of plant species collected from exploration (1970 – 2000) by Bali Botanical Garden on Mount Agung and its surrounding

Collection year	Species name	Family	Location
1970s	*Eria multiflora*	Orchidaceae	Bebandem village
	Phalaenopsis sp.	Orchidaceae	Tihingan, bebandem, karangasem
	Dendrobium sp.	Orchidaceae	Abang village
	Aegle marmelos	Rutaceae	Tista village, Abang
	Acriopsis sp.	Orchidaceae	Batugunung
	Piper sp.	Piperaceae	Batugunung
	Arachnis sp.	Leguminosae	Batugunung
	Vanilla sp.	Orchidaceae	Batugunung
	Musaenda sp.	Rubiaceae	Batugunung
	Opuntia sp.	Cactaceae	Kubu, Karangsem
	Euphorbia sp.	Euph.	Kubu, Karangsem
	Bulbophyllumbiflorum	Orchidaceae	Karangasem
	Dendrobium plicatile	Orchidaceae	Lempuyang Hill
	Appendicula angustifolia	Orchidaceae	Lempuyang Hill
	Dendrobium sp.	Orchidaceae	Lempuyang Hill
	Corimborchis sp.	Orchidaceae	Lempuyang Hill
	Phaius sp.	Orchidaceae	Lempuyang Hill
	Thevetia peruviana	Apoc.	Lempuyang Hill
1980s	*Santalum album*	Santalaceae	BatuGiling, Kubu, Karangasem
	Kalanchoe sp.	Crass.	BatuDewaKubu, Karangasem
	Lygodium sp.	Lygodiaceae	BatuDewa, Kubu, Karangasem
	Clerodendron sp.	Verb.	BatuDewa, Kubu, Karangasem
	Acacia cincinnata.	Leguminosae	abang
	Acacia polystachyaBenth.	Leguminosae	abang
	Caladium sp.	Araceae	abang
	Euchrestahorsfieldii	Leguminosae	abang
	Garcinia dulcis	Clusiaceae	abang
	Begonia sp.	Begoniaceae	abang
	Raphodopora sp.	Araceae	abang
1990s	*Ardisia humilis*	Primulaceae	Gunung Agung Forest
	Syzygium racemosum	Myrtaceae	Gunung Agung Fores
	Phaius tankervilleae	Orchidaceae	Gunung Agung Forest
	Calanthe veratrifolia	Orchidaceae	Gunung Agung Forest
	Goodyera sp.	Orchidaceae	Gunung Agung Forest
	Pandanus tectorius	Pandanaceae	Gunung Agung Forest
	Coelogyne flexousa	Orchidaceae	Gunung Agung Forest
	Dodonaea sp.	Sapindaceae	Gunung Agung Forest
	Pteridium sp.	Pteridaceae	Gunung Agung Forest
	Musa sp.	Musaceae	Gunung Agung Forest
	Platea sp.	Icac.	Gunung Agung Forest
	Dianella sp.	Xanthorrhoeaceae	Gunung Agung Forest
	Orthosiphon aristatus	Lamiaceae	Gunung Agung Forest
	Clematis sp.	Ranunculaceae	Gunung Agung Forest
	Nephrolepis duffii	Nephrolepidaceae	Gunung Agung Forest
	Clerodendron serratum.	Verbenaceae	Gunung Agung Forest
	Asplenium caudatum	Aspleniaceae	Gunung Agung Forest

Table 1. Cont'd.

Collection year	Species name	Family	Location
1990s	*Weinmannia blumei*	Cunoniaceae	Gunung Agung Forest
	Vanda tricolor	Orchidaceae	Gunung Agung Forest
	Dendrobium sagitatum	Orchidaceae	Gunung Agung Forest
	Hippeastrum sp.	Amaryllidaceae	Gunung Agung Forest
	Dendrobium linearifolium	Orchidaceae	Gunung Agung Forest
	Homalomena sp.	Araceae	Gunung Agung Forest
	Anaphalis sp.	Compositae	Gunung Agung Forest
	Phreatia secunda	Orchidaceae	Gunung Agung Forest
	Magnolia champaca	Magnoliaceae	Gunung Agung Forest
	Laplacea amboinensisMiq.	Theaceae	Gunung Agung Forest
	Platea sp.	Icac.	Gunung Agung Forest
2000s	*Mesuaferea*	Clusiaceae	Dsn. Brahma
	Hibiscus sp.	Malvaceae	Dsn. Brahma
	Cajanus cajan	Leguminosae	Dsn. Brahma
	Delichos lablab	Leguminosae	Dsn. Brahma
	Zingiber pupureum	Zingiberaceae	Dsn. Brahma
	Coleus amboinensis	Lamiaceae	Dsn. Brahma
	Michelia sp.	Magnoliaceae	Dsn. Dukuh
	Arenga sp.	Arecaceae	Dsn. Dukuh
	Curcuma sp.	Zingiberaceae	Dsn. Dukuh
	Garcinia mangostana	Clusiaceae	Dsn. Dukuh
	Musa sp.	Musaceae	Dsn. Dukuh
	Parmentiera sp.	Bignoniaceae	Dsn. Dukuh
	Alpiniagalanga .	Zingiberaceae	Dsn. Dukuh
	Curcuma sp.	Zingiberaceae	Dsn. Dukuh
	Zingiberofficinale	Zingiberaceae	Dsn. Dukuh
	Musa paradisiaca	Musaceae	Dsn. Dukuh
	Mangifera caesia	Anac.	Dsn. Dukuh
	Cocos nucifera	Arecaceae	Dsn. Dukuh
	Gmelina arborea	Verb.	Pempatan village, Karangasem
	Gmelina arborea	Verb.	Pempatan village, Karangasem
	Litsea sp.	Laur.	Lebah village, Rendang, Karangasem
	Meliosma sp.	Sab.	Munduk village, Karangasem
	Homalomena sp.	Araceae	Munduk village Karangasem
	Calanthe veratrifolia	Orchid.	Munduk village Karangasem
	Saurauia sp.	Saurauiac.	Munduk village Karangasem
	Ligustrum glomeratum	Anac.	Munduk village, Karangasem
	Trevesia sundaica	Anac.	Munduk village, Karangasem
	Vernonia arborea	Aster.	Munduk village, Karangasem
	Begonia longifolia	Beg.	Munduk village, Karangasem

Source: Plant registration division, Bali Botanical Garden-Indonesian Institute of Sciences (LIPI)

surrounding location) and the presence or absence of ecological intervention. Ecological intervention is human intervention to accelerate the natural succession process. This is called ecosystem restoration. In addition to ecosystem restoration efforts, it is also necessary to monitor or monitor ecosystem dynamics, especially the dynamics of plant vegetation in the volcanic region. Remote sensing technology can be used to monitor vegetation in the volcano area. Satellite image data in different years can be collected and processed for analysis and comparison on whether there is a change in the area of vegetation, whether there is a change in vegetation density or is there a change in the greenness index of vegetation or there may be changes in land use from the vegetation area to the area for other purposes. Given the level of damage and change of land in lowland forests mainly on Java and Bali, it is now undeniable that mountainous/ upland forest areas (including volcanoes) play a very important role and become a place where high biodiversity can still be we find.

Although from the results there has been an improvement in terms of vegetated areas and also increase in species richness over time, however, as the threat of habitat and ecosystem destruction due to the consequences of climate change and anthropogenic disturbance increases, these volcanic-forests highlight the continuing need and importance of research on plant community succession and restoration on a volcanic terrain in Indonesia.

ACKNOWLEDGEMENT

Thanks to Mr. Agung Kurniawan and Rajif Iryadi from Plant Registration Division, Bali Botanical Garden – LIPI for providing the plant collection data.

REFERENCES

Antos, J.A. & Zobel, D.B., 2005, Plant responses in forest of the Tephra-fall zone. In: *Ecological responses to the 1980 eruption of Mount St. Helens* (eds V. H. Dale, F. J. Swanson and C. M. Crisafulli) p. 47. Springer, New York.

Arinasa, I.B.K., 2017, *An Alphabetical List of Plant Species Cultivated in Bali Botanical Garden*. Kebun Raya "Eka Karya" Bali LIPI, Tabanan.

Arno, S.F., Sneck, K.M. & Forest, I., 1977, A method for determining fire history in coniferous forests of the mountain west.

Bardintzeff, J.M., 1984, Merapi Volcano (Java, Indonesia) and Merapi-type *nuees ardentes*. *Bulletin Volcanology* 47.

Chuvieco, E. & Congalton, R.G., 1989, Application of remote sensing and geographic information systems to forest fire hazard mapping. *Remote sensing of Environment* 29, 147-59.

Dilmy, A., 1965, Pioneer plants found one year after the 1963 eruption of Mt. Agung in Bali. *Pacific Science* 19, 498-501.

Eriksson, O. & Ehrlén, J., 1992, Seed and microsite limitation of recruitment in plant populations. *Oecologia* 91, 360-4.

Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D., Lovejoy, T.E., Sexton, J.O., Austin, M.P. & Collins, C.D., 2015, Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances* 1, e1500052.

Jumpponen, A., Väre, H., Mattson, K.G., Ohtonen, R. & Trappe, J.M., 1999, Characterization of 'safe sites' for pioneers in primary succession on recently deglaciated terrain. *Journal of Ecology* 87, 98-105.

Keane, R.E., Burgan, R. & van Wagtendonk, J., 2001, Mapping wildland fuels for fire management across multiple scales: integrating remote sensing, GIS, and biophysical modeling. *International Journal of Wildland Fire* 10, 301-19.

Lillesand, T.M., Kiefer, R.W. & Chipman, J., 2008, *Remote Sensing and Image Interpretation*. John Wiley and Sons, New York.

del Moral, R., & Wood, D.M., 1993, Early primary succession on a barren volcanic plain at Mount St. Helens, Washington. *American Journal of Botany*80, 981-91.

Murray, N.J., Keith, D.A., Simpson, D., Wilshire, J.H. & Lucas, R.M., 2017a, REMAP: An online remote sensing application for land cover classification and monitoring. *bioRxiv*, 212464.

Murray, N.J., Keith, D.A., Simpson, D., Wilshire, J.H. & Lucas, R.M., 2017b, REMAP: The remote sensing ecosystem monitoring and assessment pipeline https://remap-app.org/.

Sankaran, M., 2001, Disturbance, diversity and community dynamics in a southern Indian savanna-grassland ecosystem. In: *Biology* p. 313. Syracuse University, Syracuse, New York.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. & Walker, B., 2001, Catastrophic shifts in ecosystems. *Nature* 413, 591-6.

Self, S. & Rampino, M.R., 2012, The 1963-1964 eruption of Agung volcano (Bali, Indonesia). *Bulletin of Volcanology* 74, 1521-36.

Sutomo, 2010, Plant Succession Following Nuèes Ardentes of Mt. Merapi Volcano, Java Indonesia. In: *Plant Biology* p. 123. University of Western Australia, Perth.

Sutomo, 2013, *Ecological Succession on Volcanic Ecosystem of Mount Merapi Indonesia and Its Implication For Restoration*. SEAMEO-BIOTROP, Bogor.

Sutomo & Hasanbahri, S., 2008, Dampak Bencana Awan Panas Erupsi Merapi Tahun 2006 Terhadap Hutan Pinus di Wilayah Kaliadem Yogyakarta Menggunakan Model Non Metric Multidimensional Scalling Serta Respon dan Harapan Pemulihannya [Disaster Impacts of 2006 Merapi Eruption on Pine Forests in the Kaliadem, Yogyakarta using Non Metric Multidimensional Scaling Model, Response and Hope for Recovery]. *Jurnal Sains dan Teknologi Mitigasi Bencana* 3, 1-8.

Sutomo, Hobbs, R.J. & Cramer, V.A., 2011, Plant community establishment on the volcanic deposit following nuees ardentes of Mount Merapi: diversity and floristic variation. *Biodiversitas* 12, 86-91.

Tsuyuzaki, S., Titus, J.H. & del Moral, R., 1997, Seedling establishment patterns on the pumice plain, Mount St. Helens, Washington. *Journal of Vegetation Science* 8, 727-34.

van Wilgen B., Biggs, H., Mare, N. & O'Regan S., 2000, A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. *South African Journal of Science* 96.

Verlinden, A. & Laamanen, R., 2006, Long term fire scar monitoring with remote sensing in northern namibia: relations between fire frequency, rainfall, land cover, fire management and trees. *Environmental Monitoring and Assessment* 112, 231–53.

Weill, A., 2004, *Volcanoes*. Saddleback educational publishing, California.

Whitten, T., Soeriaatmadja, R.E. & Afiff, S.A., 1996, *The ecology of Indonesia series volume II: The ecology of Java and Bali*. Periplus, Hongkong.

Yuniasih, B., 2017, Succession of vegetation in Merapi Volcano using NDVI index, *Agroista: Jurnal Agroteknologi* 1.