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*Research Article*

# Vegetation Structure and Tree Species Diversity inside and outside a Newly Established Zalon Taung National Park in Northwest Myanmar

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The Zalon Taung National Park (ZNP) in Banmauk township, northwest Myanmar, is a recently established protected area to protect the area's cultural value, ecosystems, native flora, and wildlife. This research examined the vegetation structure, tree species diversity, and composition within (ZNP) and outside (the Banmauk unclassified forest (BUCF)) the park to inform conservation and resource utilization for sustainable management. We conducted the vegetation survey in April-May of 2022 by setting up 34 sample plots (40 × 40 meters) using a random sampling approach. We used stand density, basal area, Shannon–Wiener diversity index, Simpson index, Pielou's evenness, Fisher's $\alpha$ diversity, and Importance Value Index (IVI) to determine the forest structure and tree diversity. A total of 116 tree species (≥10 cm·dbh), representing 87 genera and 48 families, were identified. The ZNP sample plots had a slightly higher stand density (201 individuals $ha^{-1}$) and basal area (20.6 $m^2 \cdot ha^{-1}$) than BUCF (stand density: 191 individuals $ha^{-1}$ and basal area: 15.0 $m^2 \cdot ha^{-1}$), which is accessible to collect firewood and timber extraction by residents. The reverse J-shaped pattern of the population structure indicated that the stands' populations were progressive and healthy. BUCF featured the most Verbenaceae (12.9%) and the ZNP the most Euphorbiaceae (7.2%) families. *Protium serratum* had the highest IVI in the BUCF (26.91%) and *Dipterocarpus alatus* (18.39%) in the ZNP. *Dipterocarpus alatus* and *Dalbergia oliveri* (IUCN Red List-endangered species) dominate in BUCF and require special attention in conservation planning. In the ZNP, previous logging activity dramatically reduced the relative density and the IVI values of commercially important species such as *Tectona grandis*, *Dalbergia oliveri*, and *Protium serratum*. According to the NMDS ordination, differences in tree species compositions were significantly linked with elevation, the intensity of logging, and distance to the village and road. The results will help park managers plan effective land use to promote biodiversity conservation and local livelihoods.

## 1. Introduction

Numerous studies focus on tropical forests since they include some of the most diverse vegetation [1], conserve carbon stocks and timber [2], and provide food, feed, shelter, energy, medicine, and revenue for human progress [3]. Globally, the highest percentage of forests (45%) is in tropical regions [4]. Tropical forests are the biodiversity hotspots of conservation priority [5], as people in poor tropical nations rely on forest resources for daily needs, compared to biodiversity conservation activities [6]. Such disparities are particularly concerning in Myanmar, a part of the Indo-Burma and Himalaya hotspots [7], with 70% of its 51.48 million people living in rural areas and dependent on forest resources [8]. Myanmar's three basic types of forests are tropical, subtropical, and temperate; all determined by climate and geography [9, 10]. Hardwoods comprise the majority of these forests [10]. National parks, marine national parks, nature reserves, wildlife refuges, and other nature reserves are designated as protected areas in Myanmar to protect biodiversity, ecosystem services, and forests' spiritual and cultural significance [11]. According to the forest resource assessment by the FAO in 2020, the forests cover in Myanmar is 42.19% of the entire country [12]. Currently, 6.43% of Myanmar's total area has been established as protected areas, although the nation has targeted to increase that to 10% by the 2015 Paris Climate Change Conference [13].

Tropical forests are being increasingly affected by population explosion, agriculture expansion, mining, logging, and road building [14]. Although illegal logging activities target the most valuable timber species with promising revenues, logging intensities have been exceptionally high in Southeast Asia, leading to loss and damage to species and ecosystems [15]. Furthermore, collecting firewood from local communities is another distinct driver of the degradation of tropical forests in Southeast Asia [16]. While emphasizing the sustainability, habitat protection, and ecosystem preservation of tropical forests, we need a comprehensive understanding of the diversity and composition of tree species in these forests [17, 18]. Understanding tropical forests' diversity and ecological features is vital to sustaining their functions in regulating species diversity, food webs, water and air filtration, microclimate, and soil fertility [19, 20]. Considerable research on tropical vegetation focuses primarily on how variations in topography, edaphic conditions, human activities, management types, and land use/land cover impact the diversity, composition, and structure of tree species in the forest reserves [21–24].

Tropical forests in Myanmar have been studied for their management status and plant community compositions [25, 26], soil and environmental characteristics [27, 28], tree species diversity distribution along a precipitation gradient [29], and topographic and edaphic variations [30]. These studies provided details on Myanmar's tropical forest structure and floristic richness. Most of these studies were conducted in well-maintained protected areas and reserved forests, ideal for conserving biodiversity. However, the unprotected forests of Myanmar have yet to be studied. A substantial portion of the biodiversity in Myanmar and the tropics remains outside of protected areas [31, 32]. Recent years have seen an increase in the importance of biodiversity conservation outside protected areas in the global conservation debate [33, 34]. Most environmentalists focus on effective land use planning to protect the biodiversity of protected areas outside to achieve conservation goals and livelihood security [35]. A specific study claimed that while certain species were more prevalent outside the protected area than inside, conservation efforts inside protected areas alone were inadequate to guarantee the long-term survival of endangered species [36]. The onservation of Southeast Asian biodiversity is geared towards the protected areas [37]; therefore, recording forest tree species outside the protected areas is rare. Supporting the maintenance of unprotected tropical forests near the protected areas might result in a situation where biodiversity conservation is achieved while also boosting the local economy [32]. To combine biodiversity protection with local livelihood security, we must understand human dependence on forest resources and its effects on forest structure and diversity. Disturbances by humans have decreased species diversity and structural characteristics such as stand density, diameter class distributions, and basal area of tropical forests [38, 39].

This study was conducted inside and outside the Zalon Taung National Park (ZNP) in Banmauk township, Northwest Myanmar. According to the FAO 2020 forest resource assessment, 42.54% of Banmauk township is forested [40]. However, as the population rise and human activities such as illicit logging, gold mining, fuel wood collection, shifting cultivation, and plantation establishment endanger forest resources [41], the extent of forest cover in the Banmauk township is declining at a rate of 0.6% per year between 2010 and 2017 [42]. The Ministry of Natural Resources and Environmental Conservation of Myanmar issued the ZNP as a protected area in 2022 [43]. However, with the expansion of human populations, their settlements and farmlands contributed to the destruction of natural forests, particularly in the periphery of the ZNP [44]. The inhabitants use forest resources to generate income, mainly to collect wood, medicinal plants, and firewood [41]. Additionally, the ZNP has a history of selective logging, in which the government extracted teak and other economically significant hardwood species for foreign revenue [45]. To implement effective conservation measures under the ZNP designation as a protected area, a quantitative investigation of the floristic composition, richness, and stand structure along this human-dependent natural forest is urgently required.

This study aimed to assess tree species diversity, composition, and stand structure inside and outside a newly established Zalon Taung National Park (ZNP) protected area in Myanmar. Our specific objectives are to (1) identify the tree species diversity and stand structural features; (2) assess the stand density, abundance, and dominance of total tree species and economically important tree species; and (3) evaluate the changes in the tree species composition, diversity, evenness, and stand structure in response to environmental variables. The results will help to evaluate the vegetation structure, diversity, and composition in and out of the ZNP for long-term conservation planning to balance biodiversity protection and resource use.

## 2. Materials and Methods

*2.1. Study Area.* We collected vegetation data during April-May 2022 in the Zalon Taung National Park (ZNP) and its adjacent Banmauk unclassified forest (BUCF), located between 95°44′E and 95°56′E longitude and 24°28′N and 24°42′N latitude in Northwest Myanmar (Figure 1). As a limitation of this study, we cannot assess the vegetation in the upper part of the ZNP because of ongoing armed conflicts between the national military and local armed groups that have rendered it insecure or inaccessible. The ZNP was designated as a protected area in January 2022 to preserve the cultural value of Zalon Taung Pagoda, the native flora, wildlife, and water resources after it was gazetted in 1994 as Nantkaunghu Reserved Forest, covering 21,616 ha [43]. ZNP is a significant protected habitat for hoolock gibbons, pangolins, dhole dogs, Asiatic black bears, and clouded leopards [44]. National parks are included in the

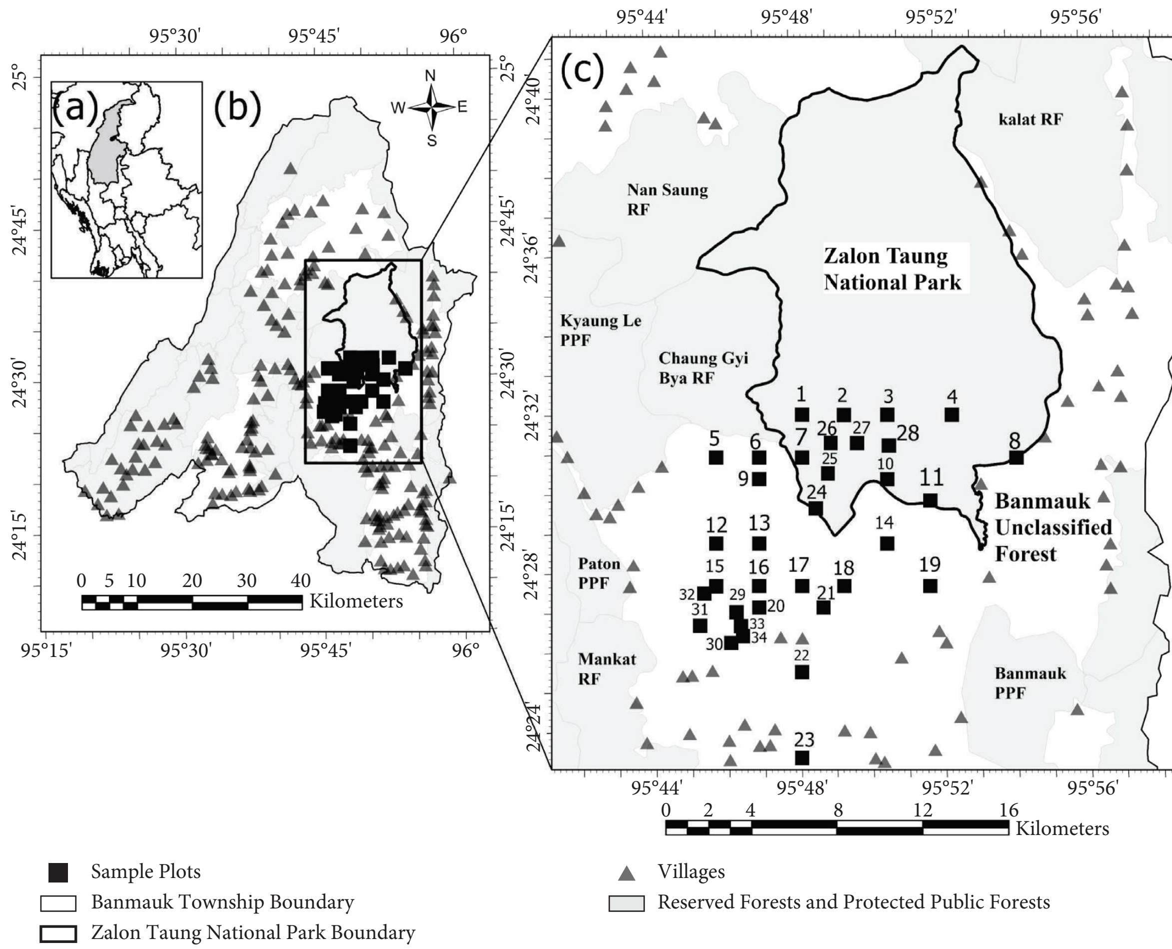


Figure 1: Map of the study area: (a) Sagaing region, Myanmar, (b) Banmauk township, and (c) sampling plots in the Zalon Taung National Park and Banmauk unclassified forest.

category of the protected area system, in which the forest law strictly prohibits harvesting forest resources [46]. Unclassified forests are included in the category of vacant land or land at government's disposal [47]. Unless the forest law expressly forbids a particular behaviour, such as cutting "reserved tree species" (e.g., teak), villagers can harvest wood and nontimber forest products for subsistence in the unclassified forest [46]. After Myanmar Timber Enterprise deliberately felled 2,439.54 tons of teak (*Tectona grandis*) and 5,207.852 tons of kanyin trees (*Dipterocarpus alatus*) between 2005 and 2010, the government stopped the exploitation in the ZNP [43]. In BUCF, the selective logging of teak and other hardwood trees has continued. The extraction of nontimber forest products, especially medicinal plants, is noticeable in the ZNP.

Natural vegetation is a diverse range of tropical moist upper mixed deciduous forests, with most species defining the deciduous forest type. Physiographic conditions include steep hills, valleys, flat plains, and flat-topped ridges, with an elevation range of 100–1,600 meters above the sea level. The typical soil types are Rhodic Ferrasols (red-brown forest soil) and Lithosols (primitive crushed stone). The region has a tropical monsoon climate with an average of 1,336 mm annual rainfall, with the most rainfall between June and September [48]. The mean monthly temperature ranges from 6.7°C to 41.9°C; the hottest month is April, and the coldest month is January. The relative humidity is high throughout the year, averaging 86% [48].

There are around 40 villages on the plains surrounding BUCF and the ZNP. Most people who live near and within the territory of BUCF and the ZNP are farmers. Data from the 2014 national census show that the population density in Banmauk township was 33 persons/km$^2$, with 83% of the population living in villages and 17% in town areas [49]. The Shan ethnic group includes 69.51% of the population, followed by the Kadu ethnic group (15.11%) and the Kanan ethnic group (12.55%) [49]. The local villagers cultivate rice and groundnut, collect firewood, timber, and nontimber forest products, especially medicinal plants, from the forest and work as gold mining labours. The residents rely on forests for extraction and timber harvesting even though the forests are under the management of the Forest Department of Myanmar.

*2.2. Sampling Design and Environmental Parameters.* We randomly selected 34 sampling plots (40 × 40 meters); 21 plots were located in BUCF and 13 plots in the ZNP at least

500 m apart (Figure 1). The sample locations had various human disturbances, including legal and illicit tree cutting and residents harvesting firewood and medicinal plants. Every tree ≥10 cm diameter at breast height (dbh) was identified, numbered, and measured for height and diameter using a clinometer and diameter tapes. The survey team, including local Forest Department staff, local guides, and the botanists of the local nongovernmental organization, assisted in identifying tree species. The local names of the species were converted into scientific names following Kress et al. [50].

Seven environmental parameters were determined for each plot, including the elevation, slope, aspect, land class, logging level, and distance to the nearest village and road. We used a GPS (Garmin 62 s) to determine each plot's latitude, longitude, and altitude. The slope and aspect were derived from the 30 m resolution digital elevation model (DEM) using the coordinates of the sample plots. In each sampling plot, we record the number of cutting and stumps as indicators of logging activities (Figure 2). We recorded the land class of each sampling plot, such as old-growth forest land (i.e., minimally disturbed land), secondary forest land (i.e., the land disturbed by selective logging and harvesting of forest products), and jungle forest land (i.e., the land heavily disturbed by road and farmland encroachment) (Figure 3). Additionally, understory vegetation, including bamboo, shrubs, and herbs, was recorded in general, although it was not considered in the woody vegetation analyses.

*2.3. Data Analysis.* To determine the stand structural characteristics, we calculated the mean dbh (cm), the maximum tree height (m), the total basal area (m$^2$), and tree density in each plot. We used the Shannon–Wiener index [51], Simpson's index [52], and Pielou's evenness [53] to calculate the woody species diversity in each sample plot.

$$\text{Shannon index } H^{'} = -\sum_{i=1}^{s} p_i \ln\left(p_i\right), \tag{1}$$

where $s$ is the number of species in the community, and $p_i$ is the percentage of individuals found in the $i^{\text{th}}$ species. The Shannon index may range from 1.5 to 3.5, seldom going over 4.5, where high levels suggest a large diversity.

$$\text{Species dominance Simpson index } D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right), \tag{2}$$

where $n$ is the number of individuals of a single species, and $N$ is the number of individuals in the total population. The Simpson index has a potential range of 0–1, with high values indicating little diversity and high stand dominance.

$$\text{Pielou evenness index } (e) = \frac{H^{'}}{\log(S)}. \tag{3}$$

$S$ is the number of species, and $H'$ is the Shannon–Wiener Index. With potential values ranging from 0 to 1.0, strong values indicate good evenness.

Figure 2: Signs of logging.

Fisher's $\alpha$ diversity [54] was quantified in each plot because it reduces the sample size and works well on tropical forest vegetation [55]. We used the biodiversity R package [56] in the R software version 4.2.1 [57] to examine the diversity of the species. The density-diameter distribution of the tree species using dbh classes set at 10 cm intervals characterized the population structures of the two sites (BUCF and the ZNP). We developed rarefaction curves using the iNEXT package [58] in R software to evaluate the direct comparison of species richness between the two sites. Then, we developed a species rank-abundance curve to evaluate the species richness of the most abundant tree species [59]. Additionally, we calculate each species' Importance Value Index (IVI) by summing up each species' relative density, frequency, and dominance [60] (Table 1).

We used the Shapiro–Wilk test to determine the normality of the data before comparing the stand structural features of the economically significant and higher IVI species at BUCF and the ZNP [61]. Since the dataset deviated from the normal distribution, we used the Wilcoxon rank sum test to compare dbh, basal area, and height between the sites.

Nonmetric multidimensional scaling (NMDS) ordination in the R vegan package [62] examined tree species composition in 34 plots of three land classes in BUCF and the ZNP. The sample plots were first arranged on the graph based on Bray–Curtis distance measure. Then, using permutation testing, significant species and environmental factors were fitted to the ordination graphs. The Wilcoxon rank sum test compared environmental variables between the two sites. We used the Spearman rank correlation coefficients to quantitatively examine all sampling plots' stand structural characteristics and diversity along with environmental conditions (elevation, slope, distance to settlement, and roads).

(a) (b) (c)

Figure 3: Land classes of study area: (a) old growth, (b) secondary forest, and (c) jungle forest land.

Table 1: Formulae for calculating the IVI.

| Parameters | Formulae |
|---|---|
| Importance Value Index | IVI = relative density + relative frequency + relative dominance |
| Density of a species | De = number of a species/total area sampled |
| Frequency of a species | $F$ = area of plots in which a species occurred/total area sampled |
| Dominance of a species | Do = total basal area of a species/total area sampled |
| Relative density of a species | RDe = density of a species/total density of all species ∗ 100 |
| Relative frequency of a species | RF = frequency of a species/total frequency of all species ∗ 100 |
| Relative dominance of a species | RDo = dominance of a species/total dominance of all species ∗ 100 |

## 3. Results

*3.1. Stand Structure and Species Diversity.* The characteristics of 34 sampling plots were described (Table 2). The ZNP had a higher tree density (201 individuals $ha^{-1}$) than BUCF, with a tree density of 109 individuals $ha^{-1}$. The ZNP had a basal area of 20.6 $m^2 \cdot ha^{-1}$ whereas BUCF had 15 $m^2 \cdot ha^{-1}$. In the ZNP, Simpson, Shannon, and Fisher diversity indices and Pielou's evenness were higher than in BUCF (Table 3). The secondary forests in the ZNP had the highest tree density (338 individuals $ha^{-1}$) with the highest basal area (22.4 $m^2 \cdot ha^{-1}$) (Figure 4). The old-growth forest in BUCF had the most significant number of trees greater than 30 cm·dbh (128 individuals $ha^{-1}$), followed by the secondary forest in the ZNP (106 individuals $ha^{-1}$) (Figure 4). The species richness of all sampling plots and plot number was investigated through rarefaction curves (Figure 5). The rarefaction curves for BUCF and the ZNP demonstrated that for the same number of individuals, the species diversity between them was comparable (Figure 6).

The population patterns of BUCF and the ZNP were analyzed using the density-diameter distribution (Figure 7). Most of the trees were between 10 and 15 cm·dbh. Only a handful of the trees in each site were larger than 50 cm·dbh. In contrast to BUCF, the ZNP plots showed more trees larger than 60 cm·dbh. The tree population structures grew with increasing densities of lower diameter classes and lower densities of higher diameter classes (Figure 7).

*3.2. Tree Species Composition, Abundance, and the Importance Value Index (IVI).* A total of 1,699 individuals with dbh 10 cm and greater were counted in BUCF and the ZNP, comprising 116 species from 87 genera and 48 families. In BUCF, 42 families represented 71 genera, 91 species, and 1,029 individuals. In the ZNP, 43 families comprised 68 genera, 84 species, and 670 individuals. Table 4 lists the families that comprise more than 5% of the composition. In BUCF, the Verbenaceae family dominated but in the ZNP, it was the Euphorbiaceae family. The IVI values indicate the ecological relevance of the tree species in community structure (Table 5). With an IVI of 26.91%, *Protium serratum* (Burseraceae) was the most prominent species in BUCF, followed by *Dipterocarpus alatus* (Dipterocarpaceae), *Tectonagrandis* (Verbenaceae), *Dilleniapentagyna* (Dilleniaceae), and *Schleichera oleosera* (Sapindaceae) with the IVI of 19.83, 19.41, 16.29, and 16.25%, respectively (Table 5). The most notable species in the ZNP was *Dipterocarpus alatus* (Dipterocarpaceae), with an IVI of 18.39%, followed by *Xerospermum noronhianum* (Sapindaceae) (15.77%), *Protium serratum* (Burseraceae) (13.44%), *Baccaurea sapida* (Euphorbiaceae) (11.60%), and *Dracontomelon dao* (Anacardiaceae) (11.16%) (Table 5). These species are considered ecologically significant in a given habitat since the IVI value is more than 10 [63]. The IVI values of all species are provided in the Appendix (Supplementary Material (available here))

The species rank-abundance curve revealed an abundance of vegetation with variations in BUCF and the ZNP (Figure 8). A steep gradient of the BUCF stand showed low evenness as high-ranking species have higher abundances than low-ranking species. On the other hand, the modest gradient of the ZNP suggested good evenness since the abundances of various species are more consistent than in the BUCF (Figure 8).

*3.3. Stand Structural Characteristics of Economically Important Tree Species.* The number of trees $ha^{-1}$ (tree density), dbh, basal area $ha^{-1}$, and the height of five commercially

Table 2: Description of 34 sample plots with plot-level species diversity, elevation, and logging level.

| Forests | Plot nos. | Land classes | Number of trees | Tree species richness | Fisher's $\alpha$ | Elevations | Logging levels |
|---|---|---|---|---|---|---|---|
| ZNP | 1 | Secondary forest | 63 | 14 | 5.530 | 703.848 | Low$^{+}$ |
| | 2 | Secondary forest | 38 | 15 | 8.717 | 783.223 | Low$^{+}$ |
| | 3 | Secondary forest | 33 | 16 | 11.036 | 774.303 | Low$^{+}$ |
| | 4 | Secondary forest | 41 | 16 | 8.869 | 435.382 | Low$^{+}$ |
| | 7 | Secondary forest | 56 | 22 | 12.009 | 812.641 | Low$^{+}$ |
| | 8 | Jungle forest | 34 | 12 | 5.612 | 213.617 | High$^{+++}$ |
| | 10 | Old-growth | 42 | 19 | 10.786 | 596.825 | Low$^{+}$ |
| | 11 | Secondary forest | 36 | 16 | 8.549 | 352.082 | High$^{+++}$ |
| | 24 | Secondary forest | 33 | 15 | 6.634 | 736.387 | High$^{+++}$ |
| | 25 | Secondary forest | 82 | 27 | 11.623 | 704.487 | Intermediate$^{++}$ |
| | 26 | Secondary forest | 42 | 20 | 9.548 | 188.118 | Intermediate$^{++}$ |
| | 27 | Secondary forest | 83 | 33 | 15.983 | 939.745 | Low$^{+}$ |
| | 28 | Secondary forest | 87 | 15 | 4.605 | 532.638 | Low$^{+}$ |
| BUCF | 5 | Secondary forest | 54 | 14 | 5.801 | 717.464 | Low$^{+}$ |
| | 6 | Old-growth | 53 | 14 | 5.801 | 760.942 | Low$^{+}$ |
| | 9 | Old-growth | 44 | 23 | 15.453 | 790.786 | Low$^{+}$ |
| | 12 | Secondary forest | 52 | 21 | 10.892 | 376.989 | Intermediate$^{++}$ |
| | 13 | Secondary forest | 39 | 22 | 14.386 | 673.089 | Low$^{+}$ |
| | 14 | Secondary forest | 52 | 14 | 5.434 | 330.444 | High$^{+++}$ |
| | 15 | Secondary forest | 47 | 20 | 10.234 | 491.251 | Intermediate$^{++}$ |
| | 16 | Secondary forest | 54 | 17 | 7.145 | 671.107 | Intermediate$^{++}$ |
| | 17 | Secondary forest | 52 | 14 | 5.303 | 566.973 | Intermediate$^{++}$ |
| | 18 | Secondary forest | 48 | 14 | 5.434 | 287.62 | Intermediate$^{++}$ |
| | 19 | Jungle forest | 35 | 10 | 3.610 | 168.732 | High$^{+++}$ |
| | 20 | Secondary forest | 49 | 15 | 5.904 | 523.386 | High$^{+++}$ |
| | 21 | Jungle forest | 28 | 7 | 2.234 | 199.395 | High$^{+++}$ |
| | 22 | Secondary forest | 52 | 17 | 6.909 | 305.792 | Intermediate$^{++}$ |
| | 23 | Secondary forest | 41 | 9 | 2.853 | 271.264 | Intermediate$^{++}$ |
| | 29 | Secondary forest | 65 | 29 | 14.341 | 284.648 | Intermediate$^{++}$ |
| | 30 | Secondary forest | 67 | 30 | 14.863 | 265.101 | Intermediate$^{++}$ |
| | 31 | Secondary forest | 50 | 28 | 15.154 | 317.911 | Intermediate$^{++}$ |
| | 32 | Secondary forest | 50 | 20 | 8.428 | 327.729 | High$^{+++}$ |
| | 33 | Secondary forest | 47 | 29 | 16.348 | 257.673 | Intermediate$^{++}$ |
| | 34 | Secondary forest | 50 | 21 | 8.987 | 281.424 | Intermediate$^{++}$ |

*Note*. ZNP = the Zalon Taung National Park, BUCF = Banmauk unclassified forest, $^{+}$ = counts of cuttings and stumps <3, $^{++}$ = counts of cuttings and stumps between 3 and 10, and $^{+++}$ = counts of cuttings and stumps >10.

Table 3: Structure and diversity of BUCF and ZNP forests.

| Variables | BUCF | ZNP |
|---|---|---|
| Mean density (no. trees/ha) | 191.00 ± 7.43 | 201.00 ± 22.20 |
| Mean dbh (cm) | 21.60 ± 2.68 | 21.00 ± 2.34 |
| Maximum height (m) | 23.60 ± 5.82 | 26.50 ± 9.51 |
| Mean basal area ($m^2$)/ha | 15.00 ± 1.16 | 20.60 ± 3.66 |
| Simpson's index | 0.85 ± 0.01 | 0.88 ± 0.01 |
| Shannon index | 2.34 ± 0.08 | 2.49 ± 0.08 |
| Pielou's evenness | 0.84 ± 0.01 | 0.87 ± 0.02 |
| Fisher's $\alpha$ | 24.45 | 25.37 |

significant wood species—*Dipterocarpus alatus*, *Dalbergia oliveri*, *Protium serratum*, *Tectona grandis*, and *Terminalia crenulata*—were examined (Table 6 and Figure 9). *Dipterocarpus alatus* had the most excellent tree density, followed by *Protium serratum* in both BUCF and the ZNP. *Dillenia pentagyna* of BUCF and *Tectona grandis* of the ZNP had the lowest. *Dipterocarpus alatus* had the most fabulous average diameter, basal area, and height in both sites, while *Tectona grandis* had the lowest except for the tree density in BUCF. The number of stems per hectare of *Tectona grandis* significantly differed between the two sites ($W = 104.5$, $p < 0.05$). The diameter and basal area of *Terminalia crenulata* significantly differed between the two sites ($W = 553.5$, $p < 0.05$). The height of *Protium serratum* was significantly different between the two sites ($W = 2510.5$, $p < 0.01$) (Figure 9).

*3.4. Differences in Species Composition and Environmental Variables.* The final stress value for the two-dimensional solution of the NMDS ordination analysis after 999 permutations was 16.61%, which is within an acceptable range of 20% for the statistical reliability of the NMDS ordination [64]. NMDS analysis revealed differences in the composition of tree species in BUCF and the ZNP with three land classes. NMDS analysis showed that secondary forest plots were significantly composed of economically significant deciduous tree species such as *Tectona grandis, Dipterocarpus alatus,* and *Shorea siamensis* (Figure 10 and Table 7). The ZNP secondary forest plots favoured the tropical moist forest habitats such as those occupied by *Dracontomelon dao*, *Malus spp*, *Syzygium kurzii*, *Baccaurea sapida*, and

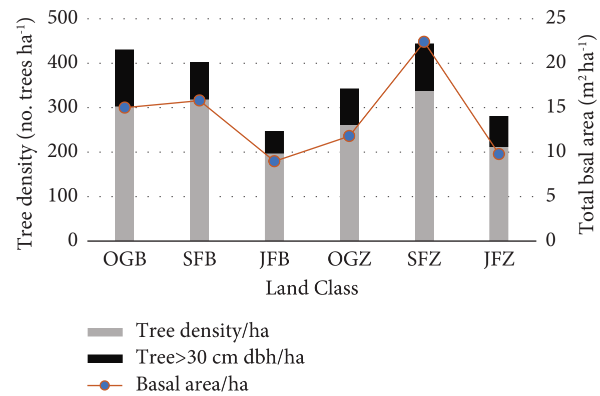


Figure 4: Tree density and basal area of three land classes in BUCF and the ZNP (OGB = old-growth forest in BUCF, SFB = secondary forest in BUCF, JFB = jungle forest in BUCF, OGZ = old-growth forest in ZNP, SFZ = secondary forest in ZNP, and JFZ = jungle forest in ZNP).

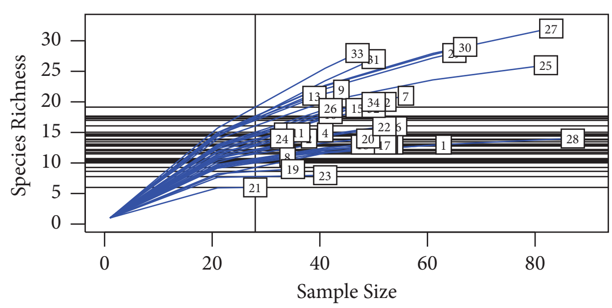


Figure 5: Rarefaction curve of species diversity in 34 sampling plots (the number represents each plot number).

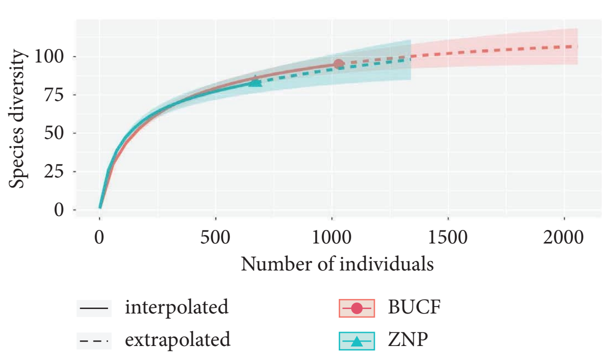


Figure 6: Rarefaction curve of species diversity in BUCF and ZNP sample plots.

medicinal plant species like *Millingtonia hortensis* and *Cinamomum inunctum* (Figure 10 and Table 7). The elevation, logging level, and access to roads and villages appeared to be the most influential factors affecting tree species composition in BUCF and the ZNP (Figure 11 and Table 7). In particular, the level of logging and distance to the road correlated with the secondary forest of BUCF (Figure 11 and Table 8). A higher elevation and a greater distance from the villages may favour the substantial composition of

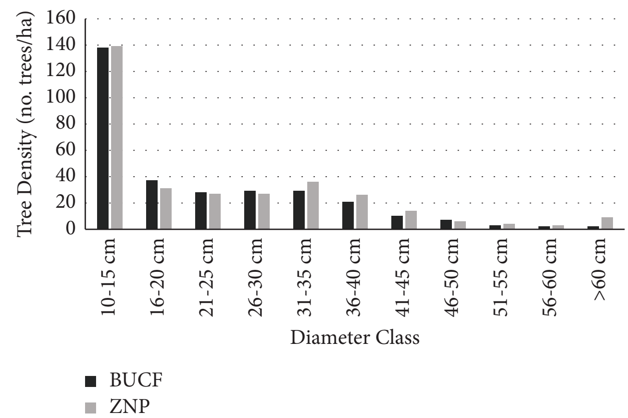


Figure 7: Population structure of BUCF and ZNP sample plots.

Table 4: Families with a composition greater than 5% in BUCF and the ZNP.

| Families | Compositions (%) | Nos. of species |
|---|---|---|
| *BUCF* | | |
| Verbanaceae | 12.9 | 5 |
| Burseraceae | 9.9 | 2 |
| Dipterocarpaceae | 9.9 | 4 |
| Combretaceae | 8.6 | 4 |
| Sapindaceae | 7.2 | 2 |
| Euphorbiaceae | 5.9 | 6 |
| Fagaceae | 5.5 | 4 |
| Fabaceae | 5.5 | 4 |
| Dilleniaceae | 5.3 | 1 |
| *ZNP* | | |
| Euphorbiaceae | 7.2 | 3 |
| Dipterocarpaceae | 6.7 | 2 |
| Combretaceae | 6.5 | 4 |
| Anacardiaceae | 6.4 | 4 |
| Sapindaceae | 6.4 | 2 |
| Fagaceae | 6.1 | 4 |
| Burseraceae | 5.8 | 1 |
| Moraceae | 5.7 | 6 |
| Verbanaceae | 5.0 | 2 |

tree species, such as *Dracontomelon dao*, *Malus* spp, *Morus alba*, and *Swintonia floribunda* in the secondary forest of the ZNP according to the NMDS and the Wilcoxon rank sum test (Figure 11 and Table 9). The Wilcoxon rank sum test revealed that elevation and distance to the village significantly differed, whereas slope, aspect, land classes, logging level, and distance to the roads were not significantly different between BUCF and the ZNP (Table 9).

*3.5. Relationships between Environmental Factors, Forest Structure, and Biodiversity Indices.* Spearman correlation analyses showed that the sample plots' basal area, maximum height, diversity, and evenness were affected by environmental factors such as elevation and distance to the village and road (Table 10). In all the sample plots, elevation had a substantial impact on species diversity and evenness, while the distance to the village and the road significantly affected

Table 5: Total number, relative frequency, relative dominance, relative density, and Importance Value Index of ten tree species in BUCF and the ZNP.

| Species | *N* | RF | RDo | RDe | IVI |
|---|---|---|---|---|---|
| *BUCF* | | | | | |
| *Protium serratum* | 96 | 9.33 | 12.93 | 4.64 | 26.91 |
| *Dipterocarpus alatus* | 65 | 6.32 | 11.05 | 2.46 | 19.83 |
| *Tectona grandis* | 103 | 10.01 | 3.66 | 5.74 | 19.41 |
| *Dillenia pentagyna* | 55 | 5.34 | 6.30 | 4.64 | 16.29 |
| *Schleichera oleosa* | 57 | 5.54 | 6.61 | 4.10 | 16.25 |
| *Terminalia crenulata* | 56 | 5.44 | 5.77 | 3.55 | 14.77 |
| *Dalbergia oliveri* | 51 | 4.96 | 3.53 | 4.64 | 13.13 |
| *Aporusa roxburghii* | 34 | 3.30 | 1.62 | 2.73 | 7.65 |
| *Shorea siamensis* | 25 | 2.43 | 2.98 | 2.19 | 7.60 |
| *Terminalia chebula* | 19 | 1.85 | 1.72 | 2.73 | 6.30 |
| *ZNP* | | | | | |
| *Dipterocarpus alatus* | 35 | 5.22 | 10.08 | 3.08 | 18.39 |
| *Xerospermum noronhianum* | 36 | 5.37 | 6.87 | 3.52 | 15.77 |
| *Protium serratum* | 39 | 5.82 | 4.10 | 3.52 | 13.44 |
| *Baccaurea sapida* | 36 | 5.37 | 3.58 | 2.64 | 11.60 |
| *Dracontomelon dao* | 11 | 1.64 | 6.97 | 2.64 | 11.26 |
| *Terminalia crenulata* | 27 | 4.03 | 4.08 | 3.08 | 11.20 |
| *Dillenia pentagyna* | 32 | 4.78 | 2.23 | 3.96 | 10.97 |
| *Premna latifolia* | 21 | 3.13 | 3.51 | 2.20 | 8.84 |
| *Cedrela serrata* | 21 | 3.13 | 2.36 | 3.08 | 8.58 |
| *Decaspermum parviflorum* | 16 | 2.39 | 2.52 | 2.20 | 7.12 |

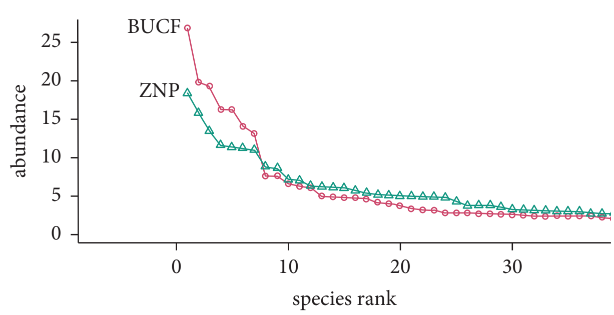


Figure 8: Species rank-abundance curve.

the structural features such as the total basal area and maximum height (Table 10). Elevation exhibited positive correlations with average dbh ($S = 4694$, $p = 0.105$), total basal area ($S = 4500$, $p = 0.072$), and maximum tree height ($S = 6224.9$, $p = 0.784$) of the plots. In contrast, the slope had a negative relationship with the total basal area ($S = 7618$, $p = 0.352$) and maximum height ($S = 7871.3$, $p = 0.250$) of the plots. Elevation had a significant positive relationship with Shannon diversity ($S = 3816$, $p < 0.05$), Simpson diversity ($S = 2598$, $p < 0.001$), and Pielou's evenness ($S = 3742$, $p < 0.05$). Distance to the village showed a strong positive correlation with the total basal area ($S = 3690$, $p < 0.01$) and the Simpson diversity index ($S = 3492$, $p < 0.01$). The distance to the road also exhibited a strong positive correlation with Pielou's evenness index ($S = 3422$, $p < 0.01$) of the plots. On the contrary, the distance to the road showed a strong negative relationship with the maximum tree height ($S = 91286$, $p < 0.05$) and showed a negative but insignificant relationship with the total basal area ($S = 8106$, $p = 0.174$) of the plots (Table 10).

The linear regression analyses revealed the relationship between the structural attributes (proportion of the number of trees >30 cm·dbh and the total basal area), diversity, and evenness with the elevation (Figure 12). The regression was statistically significant for the increasing pattern of the percentage of trees greater than 30 cm dbh with increasing elevation ($R^2 = 0.183$, $p < 0.01$) (Figure 12(a)). The total basal area of the trees in the sampling plots increased significantly with increasing elevation ($R^2 = 0.0976$, $p < 0.05$) (Figure 12(b)). The higher Simpson's index ($R^2 = 0.126$, $p < 0.05$) and Pielou's evenness ($R^2 = 0.098$, $p < 0.05$) of the sample plots regarding increased elevation was also significant in the regressions (Figures 12(c) and 12(d)).

## 4. Discussion

*4.1. Do Tree Density, Dominance, and Diversity Differ between BUCF and the ZNP?* All 34 sample plots were located in the natural forest at altitudes ranging from 168 m to 812 m, dominated mainly by deciduous tree species, which characterizes the study forest as a tropical moist upper mixed deciduous forest [9]. Since all sample plots were in a continuous landscape accessible to nearby villages, local populations' dependency on them would likely be comparable. Tree density (191–201 individuals ha$^{-1}$) in BUCF and the ZNP was lower compared to tree densities reported from the Popa Mountain Park (604–957 individuals ha$^{-1}$) [27], the evergreen montane forest of Ywa Ngan township (312–1372 individuals ha$^{-1}$) [28], and tropical deciduous forests (229–336 individuals ha$^{-1}$) [29] in Myanmar. However, the current research's tree densities were higher than that of a degraded forest (168 individuals ha$^{-1}$) in Oak-twin township [25] and comparable to that of the reserved tropical forest (229 individuals ha$^{-1}$) reported from Seikphyu township [29] in Myanmar. Although the ZNP plots have higher tree density and dominance than the BUCF plots, there was no significant difference between them. The dominance range (15.0–20.6 m$^2$·ha$^{-1}$) in this study was well comparable to the value reported for the human-disturbed forest (17.77-24.47 m$^2$·ha$^{-1}$) in the Popa Mountain Park [27]. However, it was much lower than those recorded in the Alaungdaw Kathapa National Park (60.03 m$^2$·ha$^{-1}$) [25] and the Natmataung National Park (55.63 m$^2$·ha$^{-1}$) [65], which have been protected since 1984 and 1994 in upper Myanmar.

Plant diversity indices provide more accurate measurements of species diversity and abundance in forests than species counts alone [66, 67]. The ZNP had higher diversity indices and Pielou's evenness than BUCF, although not so significantly. The steeper gradient rank-abundance curve of the BUCF revealed unequal resource sharing (Figure 8), with *Protium serratum* and *Dipterocarpus alatus* having much greater relative dominance than neighbouring species (Table 5). The growing human demand for wood for housing and fuel causes the repeated exploitation of preferable tree species, which can alter the species composition in the BUCF, where the forest law does not strictly prohibit the exploitation of forest products.

Table 6: Mean and standard error value of structural characteristics of five species.

| | BUCF | | | | | ZNP | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Da | Do | Ps | Tg | Tc | Da | Do | Ps | Tg | Tc |
| Tree density ($ha^{-1}$) | 37 ± 12 | 19 ± 4 | 35 ± 5 | 31 ± 3 | 27 ± 4 | 31 ± 6 | 17 ± 3 | 30 ± 4 | 13 ± 4 | 24 ± 7 |
| DBH (cm) | 29.40 ± 1.89 | 19.00 ± 1.30 | 26.10 ± 1.41 | 13.80 ± 0.60 | 23.10 ± 1.54 | 36.00 ± 2.86 | 19.10 ± 3.17 | 21.40 ± 1.74 | 12.40 ± 1.34 | 27.30 ± 1.74 |
| Basal area ($m^2$ $ha^{-1}$) | 0.54 ± 0.06 | 0.22 ± 0.03 | 0.43 ± 0.04 | 0.11 ± 0.01 | 0.33 ± 0.04 | 0.77 ± 0.16 | 0.23 ± 0.07 | 0.28 ± 0.04 | 0.09 ± 0.02 | 0.41 ± 0.04 |
| Height (m) | 14.80 ± 0.74 | 9.84 ± 0.50 | 12.80 ± 0.52 | 8.36 ± 0.27 | 11.30 ± 0.62 | 17.20 ± 1.12 | 9.99 ± 1.31 | 9.81 ± 0.75 | 8.68 ± 0.63 | 12.10 ± 0.80 |

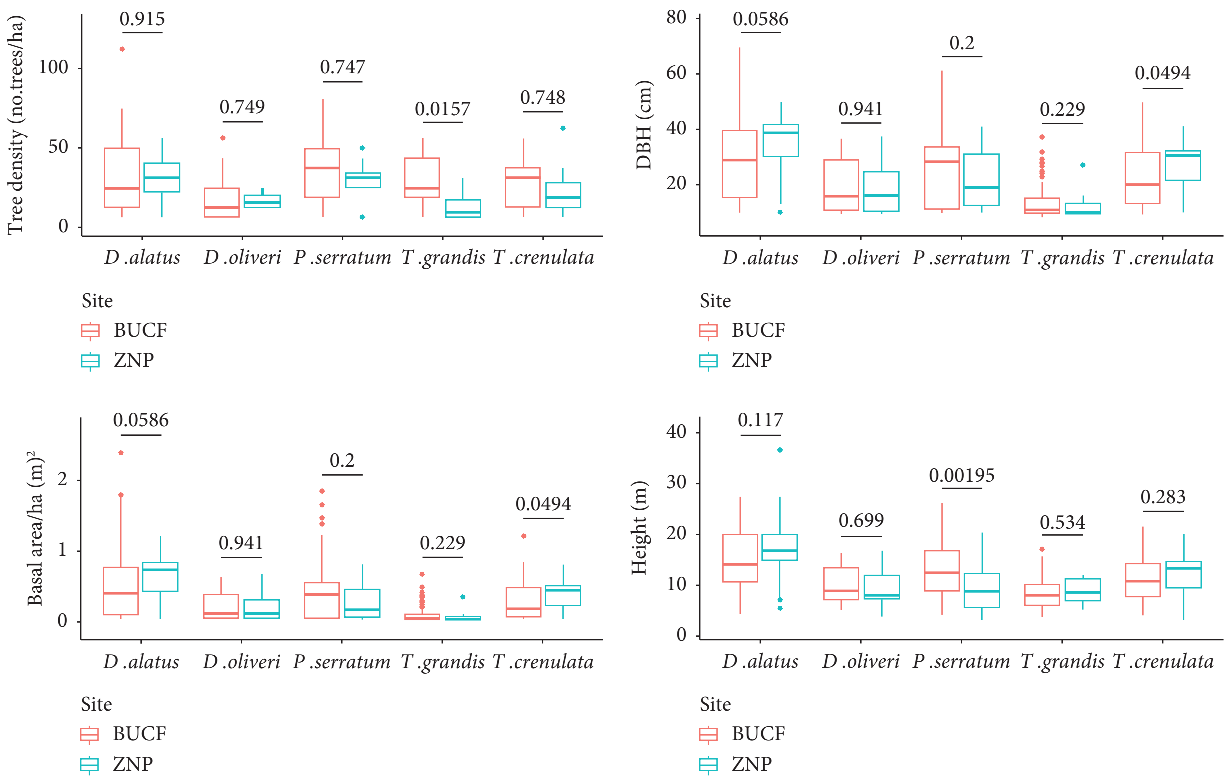


Figure 9: Tree density, dbh, basal area, and height of five important tree species by the Wilcoxon rank sum test ($p$ values are shown above the whisker plots).

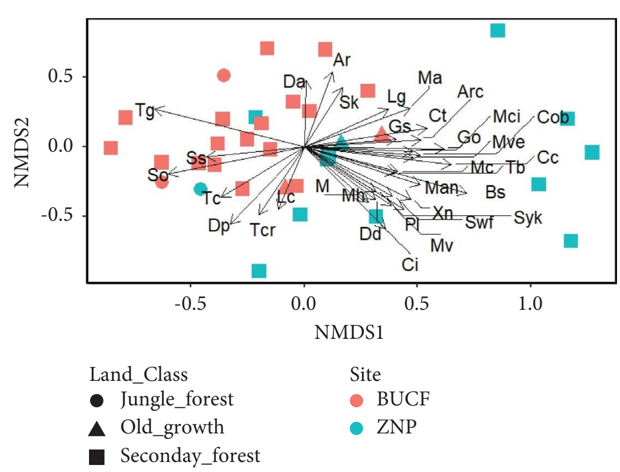


Figure 10: NMDS ordination of significant tree species. (Note: Tg = *Tectona grandis*, Ss = *Shorea siamensis*, So = *Schleichera oleosa*, Tc = *Terminalia chebula*, Dp = *Dillenia pentagyna*, Tcr = *Terminalia crenulata*, Lc = *Lannea coromandelica*, *M* = *Malus* spp, Mh = *Millingtonia hortensis*, Dd = *Dracontomelon dao*, Ci = *Cinamomum inunctum*, Pl = *Premna latifolia*, Mv = *Machilus villosa*, Syk = *Syzygium kurzii*, Swf = *Swintonia floribunda*, Xn = *Xerospermum noronhianum*, Man = *Myristica angustifolia*, Bs = *Baccaurea sapida*, Mc = *Mangifera caloneura*, Tb = *Terminalia bellerica*, Cc = *Celtis cinnamomea*, Mve = *Miliusa velutina*, Go = *Gynocardia odorata*, Mci = *Millettia cinerea*, Cob = *Croton oblongifolius*, Gs = *Gardenia sootepensis*, Ct = *Castanopsis tribuloids*, Arc = *Artocarpus chaplasha*, Ma = *Morus alba*, Lg = *Lithocarpus grandifolia*, Sk = *Schima khasiana*, Ar = *Aporusa roxburghii*, and Da = *Dipterocarpus alatus*).

The secondary forest plots had the highest species diversity, while the jungle forest plots had the lowest species diversity in rarefaction-based species richness (Figure 5). The limited diversity of woody species in the jungle forest today is due to the dominance of bamboo and shrubs, notably *Pseudostachyum polymorphum*, *Dendrocalamus strictus*, *Ziziphus oenoplia*, *Caryota mitis*, and *Arenga nana* after it was previously disturbed by the heavy extraction of forest products by road and farmland invasion. The people's substantial dependence on unlawful access to forest resources may cause similar patterns of rarefaction-based species diversity in BUCF and the ZNP (Figure 6). We

Table 7: NMDS scores of significant species variables.

| Variables | NMDS1 | NMDS2 | $p$ value |
|---|---|---|---|
| Tg | −0.69603185 | 0.26815787 | 0.001 |
| Ss | −0.41232026 | −0.10011299 | 0.043 |
| So | −0.56436402 | −0.20665331 | 0.002 |
| Tc | −0.34134782 | −0.36691586 | 0.014 |
| Dp | −0.31340380 | −0.56476761 | 0.001 |
| Tcr | −0.19001198 | −0.48470993 | 0.006 |
| Lc | −0.11063047 | −0.45432132 | 0.033 |
| *M* | 0.27972265 | −0.40814073 | 0.023 |
| Mh | 0.31190539 | −0.38333656 | 0.031 |
| Dd | 0.36178355 | −0.58436682 | 0.001 |
| Ci | 0.31190539 | −0.38333656 | 0.031 |
| Pl | 0.43699282 | −0.45633904 | 0.001 |
| Mv | 0.38140881 | −0.42839178 | 0.001 |
| Syk | 0.31503950 | −0.31214872 | 0.033 |
| Swf | 0.38823855 | −0.36219381 | 0.002 |
| Xn | 0.46558492 | −0.37516819 | 0.002 |
| Man | 0.52531797 | −0.27657385 | 0.003 |
| Bs | 0.71739058 | −0.32149891 | 0.001 |
| Mc | 0.41662382 | −0.16526151 | 0.031 |
| Tb | 0.40502089 | −0.17997396 | 0.037 |
| Cc | 0.65185846 | −0.10835249 | 0.001 |
| Mve | 0.48227540 | −0.06323046 | 0.021 |
| Go | 0.61740474 | 0.00877868 | 0.002 |
| Mci | 0.47986555 | −0.01922995 | 0.023 |
| Cob | 0.51353662 | −0.04134883 | 0.011 |
| Gs | 0.07242523 | −0.43701499 | 0.034 |
| Ct | 0.59246628 | 0.12546485 | 0.004 |
| Arc | 0.51638375 | 0.06435238 | 0.007 |
| Ma | 0.46983267 | 0.28921954 | 0.008 |
| Lg | 0.41544319 | 0.27291349 | 0.016 |
| Sk | 0.21492955 | 0.41970285 | 0.024 |
| Ar | 0.13294825 | 0.53628319 | 0.003 |
| Da | −0.02393154 | 0.49260289 | 0.016 |

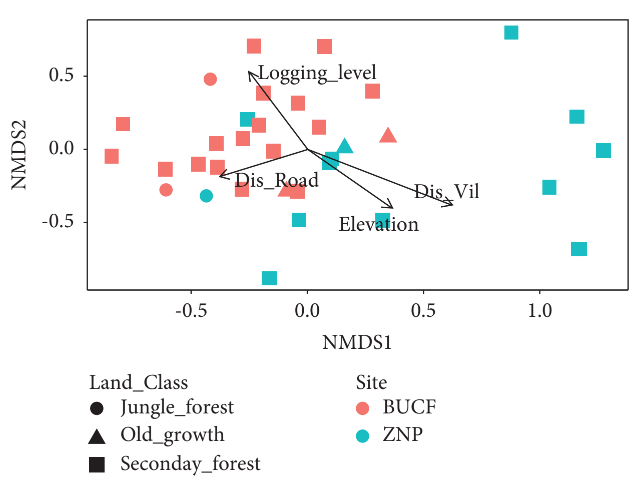


Figure 11: NMDS ordination of significant environmental variables.

anticipated that the similar level of species richness in the ZNP to the nearby unclassified forest (BUCF) was caused by previous heavy logging, the exploitation of forest products, and human intrusion. The ZNP became a protected area (PA) in 2022. We predict that the ZNP plots will evolve into

Table 8: NMDS scores of environmental variables.

| Variables | NMDS1 | NMDS2 | $p$ value |
|---|---|---|---|
| Elevation | 0.3584668 | −0.42761819 | 0.002 |
| Slope | −0.2444795 | 0.10440320 | 0.329 |
| Logging level | −0.2534578 | 0.5300098 | 0.004 |
| Aspect | −0.0691470 | −0.11087101 | 0.764 |
| Distance to village | 0.6187588 | −0.39816994 | 0.001 |
| Distance to road | −0.3827346 | −0.17037371 | 0.053 |

Table 9: Average values, standard errors, and $p$ values of environmental variables between BUCF and the ZNP by the Wilcoxon rank sum test.

| Variables | BUCF | ZNP | $W$ value | $p$ value |
|---|---|---|---|---|
| Elevation | 422.00 ± 43.3 | 598.00 ± 65.90 | 77 | 0.036 |
| Slope | 12.50 ± 1.58 | 13.20 ± 2.02 | 127 | 0.749 |
| Aspect (%) | | | 38 | 0.560 |
| South | 14.29 | 15.38 | | |
| North | 4.76 | 0 | | |
| East | 4.76 | 23.08 | | |
| West | 28.57 | 0 | | |
| Southeast | 14.29 | 46.15 | | |
| Southwest | 14.29 | 0 | | |
| Northeast | 9.52 | 7.69 | | |
| Northwest | 9.52 | 7.69 | | |
| Land class (%) | | | 7 | 0.369 |
| Jungle forest | 5.88 | 2.94 | | |
| Old growth | 5.88 | 2.94 | | |
| Secondary forest | 50.00 | 32.36 | | |
| Logging level (%) | | | 7 | 0.383 |
| High | 14.71 | 8.82 | | |
| Medium | 35.29 | 5.88 | | |
| Low | 11.77 | 23.53 | | |
| Distance to village | 2.78 ± 0.25 | 5.32 ± 0.52 | 40 | 0.001 |
| Distance to road | 2.20 ± 0.24 | 1.55 ± 0.37 | 186 | 0.082 |

excellent forest conditions if they are sufficiently protected under the PA status. The large-diameter trees (dbh > 60 cm) considerably contribute to biomass; thus, the increasing frequency of these giant trees in the ZNP (Figure 7) may increase structural variability and the forest's capacity to store carbon [68].

According to the distribution of the families, Verbenaceae (12.9%), Burseraceae (9.9%), and Dipterocarpaceae (9.9%) are the families with the highest representation in the BUCF. The family with the highest representation in the ZNP plots is Euphorbiaceae (7.2%), followed by Dipterocarpaceae (6.7%) and Combretaceae (6.5%). The highest abundance of Euphorbiaceae in the ZNP mirrored a feature of tropical forests reported by the study of the tropical forest in the Congo [69]. However, Verbenaceae, Burseraceae, Dipterocarpaceae, and Combretaceae are distinctive families to the tropical mixed deciduous forests frequently disturbed by logging activities [29]. The abundance of Fagaceae and Fabaceae in some plots proves the old age or maturity of the

Table 10: Spearman correlation coefficients of forest structure and species diversity of 34 sampling plots related with environmental variables.

| Parameters | Elevations | Slopes | Distances to the village | Distances to road |
|---|---|---|---|---|
| Average dbh (cm) | 0.2828113 | 0.2186402 | 0.2073338 | 0.2748663 |
| Total basal area ($m^2$) | 0.3124523 | −0.1639419 | 0.4362108** | −0.2385027 |
| Maximum height (m) | 0.04890349 | −0.2026439 | 0.2332085 | −0.3947429** |
| Shannon diversity | 0.4169595** | 0.036822 | 0.3191749 | 0.1792208 |
| Simpson diversity | 0.6030558*** | 0.1446906 | 0.4664629** | 0.3262032 |
| Pielou's evenness | 0.4282659** | 0.1880825 | 0.281589 | 0.4771581** |

The correlation is considered significant at $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

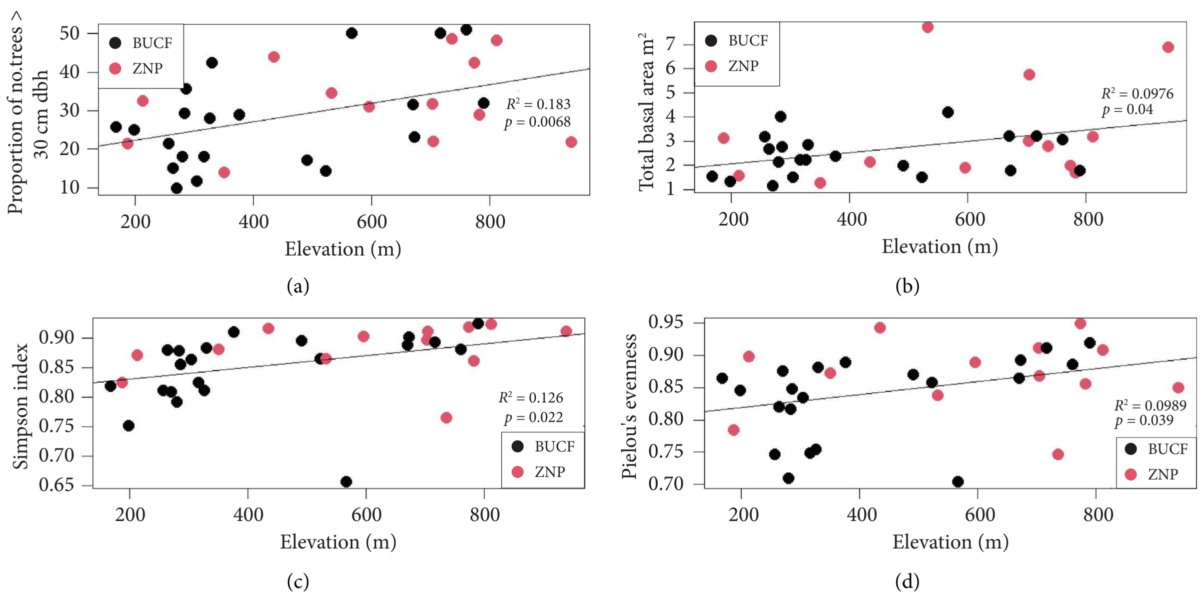


Figure 12: Linear regressions of (a) proportion of tree species >30 cm·dbh, (b) total basal area, (c) Simpson's index, and (d) Pielou's evenness with the elevation.

forest [28, 69]. Each forest lacked a few families. For example, Apocynaceae, Caesalpiniaceae, Convolvulaceae, Lecythidaceae, and Ulmaceae were found in BUCF but not the ZNP. Oleaceae, Capparaceae, Juglandaceae, Lythraceae, and Tetramelaceae did not appear in BUCF while present in the ZNP. Elevation patterns, logging levels, and access to roads and settlements throughout the sample plots help explain the compositional variances of different families (Figures 10 and 11).

The IVI gives a total picture of the social structure of species in a community and can be used to form an association of dominant species [70]. Our results indicated that *Protium serratum*, *Dipterocarpus alatus*, *Tectona grandis*, *Dillenia pentagyna*, *Schleichera oleosa*, and *Xerospermum noronhianum* had the highest IVI (>15%), reflecting their relatively high ecological importance in the study area. However, compared to the ZNP, BUCF revealed lower IVI and proportionately fewer trees per unit area for *Baccaurea sapida*, *Dracontomelon dao*, *Terminalia crenulate,* and *Xerospermum noronhianum*. *Dalbergia oliveri*, *Dillenia pentagyna*, *Schleichera oleosa*, and *Tectona grandis* had lower IVI and densities in the ZNP than in BUCF plots. Importantly, *Tectona grandis* (teak) had the best relative density in BUCF but severely decreased numbers in the ZNP. The lower tree density of teak in the ZNP may be due to the effects of previous extensive logging by the government before its declaration as a national park. Due to its better wood quality and higher demand than other species, the overuse and overharvesting of teak causes the deterioration of forests and biodiversity [68, 71]. Our results highlighted that *Tectona grandis*, *Dalbergia oliveri*, and *Protium serratum* had been overharvested in the ZNP plots resulting in a lower relative density and IVI. This finding suggested that the last logging activities significantly affected the abundance and dominance of certain commercially important tree species in the ZNP. In the ZNP, 23 species (27.38%) of all species exhibited the lowest IVI (<1%), while 32 species (35.16%) of those in BUCF did the same. The species with the lowest IVI ratings, including *Melastoma* spp. (Melastomataceae), *Atalantia monophyla* (Rutaceae), *Zanthoxylum* spp. (Rutaceae), and *Dalbergia* spp. (Fabaceae), are all tolerant to considerable shade. Due to their higher mortality, slower development, and reduced dispersion capacity, shade-tolerant species are more vulnerable to disturbance and fragmentation [72] than light-demanding species such as *Tectona grandis*, *Terminalia crenulata*, and *Dillenia pentagyna*, which showed greater IVI. Controlling fragmentation-induced human activities and using specific silvicultural techniques, such as enrichment planting, are necessary if these tree species are to be conserved and managed to enhance their ecological value.

Variations in structural attributes (tree density, dbh, basal area, and height) were affected by many factors and varied between species [73]. The structural characteristics of woody vegetation were associated with forest types, land uses, human activities, and environmental factors such as elevation, slope, aspect, soil, and light conditions [74, 75]. The peculiarities of the habitat preferences and favoured light conditions affect *Tectona grandis*'s much higher tree density in BUCF than in the ZNP [66]. Human activities like logging and exploiting forest products leave gaps in the forests, which may help certain species respond positively to light conditions [76]. In the ZNP, *Dipterocarpus alatus* performed slightly better than BUCF in tree density, dbh, basal area, and height. The dominance of *Dipterocarpus alatus* (IUCN endangered species) demonstrated its habitat preferences and the significance of its protection. *Dalbergia oliveri* (IUCN endangered species) showed lower tree density, dbh, basal area, and height compared to *Dipterocarpus alatus*, demonstrating its lower dominance in the tree community. The fact that the villager favour *Tectona grandis*, *Dalbergia oliveri*, and *Terminalia crenulata* for housing, firewood, and income may help to explain the frequency and dominance of *Dipterocarpus alatus* in the study area (source: the authors' unpublished interview data in April 2022).

*4.2. Do Variations in Species Composition Relate to Environmental Factors?* The logging intensity appears to be highly influential on tree species present in the jungle and secondary forest of BUCF (Figure 11). Logging operations favour light-demanding species such as *Tectona grandis*, *Aporusa roxburghii*, *Schleichera oleosa*, and *Dipterocarpus alatus* in the BUCF jungle and secondary forests since light influences the abundance and dominance of pioneer and light-demanding species [77, 78]. The dominance of *Dracontomelon dao* in ZNP's secondary forest seemed to be influenced by elevation (Figures 10 and 11). This endorsed the species' predilection for elevation up to 500 m above the sea level in the ZNP [79]. The prevalence of *Dillenia pentagyna* and *Terminalia chebula* in BUCF plots near roads may be owing to their less-desirable timber (Figures 10 and 11). Local populations use these two species for food and medicine, not for wood. The greater distance to the village affects the considerable composition of *Swintonia floribunda* (used as firewood) in the secondary forest of the ZNP, presumably due to the species' lessened stress from being far away from populated areas. NMDS ordination indicated that BUCF plots clustered closely while ZNP plots were more dispersed (Figures 10 and 11). The presence of different species in each plot may help explain some of the dispersion seen in the ZNP. In the current study, we exclusively evaluated parts of the ZNP that are accessible and are under significant human danger, restricting the species composition and richness of the species. We suggested that additional edaphic factors, such as soil properties and moisture, along with canopy openness, may affect changes in tree composition.

*4.3. Do the Stand Structure and Floristic Diversity Relate to Environmental Factors?* In the current research, higher altitudes, which are not easily accessible to gather forest resources, tended to have a significantly higher number of trees, more giant than 30 cm·dbh, a larger basal area, and more diverse, and evenly distributed tree species (Figure 12). Evidence suggests that human activities such as harvesting wood and forest products at lower elevations diminish the diversity of tropical forest tree species [80, 81]. The steeper slope has a favourable relationship with species diversity and evenness owing to difficult logging access but a negative link with the basal area and height may be due to a natural process of loosening soil structure [82], which may influence the growth of trees (Table 10). There was a favourable relationship between tree species' dominance, diversity, and evenness and the distance of sample plots from the villages and roads (Table 10). Due to easy accessibility from the villages and road network, unlawful logging reduces tree species' dominance (basal area), diversity, and evenness. According to several studies, tree species' abundance, dominance, and diversity are all impacted by logging and the exploitation of forest products [83–86]. However, some studies claimed that logging creates gaps in the forest that allow shade-intolerant species to regrow and thrive, increasing their range and dominance [78, 87, 88].

*4.4. Consequences for Conservation inside and outside of the Protected Area.* Two of the 116 total species, *Dalbergia oliveri* and *Dipterocarpus alatus* (IUCN endangered species), were discovered in both BUCF and the ZNP, demonstrating their moderate dominance and tree density per hectare. The remnant forests of BUCF (outside PA) had a higher frequency and dominance of these two endangered species, suggesting its potential to boost biodiversity conservation. However, several studies have shown that protected areas promote greater abundance and dominance of endangered species, which contradicts this finding [35, 89–91]. The studied forests provide ecological services and assist local economies by giving timber, firewood, medicinal plants, and food supplies. The profusion of high-quality timber species like *Tectona grandis*, *Dalbergia oliveri*, *Dalbergia stipulaceae*, *Chukrasia velutina*, *Gmelina arborea*, *Quercus glauca*, and *Shorea* spp. showed that forests could be crucial seed sources for future regrowth. However, an efficient conservation approach is needed to reduce overexploitation, which perils these species' survival, particularly in BUCF. The three prominent species in both sites, *Baccaurea sapida*, *Dracontomelon dao*, and *Dillenia pentagyna* provide the bulk of edible food supplies for surrounding local populations. *Cinamomum obtusifolia*, *Millettia cinerea*, *Garcinia paniculata*, and *Millingtonia hortensis* were known to be medicinal and economically important species for local communities via the sale of these medicinal plant parts; yet, they prevailed in the ZNP.

Our study showed that the ZNP requires effective conservation compared to species richness in other protected areas in Myanmar [25, 26, 65]. However, the proximity of the sample plots to human-dominated areas may explain the restricted diversity of the species. In addition, selective logging was widespread in the ZNP before 2011, and local people's continuing harvest of forest products might affect the dominance and diversity of economically important species. We suggested that the ZNP would recover richer vegetation by the year after protection. The whole part of the ZNP is said to have various types of forest, including evergreen, deciduous, dry dipterocarp, low indaing (a seasonally dry tropical forest), and native flora and wildlife [43], although official statistics are not available. The whole part of the ZNP could contain more species diversity than the current research. For instance, a recently discovered endemic plant species from Myanmar, *Sapria myanmarensis* (Rafflesiaceae), was only found in Kachin State and the Sagaing Region, encompassing the ZNP [92].

Many tree species recorded in the BUCF with a high dominance were commercially valuable timber species. It was mistakenly believed that the BUCF region has minimal conservation importance, as it is an open forest environment and is not officially protected as a reserved forest. Our research indicated that while BUCF jungle forest plots have low basal area, old-growth and secondary forest plots are rich in economically relevant species. However, the BUCF is imperilled by road development, human habitation, agriculture encroachment, and illicit logging. The continued fragmentation of the habitat of the BUCF will probably increase the disturbance to the nearby ZNP. Many studies reported that increased human disturbances quickly become problematic in conserving protected areas in Myanmar and tropical Asia [93–96]. For this reason, we urge the remaining forests of the BUCF to be acknowledged as an ecosystem of a high conservation value to protect its biodiversity and economic viability. Community forest management ensures the participation of the local community in forest management by granting 30-year land use rights and removing forest products [97]. Community forests should be established in the BUCF's degraded forest land to enable local engagement in forest management and potentially lessen stress inside the ZNP.

## 5. Conclusion and Recommendation

Through our study, we determined the vegetation structure and diversity in and around the ZNP and how the composition of tree species had varied in response to various environmental factors. Despite the human impact on forests, the high richness and basal area of valuable timber species suggest that these forests remain essential for human well-being. Numerous medicinal plant species, including *Lannea coromandelica*, *Cinamomum obtusifolia*, *Millettia cinerea*, *Garcinia paniculata*, and *Millingtonia hortensis*, are present in the ZNP, demonstrating a high congruence of conservation values and meriting protection for both biodiversity and human security. The dominance of two endangered tree species, *Dipterocarpus alatus* and *Dalbergia oliveri*, in BUCF presents a high conservation value and demands special attention in conservation planning. The research found that even if the densities of commercially relevant tree species are declining in the ZNP and maintaining their big-diameter trees is favourable. Establishing permanent sample plots would be a helpful alternative for future evaluation to track the effectiveness of the protected area and assess the dynamics and natural regeneration of certain tree species in the ZNP. Moreover, the assisted natural regeneration and enrichment planting of valuable tree species should be promoted in degraded areas of the ZNP.

As the primary goals for establishing protected areas are to conserve forests and biodiversity, park managers focus mainly on conservation inside the park. We can understand the importance of protecting the ZNP as a PA. However, to effectively conserve the biodiversity of the ZNP, it is necessary to preserve it in the adjacent BUCF. Due to easy accessibility, unclassified forests are more prone to species compositional fluctuation and loss. Thus, forest managers should take action to regularize the local exploitation of specific tree species in BUCF. Controlling firewood collection and illicit logging will be crucial in unclassified forest ecosystems. Encouraging fast-growing tree species for firewood plantations in nearby villages might satisfy the people's fundamental demands for firewood and poles. The local populations who depend on and live close to forests know the potential of tree species diversity and the value of ecological sustainability [98]. We expect nearby communities to actively participate in forest management and conservation efforts to ensure long-term sustainability. Myanmar's biodiversity and protected areas legislation allows the sustainable use of the buffer zone [99]. Therefore, creating buffer zones within and outside the ZNP may balance the competing interests of biodiversity protection and socioeconomic development. The favourable stand density and species richness of BUCF provide a future avenue for conservation. In the jungle areas of the BUCF, community forestry development might encourage local participation in forest management, therefore decreasing poverty and reliance on the forest in the park's core part. This study does not indicate that the protected areas are unnecessary. Instead, the findings of this study suggest that if the remaining natural habitats in the BUCF, where humans collect forest resources, are effectively managed to encourage native species to persist, we may gain enormous biodiversity both inside and outside the protected area.

## Data Availability

Some of the data used to support the findings of this study are included within the article and the supplementary materials, and the remaining data (figures and tables in R and Excel) are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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## Supplementary Materials

Appendix: the IVI lists of tree species in the ZNP and BUCF. (*Supplementary Materials*)

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