BioOne COMPLETE

Forest Composition and Structure after 200 Years of Succession Following the Eruption of Mount Tambora (Indonesia)

Authors: Sadili, Asep, Hidayat, Arief, Jakalalana, Supardi, Kurniawan, Adi, Sahroni, Deni, et al.

Source: Ecoscience, 29(3) : 191-198

Published By: Centre d'études nordiques, Université Laval

URL: https://doi.org/10.1080/11956860.2021.2010332

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

ÉCOSCIENCE
2022, VOL. 29, NO. 3, 191–198
https://doi.org/10.1080/11956860.2021.2010332

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Forest composition and structure after 200 years of succession following the eruption of Mount Tambora (Indonesia)

Asep Sadili[a], Arief Hidayat[b], Supardi Jakalalana[a], Adi Kurniawan[c], Deni Sahroni[a], Solikin[d] and Francis Q. Brearley[e]

[a]Botany Division, Research Center for Biology, Indonesian Institute of Sciences, Cibinong Science Center, Cibinong, Indonesia; [b]Research Center for Plant Conservation and Botanic Gardens, Indonesian Institute of Sciences, Bogor, Indonesia; [c]Tambora National Park, Directorate General of Natural Resources and Ecosystem Conservation, Ministry of Environment and Forestry of Indonesia, Dompu, Indonesia; [d]Purwodadi Botanical Gardens, Indonesian Institute of Sciences, Pasuruan, Indonesia; [e]Department of Natural Sciences, Manchester Metropolitan University, Manchester, UK

ABSTRACT

We examined the changes in tropical forest diversity, structure and trait composition during primary succession after volcanic disturbance. Whilst many studies have examined early stages of succession, fewer have looked at a precisely dated older location: 200 years old in this instance. To do this, we established a 0.5 ha plot on the lower slopes of Gunung (Mount) Tambora (Sumbawa, Indonesia) in which we enumerated and identified all trees ≥ 10 cm dbh, determined their key traits and calculated forest above-ground biomass. Saplings (1.5–3.0 cm dbh) were enumerated in one quarter of this area. We recorded 214 stems ≥ 10 cm dbh within 21 taxa contributing to an above-ground biomass of 135 Mg ha^{-1}. Most trees had light wood and broad distributions suggestive of early successional traits, but leaves were generally small; most trees were insect pollinated and animal dispersed as expected at later stages of succession. Saplings were variable in their density and showed some floristic similarity with adult trees, but differences indicated the future trajectory of succession. Our floristic and structural data from the poorly studied drier forests of eastern Indonesia show that this 200-year-old forest is still undergoing succession at a slow rate.

RÉSUMÉ

Nous avons examiné les changements de diversité, de structure et de composition des traits dans une forêt tropicale pendant la succession primaire suite à une éruption volcanique. Tandis que plusieurs études ont examiné les premiers stades de la succession, peu se sont attardées à des stades plus avancés: 200 ans dans le cas présent. Pour ce faire, nous avons établi un quadrat de 0,5 ha sur le bas de la pente du Gunung (Mont) Tambora (Sumbawa, Indonésie), à l'intérieur duquel nous avons énuméré et identifié tous les arbres ≥ 10 cm dhp, déterminé leurs traits principaux et calculé la biomasse forestière aérienne. Les gaulis (1,5 – 3,0 cm dhp) ont été dénombrés dans un quart du quadrat. Nous avons relevé 214 tiges ≥ 10 cm dhp appartenant à 21 taxons contribuant à une biomasse aérienne de 135 Mg ha^{-1}. La plupart des arbres avaient du bois clair et une répartition étendue, suggérant des traits de début de succession, mais leurs feuilles étaient généralement petites et la plupart des espèces étaient pollinisées par des insectes et zoochores, tel qu'attendu pour les stades plus avancés de la succession. Les gaulis avaient une densité variable et une certaine similarité floristique avec les arbres adultes. Des différences indiquaient toutefois la future trajectoire successionnelle. Les données floristiques et structurelles que nous avons amassées concernant les forêts sèches peu étudiées de l'est de l'Indonésie montrent que la succession s'y poursuit, à un rythme lent, 200 ans après une éruption volcanique.

ARTICLE HISTORY
Received 28 July 2021
Accepted 21 November 2021

KEYWORDS
Primary succession; seasonal forest; secondary forest; tephra; tropics

MOTS CLÉS
succession primaire; forêt saisonnière; forêt secondaire; téphra; tropiques

Introduction

Volcanic activity is a major disturbance to ecosystems, regularly destroying existing communities and creating new substrates for colonisation. Understanding how vegetation changes following disturbance is a central goal of much ecological research and, thus, succession in volcanic landscapes can be informative in this regard. We have information on changes in species composition and diversity during post-volcanic succession from many sites globally (e.g., Aplet et al. 1998; Kamijo et al. 2002; Dale et al. 2005; Elias and Dias 2007; Walker et al. 2013; Karadimou et al. 2018) including South-east Asian tropical regions such as Indonesia (Whittaker et al. 1989; Sutomo and Cramer 2011), Papua New Guinea (Taylor 1957; Harrison et al. 2001) and the Philippines (Marler and Del Moral 2011, 2018).

Indonesia is an island nation lying on the 'Ring of Fire' and, as such, much of the country has been, and continues to be, influenced by volcanic processes from one

CONTACT Francis Q. Brearley f.q.brearley@mmu.ac.uk Department of Natural Sciences, Manchester Metropolitan University, Manchester M1 5GD, UK

© 2021 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

of the many active volcanoes present. Whilst post-disturbance secondary forests have been well-studied across Indonesia (e.g., Brearley et al. 2004; Samsoedin and Heriyanto 2010; Stas et al. 2017) primary succession has been less well studied although described from Gunung (Mount) Merapi on Java (Sutomo and Cramer 2011) and the particularly well-known Krakatau Islands (Whittaker et al. 1989; Thornton 1996). Furthermore, the forests of western Indonesia have been much better studied than the drier forests of the south-eastern regions of the country (Brearley et al. 2019) with only a few quantitative floristic studies from these seasonal forests (Laumonier and Nasi 2018; Mansur 2020; Sutomo et al. 2020).

The April 1815 eruption of Gunung Tambora was one of the most powerful and destructive in recorded history with a huge amount of material released into the atmosphere leading to subsequent global climatic anomalies and the infamous 'year without a summer' (Stothers 1984; de Jong Boers 1995; Oppenheimer 2003). More locally, areas in the immediate vicinity of the volcano were subject to extremely destructive pyroclastic flows and likely completed destroyed and sterilised. The eruption formed the largest caldera in Indonesia with a diameter 6 to 7 kilometres, a depth of about 950 m and with the highest point of the crater rim 2850 m above sea level. The area around Gunung Tambora was designated a conservation area since 1937 and, in commemorating the 200th anniversary of the eruption, Gunung Tambora National Park with an area of 71,646 hectares, was inaugurated on 11 April 2015. The national park is one of the youngest national parks in Indonesia and research is still minimal (Santika and Hidayat 2017); therefore, the aim of this study was to describe the vegetation structure, species diversity and species traits on the northern slopes of the volcano within the national park. Our study provides data on forest composition in an area of Indonesia that is generally poorly studied and leads to improved knowledge on post-volcanic tropical forest succession more generally.

Methods

Study site

Gunung Tambora is found in north-central Sumbawa, an island in the Lesser Sunda chain of Indonesia, where it forms the majority of the Sanggar peninsula. Mean annual precipitation is poorly documented but is around 1600 to 2200 mm and seasonal, with the greatest rainfall in January and the driest month in July with the climate classified as Köppen's Aw; precipitation appears to increase with elevation on the mountain. The research location is lowland forest at Kawinda To'i Village (Tambora District, Bima Regency, Nusa Tenggara Barat Province). The study site is about 1 km east of the Oi Maray river near the border of the National Park (8° 07′00″S 118°01′24″E) at an altitude of 50 m a.m.s.l. The volcanic deposits under the forest may be tens of metres thick composed of layers of pyroclastic flows, ash and pumice from trachyandesitic lava (Self et al. 1984; Sigurdsson and Carey 1989; Sutawidjaja et al. 2006).

Field sampling

We established a permanent sampling plot measuring 50 m x 100 m (0.5 ha), with 50 subplots of 10 m x 10 m, in which all trees ≥ 10 cm dbh (diameter at breast height; 1.3 m) were recorded; lianas were not present and thus not enumerated. The plot was located in undisturbed forest considered representative of the north side of the volcano and close to a path to the summit. The slope was about 10° with the plot long axis running perpendicular to it. We marked each tree permanently with an aluminium tag and recorded their diameters (at 1.3 m) using a measuring tape or taking the measurement 10 cm above the buttress for buttressed trees. Tree height was measured using a Haga meter. Each individual was identified with the aid of local assistants using the name of the species in the local (Bima) language. Voucher specimens were then collected for subsequent naming at Herbarium Bogoriense where the vouchers were deposited. Most individuals (86%) could be identified to species with two taxa identified to genus only. For saplings, (diameter 1.5 to 3.0 cm) we recorded all individuals in a 5 m x 5 m area within each larger 10 × 10 m subplot. Again, 86% could be identified to species with two taxa (one of which was the same as above) identified to genus only.

Analyses

We calculated species diversity metrics (Chao1, Fisher's alpha, Shannon-Wiener) for all trees ≥ 10 cm dbh using the equations in Colwell (2009) and the importance value index (IVI) according to Mueller-Dombois and Ellenberg (1974). For plant traits, we used the Global Wood Density database of Zanne et al. (2009) (the genus mean was used for four species) and measured leaf area (length x width x ⅔; Li et al. 2020) on herbarium specimens using the median leaf area (on a mean of 28.7 ± SD 13.9 leaves) to categorise leaf sizes according to Webb (1959). Species' distributions were assessed by reference to Plants of the World Online (POWO 2020) and pollination and dispersal syndromes were assessed

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

by reference to relevant literature. To estimate forest above-ground biomass, the pan-tropical M4 allometric equation of Chave et al. (2014) was used, as well as that of Stas et al. (2017) which was developed for old secondary forest on Seram and is therefore more appropriate biogeographically (Anitha et al. 2015).

Results

In the half-a-hectare permanent sampling plot, we enumerated 214 stems ≥ 10 cm dbh within 21 'species' and 14 families (Table 1). The most abundant species were *Palaquium amboinense* (Sapotaceae), *Mallotus philippensis* (Euphorbiaceae) and *Alstonia spectabilis* (Apocynaceae), and the family with most species was Malvaceae (four species) followed by Euphorbiaceae (three species) (Table 1). All trees could be identified to genus but there was an unidentified *Syzygium* (Myrtaceae) and *Mallotus* (Euphorbiaceae) species that were both fairly common. Fisher's alpha was 5.77 and Shannon-Wiener H' was 2.45. Our sampling area appeared to be sufficient as the species area curve levelled off (Figure 1(a)) but the Chao 1 estimate of species richness was 48 species, as we had a relatively large number (8) of singletons (Figure 1(b)).

The stem size abundance showed a typical distribution for tropical forests (Figure 2(a)); there were only three stems greater than 60 cm dbh: one each of *Alstonia scholaris* (Apocynaceae), *Ficus racemosa* (Moraceae) and *Palaquium amboinense*. The five most important species (i.e., greatest IVI) had contrasting stem size distributions: *Palaquium amboinense* and

Table 1. Abundance and characteristics of tree species in a 0.5 ha sampling plot in a secondary forest on a 200-year-old volcanic substrate in Gunung Tambora National Park (Sumbawa, Indonesia). Species are ranked by their importance value index (IVI). * = genus mean wood density.

Species	Family	Bima name	No. Stems	IVI	Mean (± s.d.) diameter (cm)	Wood density (g cm^{-2})	Leaf size
Palaquium amboinense	Sapotaceae	Katowi	34	56.40	27.0 ± 11.9	0.38	Notophyll
Mallotus philippensis	Euphorbiaceae	Safiru doro	39	41.01	16.3 ± 3.7	0.60	Microphyll
Alstonia spectabilis	Apocynaceae	Tula	28	35.24	19.6 ± 6.6	0.63	Mesophyll
Syzygium sp.	Myrtaceae	Monggo merah	19	33.44	29.6 ± 13.5	0.67*	Notophyll
Ficus racemosa	Moraceae	Na'a	12	28.92	43.4 ± 15.0	0.36	Microphyll
Grewia eriocarpa	Malvaceae	Rino kafa	21	22.59	14.2 ± 2.2	0.67	Microphyll
Schleichera oleosa	Sapindaceae	Kusambi	16	21.06	22.5 ± 8.9	0.90	Microphyll
Alstonia scholaris	Apocynaceae	Rida	10	16.47	22.1 ± 15.0	0.38	Mesophyll
Mallotus sp.	Euphorbiaceae	Safiri	12	11.35	15.0 ± 2.7	0.50*	Mesophyll
Buchanania arborescens	Anacardiaceae	Pato	6	9.37	27.9 ± 5.5	0.45	Notophyll
Pterospermum diversifolium	Malvaceae	Sala	4	5.39	19.6 ± 8.6	0.57	Notophyll
Gmelina asiatica	Lamiaceae	Kenanga	3	4.01	21.4 ± 8,6	0.47*	Microphyll
Ficus hispida	Moraceae	Mpusu	2	2.70	14.2 ± 3.0	0.38	Mesophyll
Schoutenia ovata	Malvaceae	Luhu/ Walikunkun	1	1.99	-	0.79	Microphyll
Protium javanicum	Burseraceae	Loa ketimis	1	1.78	-	0.75	Microphyll
Exocarpos latifolius	Santalaceae	Ncawu wera	1	1.69	-	0.86	Microphyll
Phyllanthus emblica	Phyllanthaceae	Sarume maju	1	1.40	-	0.64	Leptophyll
Homalanthus giganteus	Euphorbiaceae	Danta dolo	1	1.30	-	0.28*	Mesophyll
Diospyros maritima	Ebenaceae	Haju api	1	1.29	-	0.56	Notophyll
Glochidion zeylanicum var. *arborescens*	Phyllanthaceae	Mbune	1	1.29	-	0.52	Microphyll
Kleinhovia hospita	Malvaceae	Ntana mee	1	1.29	-	0.43	Notophyll

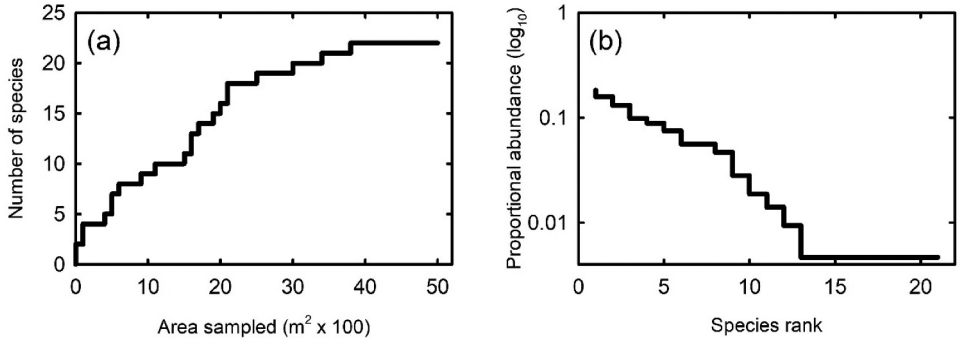


Figure 1. (a) Species-area and (b) rank abundance curve for trees in a secondary forest on a 200-year-old volcanic substrate in Gunung Tambora National Park (Sumbawa, Indonesia).

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

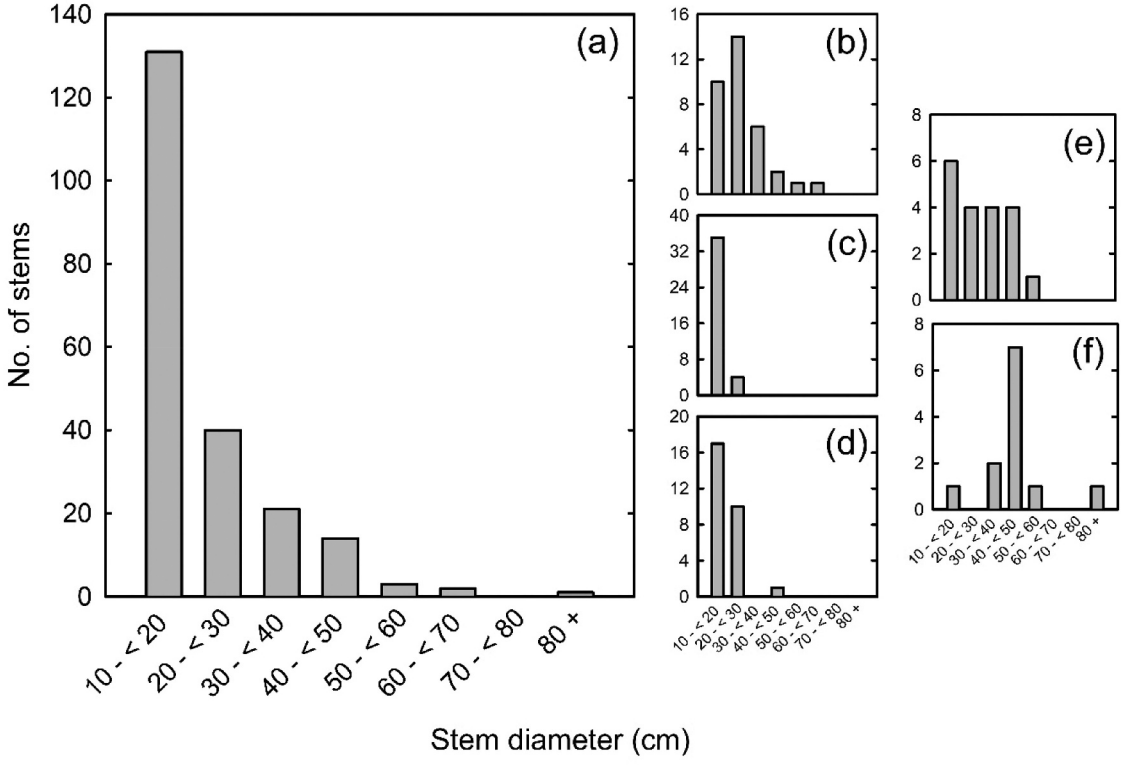


Figure 2. Stem diameter distribution for trees in a secondary forest on a 200-year-old volcanic substrate in Gunung Tambora National Park (Sumbawa, Indonesia). Panel (a) shows all trees, whereas panels (b) to (f) show diameter distributions for the five most important (i.e., with greatest IVI) species: (b) *Palaquium amboinense* (c) *Mallotus philippensis* (d) *Alstonia spectabilis* (e) *Syzygium* sp. and (f) *Ficus racemosa* (note different scales on the y-axis for each species).

Syzygium sp. showed typical distributions (Figure 2(b,e)) although there were fewer trees in the smallest size class for *Palaquium amboinense* (Figure 2(b)); *Mallotus philippensis* was truncated towards the smaller size classes (Figure 2(c)), as was *Alstonia spectabilis* indicating more recent colonisation and/or generally smaller trees (Figure 2(d)); *Ficus racemosa* showed a random distribution across the tree size classes (Figure 2(f)).

Forest basal area was 20.8 m^2 ha^{-1} and above-ground biomass was 135 Mg ha^{-1} using the equation of Chave et al. (2014), which was very similar to 142 Mg ha^{-1} using the Stas et al. (2017) equation; the species that contributed most to the forest biomass were *Palaquium amboinense* and *Syzygium* sp. The forest canopy height was approximately 20 m with some emergents, which were mostly *Palaquium amboinense* or *Syzygium* sp., up to 27 m tall.

About half of the species, and stems, had microphyllous leaves and around 40% were light wooded (i.e., less than 0.50 g cm^{-3}). The median leaf size across all stems was notophyllous and the mean wood density was 0.57 g cm^{-3} (Table 1). Two-thirds of the species had broad distributions that also included areas outside of Malesia; in many cases these included India, China and/or Australia. Some of these species (three) had an eastern Malesian centre to their distribution extending into Australia or the Solomon Islands whilst another group (two species) showed a dry tropical, but disjunct, distribution including the Lesser Sunda Islands and Indochina. Just two species, *Homalanthus giganteus* (Euphorbiaceae) and *Protium javanicum* (Burseraceae), had distributions restricted to Java and the Lesser Sunda Islands only. There was one naturalised species (*Gmelina asiatica*; Lamiaceae). *Mallotus* species appear to have attributes of wind-pollinated species whereas the rest of the species were insect pollinated. Similarly, the two *Alstonia* species were wind dispersed whilst the rest of the species were dispersed by a range of birds and small and large mammals.

Within one-quarter of the plot, we recorded 63 saplings (1.5 to 3.0 cm dbh) equivalent to 504 saplings ha^{-2} although variation between subplots was high. Fourteen out of the 21 taxa present as adults (i.e., ≥ 10 cm dbh) were also present as saplings along with five others not found as adults. The most abundant sapling species was *Grewia eriocarpa* (Malvaceae) followed by *Palaquium amboinense* and *Syzygium* sp., and then *Leea aequata* (Vitaceae) that was not present as an adult (Figure 3).

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

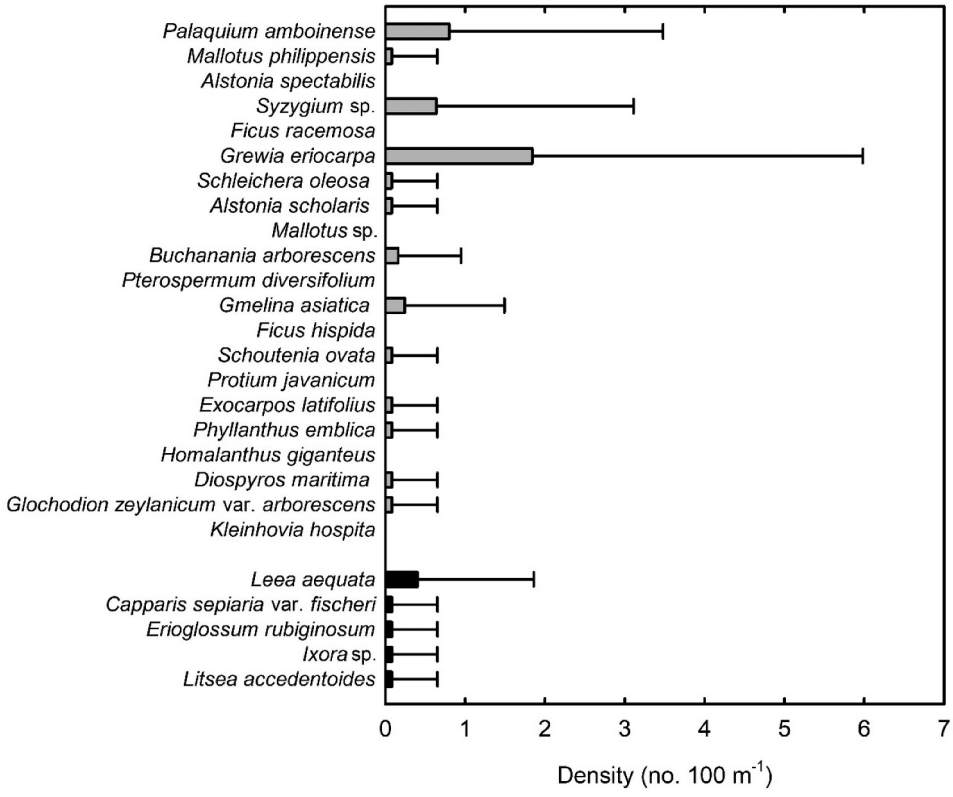


Figure 3. Sapling (1.5 to 3.0 cm dbh) density (mean ± standard error) in a secondary forest on a 200-year-old volcanic substrate in Gunung Tambora National Park (Sumbawa, Indonesia). Species are ranked according to their IVI as adults with those not present as adults depicted with black bars.

Discussion

The forest on a 200-year-old volcanic substrate that we studied on the northern slopes of Gunung Tambora in Indonesia is still undergoing succession. The tree diversity (Fisher's alpha of ca. 6) was very low when considering other forests of Sundaland (Brearley et al. 2004), Sulawesi (Trethowan et al. 2020) and Seram (Edwards et al. 1993) – indeed, this value is more typical of montane forests across Indonesia (Sulistyawati et al. 2018). Succession appears to be slow on Tambora with the landscape described as 'fairly barren' in 1933, more than 100 years after the colossal eruption (de Jong Boers 1995, in de Jong Boers 1995). In some ways the area is isolated being at the end of a peninsula and surrounded by water on three sides, although some of the western Sanggar peninsular was not influenced by pyroclastic flows (Sigurdsson and Carey 1989) leaving potential re-colonisation nuclei. In comparison with the tree communities in other post-eruption successional environments, the communities in small plots (0.04 ha) on Long Island in Papua New Guinea (trees > ca. 5 cm dbh) showed a tree diversity (Fisher's alpha) similar or lower than the current study (Harrison et al. 2001). Although the eruption was about 350 years ago on Long Island, the island is much more remote than Tambora (ca. 50 km from the mainland) leading to a slower recovery of the tree flora. Data from two plots (0.5 ha) at Ujung Kulon in west Java, near the location of the 1883 Krakatau eruption, had notably higher Fisher's alpha diversity (15.0 and 23.7) although this site likely just experienced heavy ash fall rather than extensive tree mortality from pyroclastic flows (Purwaningsih and Atikah 2018). Additionally, biomass of the Tambora dry forest at around 140 Mg ha^{-1} is also low; the nearest comparable forest is a montane forest (0.18 ha studied) in west Sumbawa with nearly three times this biomass (Mansur and Kartawinata 2017). However, biomass is similar to a disturbed dry forest on Lombok with 122 Mg ha^{-1} (0.64 ha; Mansur 2020) and 50-year-old secondary forest on Seram (1 ha; 140 Mg ha^{-1}; Stas et al. 2017) but much lower than a similar aged forest on Borneo (0.75 ha; 358 Mg ha^{-1}; Brearley et al. 2004). Similarly, Li et al. (2018), showed, through remote sensing analysis that vegetation NDVI (as a broad measure of productivity) was still showing

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

a linear increase up to 140 years after eruptions on three tropical African volcanoes indicating that they had not yet reached their maximum biomass.

We established our study plot exactly 200 years after the eruption of Gunung Tambora meaning that we obviously missed enumerating the earlier vegetation communities but we can make inferences regarding the recent successional processes. The composition of saplings is broadly similar to the trees indicating that change in the tree community is likely to be slow but there are some notable contrasts such as lack of saplings of *Alstonia spectabilis* and poor regeneration for *Mallotus philippensis*, both of which were common as adults; in contrast, *Grewia eriocarpa* had a high density of saplings that may persist to later stages of succession. The presence of a large proportion of broadly distributed trees is indicative of a generalist community and the generally light-wooded community is confirms the forest is still undergoing succession. In contrast, wind pollination and wind dispersal are notable traits at the earliest stages of succession (Tsuyuzaki and Del Moral 1995; Karadimou et al. 2018) and there was only a small proportion of wind-pollinated (*Mallotus* species) or wind-dispersed (*Alstonia* species) trees among the community. The large proportion of trees with microphyllous leaves is indicative of a drier forest community in contrast to wetter Malesian forests with mostly notophylls or mesophylls (Becker et al. 1999; Milliken and Proctor 1999). The generally small leaves may also go some way to explaining the slow rate of forest succession if primary productivity, linked to leaf size (Li et al. 2020), is reduced compared to larger-leaved forests. As succession proceeds, we would expect forest biomass and species richness to increase although it is difficult to predict the course of succession as there are few studied 'reference' forests for comparison.

Although there are studies on similarly-aged tropical forest in Hawaii' (Aplet et al. 1998; Kitayama et al. 1995) It is difficult to make comparisons with other areas of biogeographically related forest as Sumbawa has been poorly studied floristically in comparison with other Indonesian Islands (Brearley et al. 2019). Previous studies on the vegetation of Sumbawa have been conducted by Kostermans (1965) and Wiriadinata et al. (2013) among others, but there have been few quantitative studies save that of Mansur and Kartawinata (2017) at Gunung (Mount) Batulanteh in western Sumbawa which is notably wetter than Tambora. There is also floristic information from Lombok (Mansur 2020; Sutomo et al. 2021) which has dry forest and is therefore more comparable to our study site. Six tree species found in our Tambora forest community were also found at Gunung Batulanteh (Mansur and Kartawinata 2017) but only in the secondary forests they studied, not the disturbed primary forest, further confirming the secondary nature of the forests on Gunung Tambora.

In conclusion, the primary successional process in this dry forest on Gunung Tambora appears be slow as the species diversity and biomass accumulation is low compared to other comparable Malesian forests and the species composition and their traits show indications of a forest still undergoing succession. Succession post volcanic eruption may even take thousands of years as Takeuchi (2005) found a forest on the island of Ambitle (Papua New Guinea) influenced by a volcano that last erupted over 2000 years ago still dominated by early successional species. We hope to continue re-measurements of the Tambora plot for the foreseeable future and provide valuable ongoing data on tropical primary successional processes.

Acknowledgments

We thank the head of LIPI Biology Research Center, Head of the Botany Division and colleagues on the expedition to Gunung Tambora: Awal Riyanto, Cahyo Rahmadi, Dwi Narko, Dumin Ullo, Emul, Hari Nugroho, Hari Sutrisno, Heddy Juslistiono, Mulyadi, Mulyadi, Tri Haryoko, Yessi Santika and Yuli Fitriana. Appreciation and gratitude are also extended to the Gunung Tambora National Park staff and field helpers Anton and Suherman.

Data availability

Data will be deposited at ForestPlots.net.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Fieldwork was funded by the Indonesian government through the DIPA Center for Biological Research – Indonesian Institute of Sciences (LIPI) [34.00.001.011]. F.Q.B. additionally thanks NERC [NERC NE/T002050/1] for financial support.

References

Anitha K, Verchot LV, Joseph S, Herold M, Manuri S, Avitabile V. 2015. A review of forest and tree plantation biomass equations in Indonesia. Ann For Sci. 72:981–997. doi:10.1007/s13595-015-0507-4

Aplet GH, Hughes RF, Vitousek PM. 1998. Ecosystem development on Hawaiian lava flows: biomass and species composition. J Veg Sci. 9:17–26. doi:10.2307/3237219

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Becker P, Davies SJ, Moksin M, Ismail MZH, Simanjuntak PM. 1999. Leaf size distributions of understorey plants in mixed dipterocarp and heath forests of Brunei. J Trop Ecol. 15:123–128. doi:10.1017/S026646749900070X

Brearley FQ, Adinugroho WC, Cámara-Leret R, Krisnawati H, Ledo A, Qie L, Smith TEL, Aini F, Garnier F, Lestari NS, et al. 2019. Opportunities and challenges for an Indonesian forest monitoring network. Ann For Sci. 76:54. doi:10.1007/s13595-019-0840-0

Brearley FQ, Prajadinata S, Kidd PS, Proctor J, Suriantata. 2004. Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. Forest Ecol Manag. 195:385–397. doi:10.1016/j.foreco.2004.02.048

Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, et al. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biol. 20:3177–3190. doi:10.1111/gcb.12629

Colwell RK. 2009. Biodiversity: concepts, patterns, and measurement. In: Levin SA, editor. The Princeton guide to ecology. Princeton (NJ): Princeton University Press; p. 257–263.

Dale VH, Swanson FJ, Crisafulli CM. 2005. Ecological responses to the 1980 eruption of Mount St. Helens. New York (NY): Springer.

de Jong Boers B. 1995. Mount Tambora in 1815: a volcanic eruption in Indonesia and its aftermath. Indonesia. 60:37–60. doi:10.2307/3351140

Edwards ID, Proctor J, Riswan S. 1993. Rain forest types in the Manusela National Park. In: Edwards ID, Proctor J, and Macdonald AA, editors. Natural history of seram. Andover (UK): Intercept Ltd; p. 63–74.

Elias RB, Dias E. 2007. The role of habitat features in a primary succession. Arquipélago Ciências Biológicas e Marinhas. 24:1–10.

Harrison RD, Banka R, Thornton IWB, Shanahan M, Yamuna R. 2001. Colonization of an island volcano, Long Island, Papua New Guinea, and an emergent island, Motmot, in its caldera lake. II. The vascular flora. J Biogeogr. 28:1311–1337. doi:10.1046/j.1365-2699.2001.2811121311.x

Kamijo T, Kitayama K, Sugawara A, Urushimichi S, Sasai K. 2002. Primary succession of the warm-temperate broad-leaved forest on a volcanic Island, Miyake-jima, Japan. Folia Geobot. 37:71–91. doi:10.1007/BF02803192

Karadimou E, Kallimanis AS, Tsiripidis I, Raus T, Bergmeier E, Dimopoulos P. 2018. Functional diversity changes over 100 yr of primary succession on a volcanic island: insights into assembly processes. Ecosphere. 9:e02374. doi:10.1002/ecs2.2374

Kitayama K, Mueller-Dombois D, Vitousek PM. 1995. Primary succession of Hawaiian montane rain forest on a chronosequence of eight lava flows. J Veg Sci. 6:211–222. doi:10.2307/3236216

Kostermans AJGH. 1965. Notes on the vegetation of W. Sumbawa (Indonesia). In: Kostermans AJGH, Fosberg FR, editors. Symposium on ecological research in humid tropics vegetation, Kuching, Sarawak, June 1963. Bangkok, Thailand: UNESCO Science Cooperation Office for Southeast Asia; p. 15–25.

Laumonier Y, Nasi R. 2018. The last natural seasonal forests of Indonesia: implications for forest management and conservation. Appl Veg Sci. 21:461–476. doi:10.1111/avsc.12377

Li L, Bakelants L, Solana C, Canters F, Kervyn M. 2018. Dating lava flows of tropical volcanoes by means of spatial modeling of vegetation recovery. Earth Surf Proc Land. 43:840–856. doi:10.1002/esp.4284

Li Y, Reich PB, Schmid B, Shrestha N, Feng X, Lyu T, Maitner BS, Xu X, Li Y, Zou D, et al. 2020. Leaf size of woody dicots predicts ecosystem primary productivity. Ecol Lett. 23:1003–1013. doi:10.1111/ele.13503

Mansur M. 2020. Vegetasi pohon dan persebarannya di Taman Wisata Alam Gunung Tunak dan hutan keramat Mandalika, Lombok Tengah, provinsi Nusa Tenggara Barat. Ber Biol. 19:185–195. doi:10.14203/beritabiologi.v19i2.3867

Mansur M, Kartawinata K. 2017. Phytosociology of a lower montane forest on Mt. Batulanteh, Sumbawa, Indonesia. Reinwardtia. 16:77–92. doi:10.14203/reinwardtia.v16i2.3369

Marler TE, Del Moral R. 2011. Primary succession along an elevation gradient 15 years after the eruption of Mount Pinatubo, Luzon, Philippines. Pacific Sci. 65:157–173. doi:10.2984/65.2.157

Marler TE, Del Moral R. 2018. Increasing topographic influence on vegetation structure during primary succession. Plant Ecol. 219:1009–1020. doi:10.1007/s11258-018-0853-z

Milliken W, Proctor J. 1999. Montane forest in Dumoga Bone National Park, north Sulawesi. Edinb J Bot. 56:449–458. doi:10.1017/S0960428600001372

Mueller-Dombois D, Ellenberg H. 1974. Aims and methods of vegetation ecology. New York (NY): John Wiley & Sons Inc.

Oppenheimer C. 2003. Climatic, environmental and human consequences of the largest known historic eruption: Tambora volcano (Indonesia) 1815. Prog Phys Geog. 27:230–259. doi:10.1191/0309133303pp379ra

POWO. 2020. Plants of the world online. http://www.plantsoftheworldonline.org.

Purwaningsih P, Atikah TD. 2018. Diversitas floristik dan struktur vegetasi di hutan Gunung Payung, Taman Nasional Ujung Kulon. Ber Biol. 17:335–349. doi:10.14203/beritabiologi.v17i3.3434

Samsoedin I, Heriyanto NM. 2010. Struktur dan komposisi hutan pamah bekas tebangan ilegal di kelompok hutan Sei Lepan, Sei Serdang, Taman Nasional Gunung Leuser, Sumatera Utara. J Penelit Hutan Konserv Alam. 8:299–314. doi:10.20886/jphka.2010.7.3.299-314

Santika Y, Hidayat A. 2017. Keanekaragaman tumbuhan tinggi dan paku-pakuan di Gunung Tambora, Sumbawa, Nusa Tenggara Barat: 200 tahun setelah letusan dan potensinya. Pros Semin Nas Masy Biodivers Indones. 3:194–198. doi:10.13057/psnmbi/m030205

Self S, Rampino MR, Newton MS, Wolff JA. 1984. Volcanological study of the great Tambora eruption of 1815. Geology. 12:659–663. doi:10.1130/0091-7613(1984)12<659:VSOTGT>2.0.CO;2

Sigurdsson H, Carey S. 1989. Plinian and co-ignimbrite tephra from the 1815 eruption of Tambora volcano. Bull Volcanol. 51:243–270. doi:10.1007/BF01073515

Stas SM, Rutishauser E, Chave J, Anten NPR, Laumonier Y. 2017. Estimating the aboveground biomass in an old secondary forest on limestone in the Moluccas, Indonesia: comparing locally developed versus existing allometric models. For Ecol Manag. 389:27–34. doi:10.1016/j.foreco.2016.12.010

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Stothers RB. 1984. The great Tambora eruption in 1815 and its aftermath. Science. 224:1191–1198. doi:10.1126/science.224.4654.1191

Sulistyawati E, Nasution T, Rosleine D, Putra DC. 2018. Tree community structure and composition of a one-hectare permanent plot in the montane zone of Mount Kerinci, Kerinci Seblat National Park, Jambi. J Math Fund Sci. 50:315–331. doi:10.5614/j.math.fund.sci.2018.50.3.7

Sutawidjaja IS, Sigurdsson H, Abrams L. 2006. Characterization of volcanic deposits and geoarchaeological studies from the 1815 eruption of Tambora volcano. J Geol Indones. 1:49–57. doi:10.17014/ijog.vol1no1.20066a

Sutomo HR, Cramer V. 2011. Plant community establishment on the volcanic deposits following the 2006 *nuées ardentes* (pyroclastic flows) of Mount Merapi: diversity and floristic variation. Biodiversitas. 12:86–91. doi:10.13057/biodiv/d120205

Sutomo S, Darma IDP, Iryadi R. 2020. The dissimilarity in plant species composition of savanna ecosystem along the elevation gradient on Flores Island, East Nusa Tenggara, Indonesia. Biodiversitas. 21:492–496. doi:10.13057/biodiv/d210209

Sutomo, van Etten E, Iryadi R. 2021. Savanna-forest boundary on Mount Rinjani, Lombok Island, West Nusa Tenggara, Indonesia. Biodiversitas. 22:726–731. doi:10.13057/biodiv/d220225

Takeuchi W. 2005. Floristic notes from a Holocene successional environment in Papuasia. Harv Pap Bot. 10:95–116. doi:10.3100/1043-4534(2005)10[95:FNFAHS]2.0.CO;2

Taylor BW. 1957. Plant succession on recent volcanoes in Papua. J Ecol. 45:233–243. doi:10.2307/2257087

Thornton IWB. 1996. Krakatau: the destruction and reassembly of an Island ecosystem. Cambridge (MA): Harvard University Press.

Trethowan LA, Eiserhardt WL, Girmansyah D, Kintamani E, Utteridge TMA, Brearley FQ. 2020. Floristics of forests across low nutrient soils in Sulawesi, Indonesia. Biotropica. 52:1309–1318. doi:10.1111/btp.12838

Tsuyuzaki S, Del Moral R. 1995. Species attributes in early primary succession on volcanoes. J Veg Sci. 6:517–522. doi:10.2307/3236350

Walker LR, Sikes DS, Degange AR, Jewett SC, Michaelson G, Talbot SL, Talbot SS, Wang B, Williams JC. 2013. Biological legacies: direct early ecosystem recovery and food web reorganization after a volcanic eruption in Alaska. Écoscience. 20: 240–251 doi:10.2980/20-3-3603. .

Webb LJ. 1959. A physiognomic classification of Australian rain forests. J Ecol. 47:551–570. doi:10.2307/2257290

Whittaker RJ, Bush MB, Richards K. 1989. Plant recolonization and vegetation succession on the Krakatau Islands, Indonesia. Ecol Monogr. 59:59–123. doi:10.2307/2937282

Wiriadinata H, Girmansyah D, Hunter JM, Hoover WS, Kartawinata K. 2013. Floristic study of West Sumbawa, Indonesia. Reinwardtia. 13: 391–404. doi:10.14203/reinwardtia.v13i5.423

Zanne AE, López-González G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J. 2009. Data from: Towards a worldwide wood economics spectrum, v5, Dryad, Dataset. doi:10.5061/dryad.234

Downloaded From: https://complete.bioone.org/journals/Ecoscience on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use