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The Phytosociology of Tree Communities on Two Mounts in Bedugul Highland Tropical Forest, Bali, Indonesia

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Abstract

The forested regions within the Bedugul highland are among the last remaining tropical mountain rainforests in Bali. However, recent development in Bedugul indicates a surge in mass tourism, posing a threat to its diverse plant life due to increased land-use changes and overpopulation. This research aimed to assess the composition and diversity of tree communities within the Bedugul highland forest, focusing on Mt. Pohen and Mt. Tapak. While Mt. Pohen has a history of disturbances, such as establishing a geothermal power plant and forest fires, Mt. Tapak experiences less disruption. The methods included species identification, diversity index calculation, species composition and abundance assessment, and similarity analysis between permanent sample plots (PSPs) from both mounts. The results reveal a clear distinction in tree species composition and abundance between the two PSPs, with certain species unique to either Mt. Pohen or Mt. Tapak. Euphorbiaceae, a pioneer plant family known for its adaptability to disturbed habitats, dominates both mounts. *Crypteronia paniculata* and *Acronychia trifoliata* are the most abundant species on Mt. Pohen, while *Dendrochnide stimulans* dominate on Mt. Tapak. These findings highlight the influence of past disturbances on species composition and the resilience of pioneer species. This research underscores the importance of conserving the Bedugul highland tropical forest by addressing threats such as habitat fragmentation and land-use changes, ensuring the long-term preservation of its unique biodiversity and ecological functions.

Keywords: biodiversity assessment, forest disturbance, highland ecology, Permanent Sample Plot, species composition

1. Introduction

Species are not uniformly distributed or randomly distributed worldwide [1]. Phytosociology, a branch of vegetation science, examines the characteristics, classification, relationships, and distribution of plant communities through methods such as vegetation mapping, environmental monitoring, and natural resource inventories [2,3]. It also explores plant cover dynamics influenced by human activity, climate change, and other factors affecting vegetation development [4]. Analysing plant species composition and diversity is crucial for identifying the key features of plant communities [2]. Plant biodiversity serves as an indicator of an ecosystem's stability and sustainability, shaped by the structure and composition of its vegetation, while also reflecting its economic and cultural significance [5,6]. Forests play a vital role in preserving environmental values, offering protection for land and water systems [7], including preventing soil erosion, mitigating flooding, reducing avalanches, buffering precipitation, capturing atmospheric CO_2, and supporting wildlife [8,9].

The study of plant communities' composition, structure, and diversity has been a significant prerequisite to tracking ecosystem changes and improving its conservation, evaluation, and management [10,11], especially one with a unique but fragile feature. Mountain ecosystems, for example, have specific adaptations and limited species niches, tend to be fragmented, and their physical barriers keep the species from migrating [12]. They are also particularly vulnerable to hydro-climatic variability and change in the lower troposphere [13]. This paper studies tree communities' phytosociology from the Bedugul Highland forest, the last sanctuary for most of Bali Island's biodiversity [14].

Bedugul is a high plateau at the center of Bali island, about 70 km north of Denpasar. The Bedugul region was created from ancient volcanic activity [15], which now resembles an endorheic drainage basin where Bedugul is located. Endorheic drainage basins are areas with no water outlet or river flow outside the area due to their hollow shape. Only a few places have this feature, but Indonesia is fortunate to have several of these regions. The Bedugul endorheic basin is 12 x 7 km^2 and is oval-shaped.

Forest areas in the Bedugul Basin are among the remaining tropical mountain rainforests in Bali, and they play significant roles in maintaining the ecosystem, preventing erosion, preserving biodiversity, and functioning as a water source and buffer zone for the surrounding areas, including the lower regions of Bali [14]. Bedugul has high plant diversity and is also home to the endemic palm species, namely *Pinanga arinasae*, and the unique stand of *Podocarpus imbricatus* [14] Recent developments in Bedugul show that mass tourism is becoming more apparent, disturbing the ecosystem balance. Overpopulation and the increase in land-use change to accommodate mass tourism could put natural vegetation at high risk of habitat losses and increase competition with invasive alien species.

Mount Tapak and Mount Pohen are important highland forests in Bedugul, characterized by high species diversity but vulnerability to disturbances. This study aimed to analyze and compare the species composition and diversity and classify trees based on height and diameter classes in Permanent Sample Plots (PSPs) established on these mounts. Mount Pohen has experienced disturbances such as the construction of a geothermal power plant, which is now non-operational due to a dispute, and a forest fire in 1994. In contrast, the PSP on Mount Tapak represents a relatively undisturbed area with no significant anthropogenic impacts detected.

2. Materials and Methods

The choice of plot location is based on preliminary surveys, literature studies, and the analysis of regional maps and Pleiades satellite imagery of the Bali-Bedugul layer in 2010. One of the criteria is locations that still have intact forest areas. The plot, made with a size of 1 ha with sub-plots of size 20 x 20 m, is based on the results of the area-species and "calibration" curve with a similar area at other locations with permanent sample plots [16,17] The plot is made on slopes between 60° and 70 ° and has an altitude between 1,600 m and 1,700 m (Figure 1). The coordinates of the outermost points of each 1-hectare plot and its subplots were recorded using a Garmin GPS 76CSx device. In total, two hectares of permanent sample plots (PSPs), consisting of fifty 20 × 20 m subplots, were surveyed. Within each subplot, tree species were identified, and their height, diameter, and basal area were measured.

Species identification was conducted at the Herbarium of Hortus Botanicus Baliensis (THBB), located within the "Eka Karya" Bali Botanic Gardens – formerly under LIPI, now integrated into BRIN. A species-area curve was constructed to assess whether the 25 sample plots (each 20 × 20 m) within each PSP adequately captured the tree species richness. Additionally, the Shannon–Wiener diversity index was calculated using the following formula [5]:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where:

H' = Shannon diversity index, S = Number of species in the community

Pi = Proportion of total abundance represented by the species

The data were further analyzed and classified based on tree diameter classes, family proportions, and species composition within each PSP. Using species composition and abundance data, a resemblance matrix was constructed with the Bray-Curtis similarity index [18]. Analysis of Similarity (ANOSIM) was then applied to assess floristic differences between the two PSPs [19]. This analysis gives RANOSIM, ranging from 0 (no different) to 1 (very different). Non-metric Multidimensional Scaling (NMDS) was performed based on the resemblance matrix to visualize patterns in species composition. Additionally, SIMPER (Similarity Percentage) analysis was conducted to identify the species contributing most to

the dissimilarity between PSPs. All multivariate analyses were performed using the PRIMER v6 software package [20].

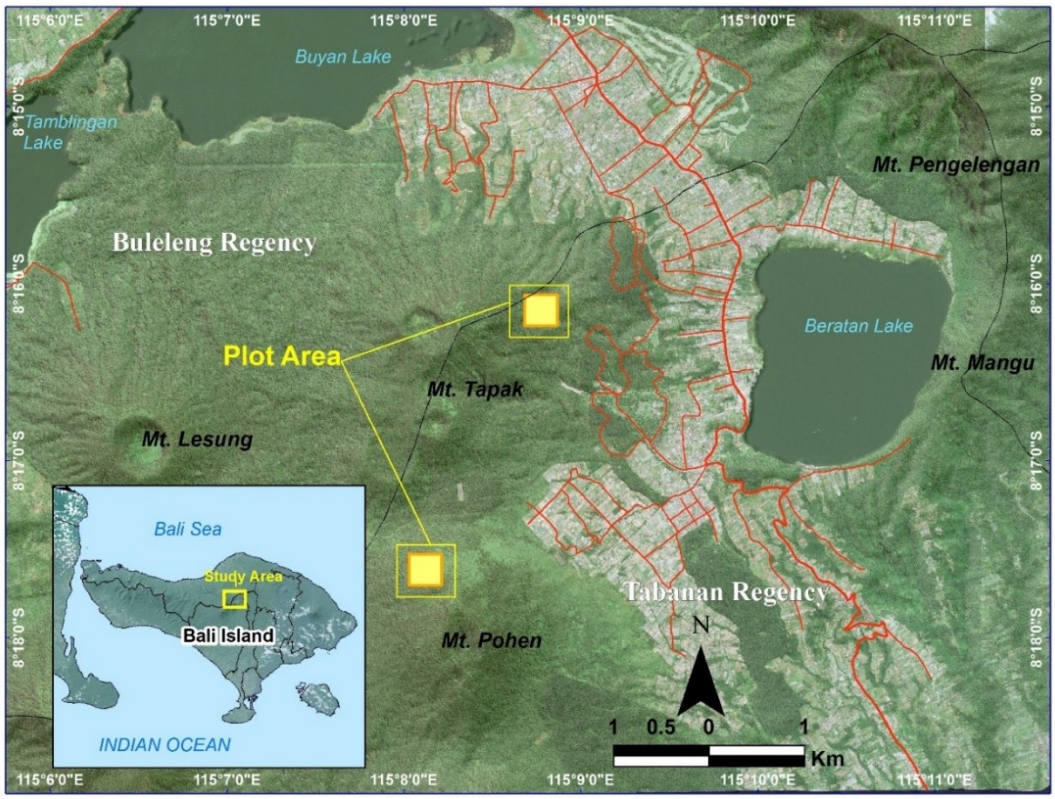


Figure 1. The location of the two PSPs in Bedugul Highland Forest Bali (yellow square).

3. Results and Discussion

3.1. Results

The species-area curve, calculated using the observed species index (Sobs), indicates that the number of sampling plots was sufficient to capture the tree species richness (Figure 2). Species diversity, as measured by the Shannon–Wiener index, was higher in Mount Tapak (2.04) than in Mount Pohen (1.79), as shown in Figure 3. Mount Tapak contained 37 tree species across 23 families, while Mount Pohen had 22 tree species from 19 families. Among the families found in Mount Pohen, Euphorbiaceae had the highest proportion of species (17%), followed by Myrsinaceae (9%). The remaining families each accounted for approximately 4% of the total species. In contrast, species proportions among tree families in the 1-hectare PSP at Mount Tapak were more evenly distributed. Euphorbiaceae, Saxifragaceae, and Myrtaceae each contributed 8% to the total number of species. Other notable families included Cyatheaceae, Elaeocarpaceae, Lauraceae, Myrsinaceae, Rutaceae, Saurauiaceae, Theaceae, and Urticaceae, each comprising 5%, followed by 12 additional families, each representing 3% of the species proportion.

Species area curve calculation using the species observed (sobs) index shows that the number of sampling plots has adequately captured the tree species richness (Figure 2). The species diversity in Mount Tapak (2.04) is superior to Mount Pohen (1.79), as shown in Figure 3. There are 37 tree species within 23 families on Tapak. In contrast, Pohen has 22 tree species with 19 tree families. Of 19 families found on Mount Pohen, only Euphorbiaceae has the most significant proportion (highest number of species), about 17% compared to the other families on Pohen, followed by Myrsinaceae, but only with 9% of the total proportion. The rest of the families share a similar ratio of 4%.

The abundance (individuals) of each species present in a 1 ha PSP on Mount Pohen varies, with *Crypteronia paniculata* and *Acronychia trifoliata* being the most abundant tree species

(89 individuals), followed by *Polyosma integrifolia* (84), *Lophopetalum javanicum* (58), *Podocarpus imbricatus* (42) and *Homalanthus giganteus* (41). In contrast, on Mount Tapak, *Dendrochnide stimulans* is the most abundant tree species (112 individuals), with *Homalanthus giganteus* (56), *Meliosma ferruginea* (36), *Trema orientalis* (32), and *Vernonia arborea* (31) also being relatively abundant. These differences in species abundance between the two mounts highlight variations in ecological conditions and possible influences of past disturbances.

On Mount Pohen, most trees fall within the 11–20 cm diameter class, with dominant species including *Acronychia trifoliata*, *Claoxylon* sp., *Celtis* sp., *Crypteronia paniculata*, *Engelhardia spicata*, *Ficus* sp., *Glochidion rubrum*, *Gordonia amboinensis*, *Litsea* sp., *Lophopetalum javanicum*, *Myrsine hasseltii*, *Homalanthus giganteus*, *Polyosma integrifolia*, *Sloanea siguns*, *Symplocos* sp., and *Vernonia arborea*. The largest tree diameters were recorded for *Podocarpus imbricatus* and *Casuarina junghuhniana*, reaching up to 122.6 cm. This variation reflects diverse growth patterns and species composition in the forest ecosystem

Similarly, on Mount Tapak, trees within the 11–20 cm diameter class dominate, with species such as *Acronychia trifoliata*, *Adinandra* sp., *Claoxylon* sp., *Cyathea contaminans*, *Cyathea latebrosa*, *Dendrocnide stimulans*, *Dichroa febrifuga*, *Ehretia javanica*, *Engelhardia spicata*, *Ficus fistulosa*, *Glochidion rubrum*, *Gordonia amboinensis*, *Helicia* sp., *Lindera* sp., *Meliosma ferruginea*, *Myrsine hasseltii*, *Homalanthus giganteus*, *Polyosma integrifolia*, *Prunus* sp., *Saurauia reinwardtiana*, *Syzygium racemosum*, *Syzygium zollingerianum*, *Trema orientalis*, and *Vernonia arborea*. The largest diameters were found in *Ficus* sp. (168.2 cm) and *Trema orientalis* (121.6 cm). These findings indicate a similarity in tree size distribution between the two mounts while also highlighting species-specific variations in growth potential.

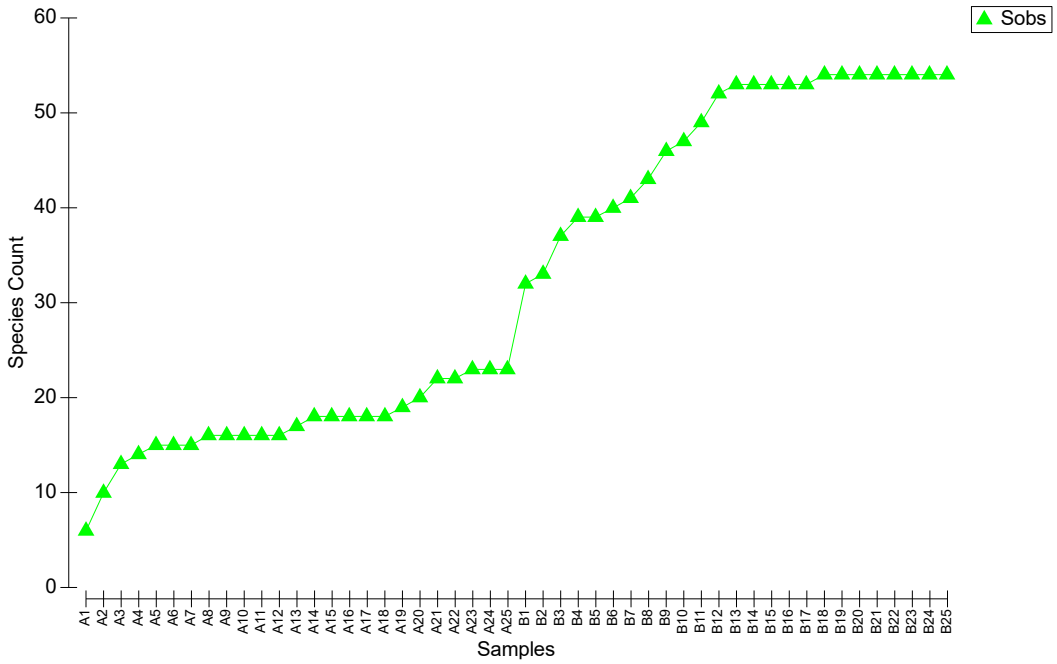


Figure 2. Species accumulation plot (Species Observed/Sobs index) of 1 ha PSP in Tropical Highland Forest Bali.

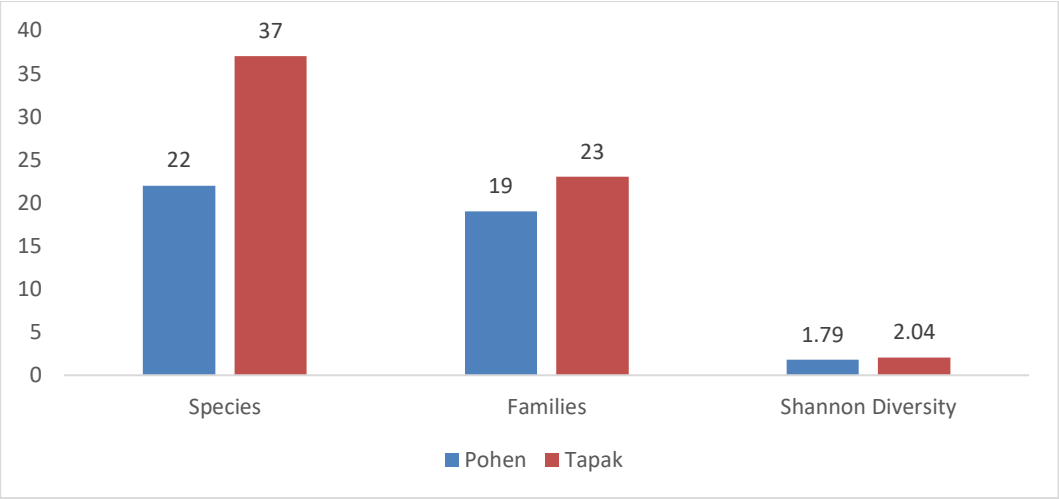
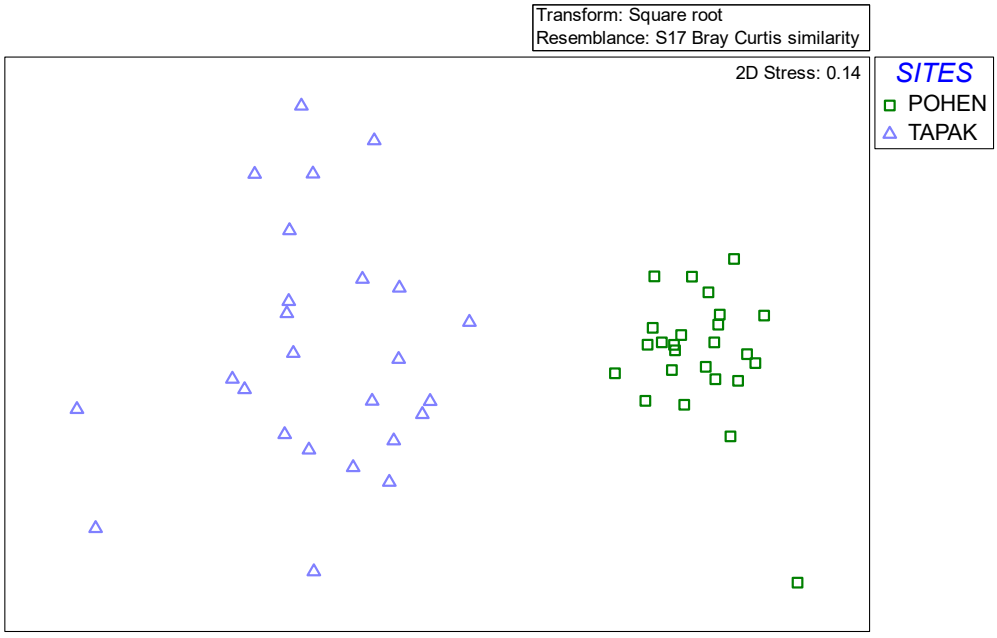


Figure 3. Comparison of the total tree species, families, and species diversity index in a 2 ha PSP of Mounts Tapak and Pohen Bedugul Highland Bali.

Figure 4 illustrates the ordination of tree communities in the two PSPs, based on species composition and abundance using the Bray-Curtis similarity index. Generally, there is a significant difference in tree species composition and abundance at the two PSP locations, showing the clear separation of the plots between the two PSPs. ANOSIM test also confirmed this result, as indicated by the high value of Global R (0.901). The larger variation within plots in Mount Tapak is shown by the more scattered plots than in Mount Pohen.



Global Test
Sample statistic (Global R): 0.901
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Figure 4. Bray-Curtis similarity index of tree communities at Mount Pohen and Mount Tapak, Bedugul Highland, Bali.

Table 1. Average species abundance and dissimilarity between the PSP of Mount Pohen and Mount Tapak, Bedugul Highland, Bali.

Species	Group POHEN Av.Abund	Group TAPAK Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dendrocnide stimulans	0.00	1.77	7.23	1.64	8.58	8.58
Crypteronia paniculata	1.67	0.00	6.46	2.58	7.67	16.25
Acronychia trifoliata	1.76	0.48	5.37	1.55	6.38	22.62
Lophopetalum javanicum	1.35	0.00	5.20	2.13	6.17	28.79
Polyosma integrifolia	1.64	0.76	4.83	1.36	5.73	34.52
Homalanthus giganteus	0.86	1.11	4.56	1.14	5.41	39.93
Podocarpus imbricatus	1.11	0.00	4.36	1.58	5.17	45.10
Meliosma ferruginea	0.00	0.88	3.46	1.19	4.11	49.21
Trema orientalis	0.00	0.87	3.45	1.12	4.09	53.30
Myrsine hasseltii	0.88	0.04	3.30	1.21	3.91	57.21
Ficus fistulosa	0.00	0.84	3.30	1.32	3.91	61.12
Vernonia arborea	0.80	0.80	3.27	1.18	3.88	65.00
Syzygium racemosum	0.00	0.70	2.81	0.86	3.34	68.33
Gordonia amboinensis	0.20	0.64	2.47	0.99	2.94	71.27
Claoxylon sp.	0.53	0.04	2.04	0.92	2.42	73.69
Saurauia sp.	0.00	0.52	1.90	0.70	2.26	75.94
Engelhardia spicata	0.14	0.42	1.70	0.79	2.02	77.97
Syzygium sp.	0.00	0.45	1.65	0.65	1.95	79.92
Cyathea latebrosa	0.00	0.41	1.50	0.64	1.78	81.70

The difference between Tapak and Pohen in terms of their species composition and abundance is seen in Table 1. Some species are only detected at Tapak but absent at Pohen or vice versa. Several species also occur at the two sites but in different abundance. *Dendrocnide stimulans*, *Meliosma ferruginea*, *Trema orientalis*, *Ficus fistulosa*, *Syzygium racemosum*, *Saurauia* sp., *Syzygium* sp., *Cyathea latebrosa* are species that present only at Mount Tapak. *Crypteronia paniculata* and *Podocarpus imbricatus* are only present at Mount Pohen. *Acronychia trifoliata*, *Polyosma integrifolia*, *Myrsine hasseltii*, *Claoxylon* sp., and *Engelhardia spicata* are more abundant at Mount Pohen than at Mount Tapak. *Homalanthus giganteus* and *Gordonia amboinensis* are of higher abundance at Mount Tapak. Only one species shared a similar abundance at Tapak and Pohen, namely *Vernonia arborea*.

3.2. Discussion

The species richness reaches a stable condition at around 20-25 subplots, as shown in Figure 2, which means no more species addition even when the plot number is increased. This phenomenon of 20-25-30 sample plots has been well observed when working in tropical forests [17,21,22]. Meanwhile, Figure 3 shows that the Shannon diversity index was detected as moderate and in the range of typical diversity in tropical rainforests, as stated by Ifo et al. [23], which is between 1.5 and 3.5 and rarely reaches up to 4.5. However, compared to PSP in Cibodas Biosphere Reserve in West Java, where the altitudinal is almost similar, the index on Tapak is lower than that of the Cibodas. PSP was established by Meijer in 1959, which was then re-sampled 50 years later, and shows that the diversity index reached 3.29 [24].

Euphorbiaceae is Mounts Pohen and Tapak's dominating species. These species are pioneer plants, especially after disturbances like fire or logging. Works on post-fire and post-logging forests in Kalimantan revealed *Homalanthus giganteus* and *Homalanthus populneus* occupied with high importance value index in a phytosociological analysis [25,26]. A similar phenomenon was also observed at Batulanteh forest on Sumbawa Island West Nusa Tenggara [27]. Mount Pohen experiences more disturbance compared to Mount Tapak, as mentioned previously. The construction of asphalt roads as a geothermal power plant infrastructure in Bedugul is causing Mount Pohen's forest, part of Batukahu Nature Preserve, to become fragmented. The wildfire occurred in 1994 and left a somehow arrested state of secondary succession with abundant pioneer plants [14,28].

Evergreen tree species dominate the abundance of individual species at Mount Pohen and Mount Tapak. *Crypteronia paniculata* from the family Crypteroniaceae are the most abundant species on Mount Pohen. It is found in Southeast Asia (especially Borneo), Sri Lanka, and New Guinea [29]. The young shoots are edible [30]. The woods are used for furniture and fuel, while the barks are used as blister medicine [31]. However, this species seeds regenerate poorly and are classified as rare [32]. *Acronychia trifoliata* is distributed through the mountain forest ecosystem in Java, Bali, Sulawesi, and New Guinea [33]. In Bali, this species is found at 1,600-1,700 m asl [34]. It can be used as an essential oil [35]. *Polyosma integrifolia* was initially distributed from Indo-China, China, and Malaysia to The Lesser Sunda Archipelago and Mollucas. The local community has used its woods for building, the inner bark for scurf medication, and the leaf sap for eye disease [36]. This species most likely survives for decades during secondary forest succession [37].

Unlike Mount Pohen, *Dendrochnide stimulans* are the most abundant on Mount Tapak. This species is distributed to Southern China and Southeast Asia. In Indonesia, the sap is utilised as cough medicine and hair wash. *Dendrochnide stimulans* contain alkaloids, steroids, tannins, saponins, and quinones [38]. The sapling roots can be used as sores paste and root poultice to reduce pain in human gum [39]. Just like *P. integrifolia*, *D. stimulansis* is also one of the significant evergreen trees with vital survival [37].

4. Conclusions

Despite varying degrees of past disturbance, Mount Pohen and Mount Tapak harbour diverse tree species, with Euphorbiaceae emerging as the dominant family. The abundance and composition of tree species differ significantly between the two mountains, reflecting the influence of historical disturbances and environmental conditions. Evergreen species, such as *Crypteronia paniculata* and *Acronychia trifoliata* on Mount Pohen and *Dendrochnide stimulans* on Mount Tapak, play crucial roles in these ecosystems, showcasing their resilience and adaptability to the highland habitat. While establishing a geothermal power plant and forest fires are historical events, they have left lasting impacts on Mount Pohen's ecosystem, highlighting the importance of considering past disturbances in conservation efforts. Conservation initiatives are crucial for mitigating further habitat fragmentation and loss, thereby safeguarding the rich biodiversity and ecological functions of the Bedugul highland tropical forest for future generations. This research underscores the importance of continued monitoring and conservation efforts to ensure the long-term sustainability of these unique and valuable ecosystems.

Author Contributions

S: Conceptualization, Methodology, Data Curation, Formal Analysis, Writing - Original Draft Preparation; **RI**: Data Curation, Formal Analysis; **MHS**: Validation, Visualization; MBA: Validation, Writing - Original Draft Preparation, Writing - Review & Editing; **EP, AH, YH, HIJ, and IH**: Writing - Original Draft Preparation; **NH, JGS, and WH**: Writing - Review & Editing.

Conflicts of interest

There are no conflicts to declare.

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