



## Highlighted Student Research

## Comparison of tree community structure in lower and upper montane forests of Mount Kampalili, Davao de Oro, Philippines

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**ABSTRACT:** Mount Kampalili, part of the Eastern Mindanao Biodiversity Corridor, is recognized as a Key Biodiversity Area due to its concentration of Mindanao-endemic, rare, and threatened species; however, its montane forest composition and structure remain poorly documented. This study addresses this gap by providing a comprehensive assessment of tree community structure and diversity between the lower montane forest (LMF) and upper montane forest (UMF) of Mt. Kampalili. Tree communities were surveyed using 2-km transects in each forest type, and species composition, diversity indices, importance values, and similarity patterns were analyzed. A total of 101 tree species from 42 families were recorded, including 23 Philippine endemics and 26 threatened taxa. Diversity indices revealed high species richness and evenness in both forest types (Shannon-Wiener index  $H' = 3.75$ ; Simpson's index  $1-D = 0.96$ ; Pielou's evenness  $J = 0.81$ ), indicating a species-rich and well-structured forest community. Cluster analysis based on Bray-Curtis similarity revealed distinct separation between LMF and UMF plots, indicating clear elevational structuring of tree assemblages. Species with highest importance values (SIVs), such as *Dacrycarpus imbricatus* and *Lithocarpus caudatifolius* exhibited broad elevational distributions, suggesting ecological generalism, while several endemic and threatened taxa were restricted to specific elevation zones. These findings demonstrate that elevational gradients play a key role in shaping the tree community compositions in Mt. Kampalili and that both montane forest zones contribute distinct assemblages to overall plant biodiversity. The presence of diverse, elevation-stratified, and conservation-relevant tree communities highlights the ecological significance of Mt. Kampalili within regional forest conservation efforts.

**KEY WORDS:** Mindanao biodiversity corridor, montane forests, terrestrial ecosystem, tree diversity, vegetation analysis.

### INTRODUCTION

The Philippines harbors one of the world's most diverse forest floras, with tropical mountain forests recognized as hotspots of species richness and endemism due to steep environmental gradients and habitat heterogeneity (Aureo *et al.*, 2021). In montane systems, elevational gradients strongly influence abiotic factors such as temperature, moisture, and soil conditions, which in turn shape species turnover and community assembly through environmental filtering and niche differentiation (Wang *et al.*, 2022).

The Philippine montane forests form a mosaic of vegetation types, each characterized by distinct physiognomy and floristic composition influenced by elevation, topography, substrate, and soil moisture (Fernando, 2008; Malabrigo *et al.*, 2017). Two principal forest types are recognized along elevational gradients: lower montane forests (750 – 1,500 masl) and upper montane forests (1,500 – 3,000 masl) (Fernando, 2008; Coritico *et al.*, 2020). Lower montane forests are generally found along mountain ridges, characterized by high humidity, evenly distributed rainfall, and dry mountainous soils. Upper montane forests, in contrast,

occur at higher elevations where cooler temperatures, frequent cloud cover, and persistent moisture promote the growth of mosses, liverworts, ferns, and other epiphytes on tree trunks and branches (ERDB, 2012; DENR-BMB, 2021). Despite their ecological importance, quantitative assessments of montane tree communities along elevational gradients remain limited in many Philippine mountain ranges (Aureo *et al.*, 2021), particularly in Eastern Mindanao. The Eastern Mindanao Biodiversity Corridor (EMBC), covering approximately 2 million hectares, represents a complex landscape of forests supporting high biodiversity, including numerous endemic and rare taxa (Forest Foundation Philippines, 2024). Within this corridor, Mount Kampalili (~2,396 masl), together with Mount Puting-Bato and Mount Mayo, forms the second-largest Key Biodiversity Area (KBA), spanning ~169,908 ha and encompassing both lower and upper montane forests. Surveys on Mt. Kampalili have documented seven globally threatened plant species (Ibañez and Delima-Baron, 2011), and the area also holds cultural significance as the ancestral domain of the Mandaya Indigenous Peoples (Nabayra, 2014). However, Mt. Kampalili faces ongoing threats from slash-and-burn agriculture, abaca cultivation



expansion, logging, road construction, and mining leading to forest degradation, habitat fragmentation, and loss of ecosystem services (Balet *et al.*, 2010; Rowsey *et al.*, 2022; Hending *et al.*, 2023). While research in EMBC has primarily focused on faunal inventories (Cadayona and Medina, 2025; Rowsey *et al.*, 2022; Yangurin *et al.*, 2025), data on forest structure and tree community composition remain unexplored. This lack of ecological baseline information limits the development of comprehensive and targeted conservation strategies within this Key Biodiversity Area.

This study addresses that gap by comparing the tree community composition and diversity between the lower montane forest (LMF) and upper montane forest (UMF) on Mt. Kampalili. As a baseline study, we adopted an exploratory approach to evaluate variation in community structure and diversity across these two forest types. Findings from this research provide necessary baseline data on conservation policies for Mt. Kampalili and add new findings on Philippine terrestrial biodiversity as part of SDG 15: Life on Land.

## MATERIALS AND METHODS

### Permits and Clearances

All necessary permits and clearances were secured prior to the conduct of the study. These include certificates and clearances from the National Commission on Indigenous Peoples – Davao de Oro Provincial Office (NCIP–DdOPO), the Barangay Local Government Units of Langawisan and Bahi. In addition, a Wildlife Gratuitous Permit (WGP No. XI-2023-08) was obtained from the Department of Environment and Natural Resources (DENR) Region XI, authorizing the collection of voucher specimens for taxonomic verification.

### Study Area

The study was conducted in the lower montane forest (LMF) and upper montane forest (UMF) of Mount Kampalili, located within Sitio Kaluyapi, Barangay Langawisan, Municipality of Maragusan, Davao de Oro, Mindanao, Philippines (Fig. 1), from January 2023 to July 2023. A reconnaissance survey was conducted to determine optimal transect line placement, with routes selected based on landscape heterogeneity, ecological representativeness, and accessibility, following the approach of Zapanta *et al.* (2019). Forest types within the study area were classified in accordance with the criteria of Fernando (2008), primarily based on elevation range and characteristic vegetation composition.

### Site Description

The first sampling site is a lower montane forest (Fig. 1C, pink dots), with elevation ranging from 1,198 meters above sea level (masl) at the lowest plot to 1,551 masl at the highest. A gradual transition to upper montane forest

was observed (Fig. 2A), as indicated by the increasing moss abundance and coverage. The area exhibited moderate anthropogenic disturbance, primarily from agricultural clearings due to abaca cultivations (Fig. 2C) and scattered households. Soils ranged from loam to clay, and a small stream was located approximately 500 m from the transect. The second sampling site (Fig. 1C, blue dots) is an upper montane forest, following the elevation-based classification of Fernando (2008) and corresponding to the mossy forest type described by Heaney and Regalado (1998). Elevation at this site ranged from 1,586 masl to 1,997 masl. This site had persistent fog conditions, which contributed to cooler temperatures and extensive moss cover on both trees and the forest floor (Fig. 2B). Human disturbance was relatively minimal. The vegetation was dominated by large canopy trees and palms, with a diverse understory composed mainly of shade-tolerant herbs, ferns, and lycophytes.

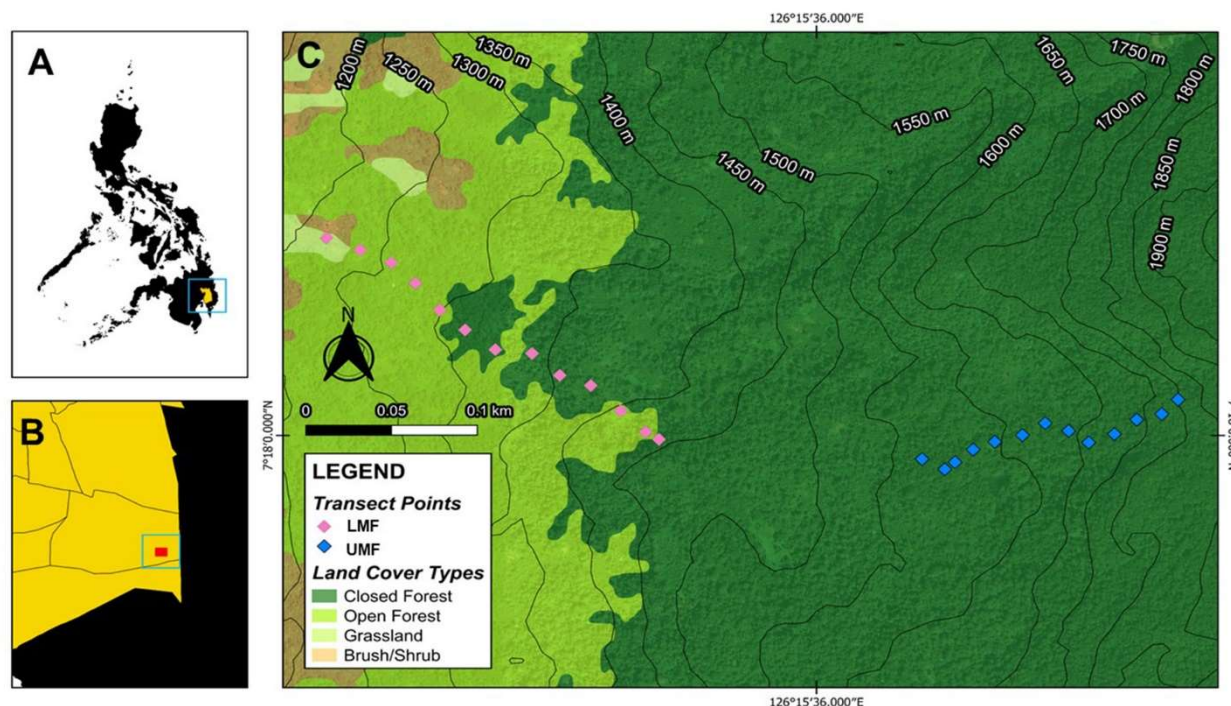
### Sampling techniques

To systematically sample tree communities, a 2-km belt transect was established in both lower and upper montane forests of Mt. Kampalili. Twenty plots (20m × 100 m) were positioned along each transect at 100 - meter intervals, for a total of 40 plots, covering an area of 40,000 m<sup>2</sup> per forest type. Geographic coordinates and elevation were also recorded at 100 – meter intervals along each transect to characterize the elevational gradient. While the transect generally followed established hiking trails, deviations of approximately 2 to 5 m were occasionally made to avoid impassable terrain and ensure continuous sampling coverage. We employed a belt transect method (Grant *et al.*, 2004), which involves enumerating all tree individuals within the designated plots. All trees with a diameter at breast height (DBH) greater than 5 cm were recorded in accordance with DENR-BMB (2017) guidelines.

### Tree species identification

The team identified the trees in situ at the lowest possible taxonomic level. For specimens that could not be conclusively identified in the field, detailed morphological descriptions were meticulously recorded. These included growth habit, leaf arrangement and shape, bark texture, and the presence and characteristics of reproductive structures such as inflorescences and fruits. Photographs and voucher specimens were also collected to support subsequent ex-situ verification.

Tree specimens with uncertain identification were further examined with the assistance of a professional plant taxonomist. Herbarium specimens were collected for verification and performed using several online taxonomic databases, including Co's Digital Flora of the Philippines (<https://www.philippineplants.org>), Plants of the World Online (<https://powo.science.kew.org>), and the International Plant Names Index (<https://www.ipni.org>).



**Fig. 1.** Map showing the location of the study site. **A.** Philippines, **B.** Mt. Kampalili, Mindanao, **C.** transect lines set in the lower (LMF) and upper (UMF) montane forests of Mt. Kampalili, located between 7° 18' 0.00" N latitude and 126° 15' 36.00" E longitude. Maps were generated using QGIS v. 3.42.



**Fig. 2.** Landscape of Mt. Kampalili showing **A.** vertical view of the mountain, **B.** upper montane forest with foggy condition and extensive moss cover, and **C.** lower montane forest with presence of abaca plantation.

The herbarium specimens collected were deposited in the Department of Biological Sciences and Environmental Studies Herbarium Facility, University of the Philippines Mindanao campus. All plant photographs were archived in a Google Drive repository.

For tree parameters, diameter at breast height (DBH) was measured following the protocols of Curtis and Marshall (2005) and Lennertz *et al.* (2017). Measurements were taken at 1.3 meters above the ground on the uphill side of each tree using measuring tapes and tree calipers. The tree height was measured using a

TruPulse® 200X Laser Rangefinder. When trees were difficult to access or located on steep slopes, parameter estimates were provided by the field forester using the Tangent Method and other indirect techniques, following the protocols by Larjavaara and Muller-Landau (2013).

#### Distribution and conservation status

The distribution status of recorded tree species was based on Co's Digital Flora of the Philippines ([www.philippineplants.org](http://www.philippineplants.org)), and each identified species was classified as native, endemic, or introduced following the approach of Lleno *et al.* (2023). Meanwhile, the conservation status of each identified species was cross-referenced using the international IUCN Red List (2025-2) and the local DENR Administrative Order No. 2017-11 classifications. Categories common to both systems such as Vulnerable (VU), Endangered (EN), Critically Endangered (CR), along with Other Threatened Species (OTS) from DAO 2017-11, were grouped as Threatened species. This information is essential for assessing extinction risk and providing a scientific basis for prioritizing conservation actions and informing biodiversity management and policy decisions in Mt. Kampalili.

#### Data Analyses

**Species similarity composition:** To assess the similarity in tree species composition between the two forest types, the Bray-Curtis similarity index was used, with values ranging from 0 (no similarity) to 1 (complete similarity) (Bray and Curtis, 1957). Cluster analysis was



performed using tree species abundance data across 40 sampling plots. Similarity among plots was further analyzed based on the presence-absence of the most abundant tree species in each plot. A dendrogram was generated using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) in PAST software Version 5.2.2 (Hammer and Harper, 2001) to visualize clustering based on species composition.

**Tree diversity and vegetation structure:** To assess and compare tree diversity between the lower and upper montane forests of Mt. Kampalili, this study adopted standard methods used in both local and international vegetation studies (Amoroso *et al.*, 2012; Lillo *et al.*, 2019; Aureo *et al.*, 2020; Herrmann *et al.*, 2022). Species richness and abundance data from all plots were used as input for diversity analyses. Standard diversity metrics included the Shannon–Wiener, Simpson’s, and Pielou’s Evenness indices, with values interpreted according to established classification schemes (Fernando, 1998, as cited in Aureo, 2020; Guajardo, 2015; and Napaldet, 2023). Calculations were performed using PAST software (Hammer and Harper, 2001). Thereafter, we produced a sample-based individual rarefaction curve to measure the sampling effort. Because the data did not meet normality assumptions, a two-sample Mann–Whitney U test was applied to test for differences in tree diversity between the two forest types.

After computing all the diversity indices, the obtained values were interpreted using their respective classification schemes by the following studies as presented below:

Shannon-Wiener index values proposed by Fernando (1998, cited in Aureo, 2020).

Shannon-Wiener Index Score	Relative Values
3.50 – above	Very high
3.00 – 3.49	High
2.50 – 2.99	Moderate
2.00 – 2.49	Low
0.00 – 1.99	Very low

Simpson’s index values according to Guajardo (2015).

Simpson’s Index Score	Interpretation
0.00	Absence of diversity (homogeneity)
0.01 – 0.40	A low degree of diversity/heterogeneity
0.41 – 0.60	A moderate degree of diversity/heterogeneity
0.61 – 0.80	A moderately high degree of diversity/heterogeneity
0.81 – 0.99	A high degree of diversity/heterogeneity
1.00	Absolute (perfect) diversity/heterogeneity

Pielou’s evenness index values according to Napaldet (2023).

Pielou’s Evenness Index Score	Interpretation
≥ 0.96–1.00	balanced
≥ 0.76 – 0.95	almost balanced
≥ 0.51 – 0.75	semi-balanced
≥ 0.26 – 0.50	less balanced
≤ 0.25	unbalanced

In addition to diversity indices, vegetation analysis was conducted to evaluate the structure of the tree communities across forest types. Parameters used included relative density, relative frequency, relative dominance (basal area), and importance value index (IVI), following methods from Amoroso *et al.* (2012), Ebate and Novero (2018), and Aureo *et al.* (2020). Relative density was determined as the proportion of individuals of a species to the total number of individuals of all species. Relative frequency was computed as the proportion of plots in which a species occurred relative to the sum of frequencies of all species. Relative dominance was calculated from the DBH of each tree using the formula  $BA = \pi \times (DBH/2)^2$ , and relative dominance of each species was determined as the proportion of its total basal area to the total basal area of all species. The Species Importance Value (IV) was then calculated as the average percentage of the relative density, relative frequency, and relative dominance of each species. These metrics provide insights into tree species composition and their ecological roles within each forest type. For the discussion, only the top five species with the highest IVI were highlighted to focus on the most ecologically important taxa within each montane forest type.

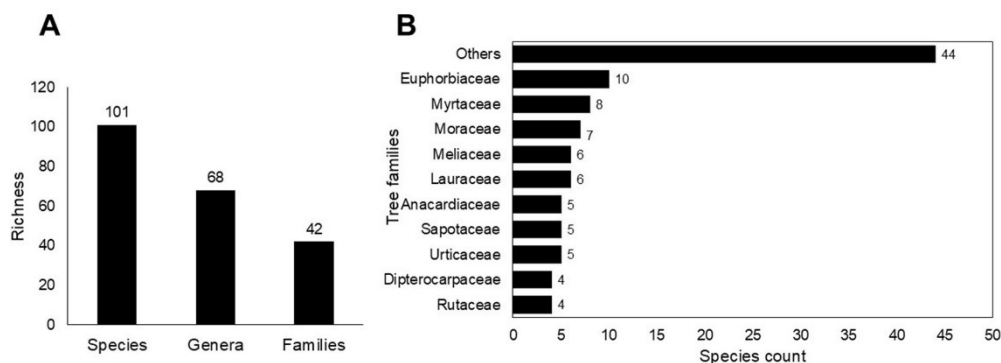
## RESULTS

### Tree composition, endemism, and conservation status

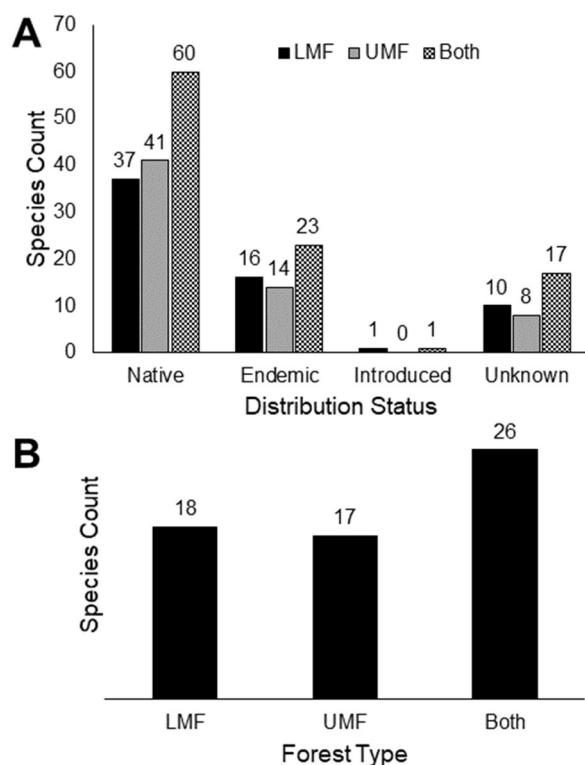
**Species composition:** The floristic survey in the lower montane forest (LMF) and upper montane forest (UMF) of Mount Kampalili documented a total of 101 tree species, encompassing 68 genera and 42 families (Fig. 3A; Table S1). Among these records, two species belong to Gymnosperm families, including Araucariaceae and Podocarpaceae represented by *Agathis philippinensis* (almaciga) and *Dacrycarpus imbricatus* (igem), respectively. The remaining 99 species belong to 40 Angiosperm families, and were distributed across both forest types.

Species richness and family-level representation in both the LMF and UMF revealed that Euphorbiaceae was the most species-rich family, with 10 recorded species, followed by Myrtaceae (8), Moraceae (7), and Meliaceae and Lauraceae (6 species each) (Fig. 3B). Anacardiaceae, Sapotaceae, and Urticaceae were each represented by five species, while Dipterocarpaceae and Rutaceae had four species each. Several other families were represented by three species or fewer.

The study recorded a total of 26 tree species were common to both forest types (Table S1). The number of species exclusively found in each forest type was nearly equal, with 38 species found solely in the LMF and 37 species restricted to the UMF. When accounting for both unique and shared species, the LMF harbored 64 species, while the UMF contained 63 species. These findings indicate a comparable level of species richness between



**Fig. 3.** Tree species composition in Mt. Kampalili, Davao de Oro, Philippines. **A.** Documented trees encompassing species, genera, and families. **B.** Top 10 tree families with the highest number of representative species. The 'Others' category includes all families with fewer than three representative species.



**Fig. 4.** Distribution status of tree species recorded in the lower montane forest (LMF) and upper montane forest (UMF) of Mt. Kampalili. **A.** Distribution status of trees ("Unknown" indicates distribution undetermined due to identification only at the family or genus level); **B.** Number of threatened tree species per forest type.

the two forest types, despite noticeable differences in species composition.

**Endemicity and conservation status:** A total of 60 native tree species, representing 60% of the total species recorded, were identified in both forest types of Mt. Kampalili. Of these tree species, 23 species (23%) were endemic to the Philippines (Fig. 4A). However, 17 species (17%) remain unidentified at the species level, leaving their distribution statuses undetermined. Comparisons between

**Table 1.** Total number of threatened tree species per category based on IUCN 2025-2 and DAO 2017-11 classifications. Legend: NE: Not Evaluated; DD: Data Deficient; LC: Least Concern; NT: Near Threatened; OWS: Other Wildlife Species; OTS: Other Threatened Species; VU: Vulnerable; EN: Endangered; CR: Critically Endangered.

Conservation status	Categories	LMF	UMF	Both
IUCN 2025-2	NE	5	8	12
	DD	1	1	1
	LC	39	38	58
	NT	5	4	6
	VU	3	2	4
	EN	1	2	3
	CR	0	0	0
	<b>Total Threatened</b>	<b>4</b>	<b>4</b>	<b>7</b>
DAO 2017-11	OWS	39	40	63
	OTS	7	7	9
	VU	6	6	9
	EN	1	0	1
	CR	1	2	2
	<b>Total Threatened</b>	<b>15</b>	<b>15</b>	<b>21</b>
OVERALL TOTAL	Non-threatened	36	38	58
	Unknown	10	8	17
	<b>Threatened</b>	<b>18</b>	<b>17</b>	<b>26</b>

forest types revealed only slight differences in native and endemic species composition. The upper montane forest (UMF) contained more native species than the lower montane forest (LMF) (UMF = 41 vs. LMF = 37), but fewer Philippine endemics (UMF = 14 vs. LMF = 16) (Fig. 4A). The results suggest that variation in tree floristic composition along the elevational gradient in Mt. Kampalili is modest and does not strongly reflect classical expectations of elevational patterns in species richness and endemicity.

Moreover, threatened species were notably well represented in both forest types (Fig. 4B). Lower montane forests contained a slightly higher number of threatened species ( $n = 18$ ) compared with upper montane forests ( $n = 17$ ) (Fig. 4B). Of all species recorded, 26 (26%) are classified as threatened under either national or international conservation frameworks.

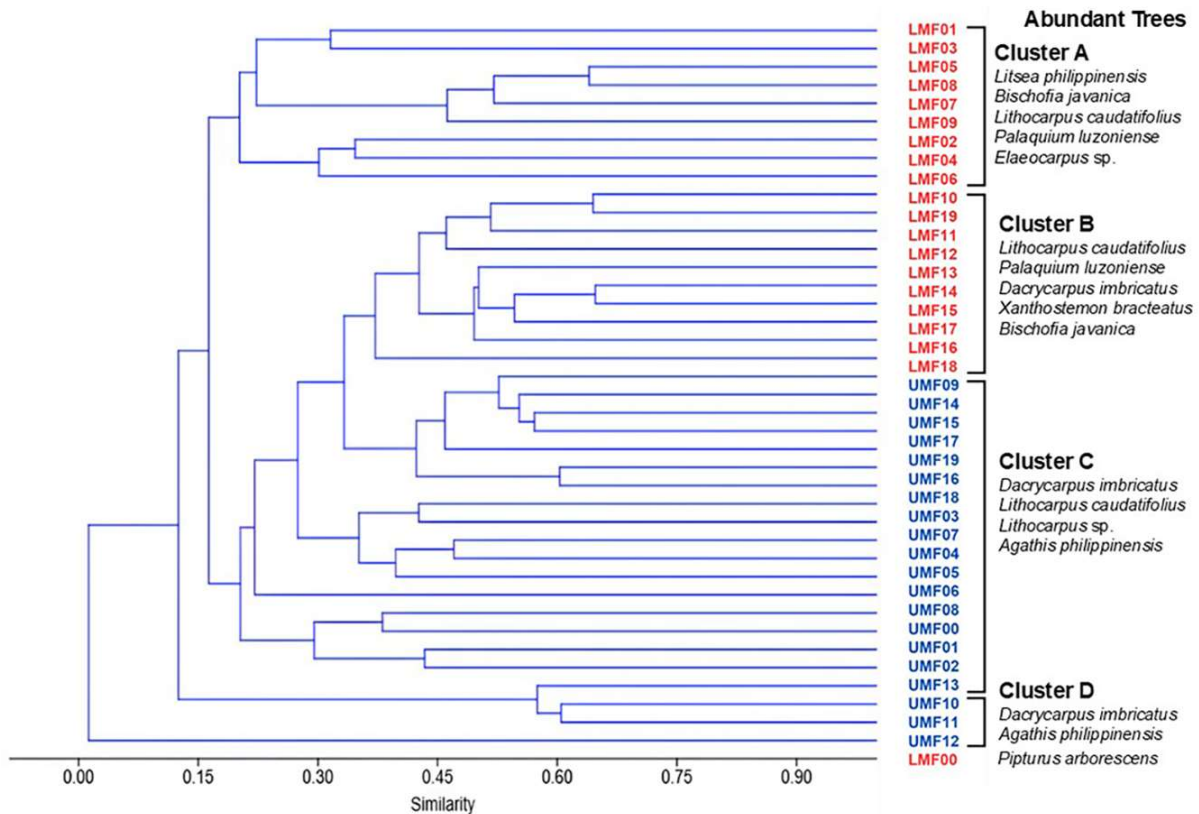


Fig. 5. Cluster dendrogram of 40 sampling plots by tree species composition in two forest types, with abundant species for each cluster indicated on the right. Cophenetic correlation = 0.8021 using Bray-Curtis Similarity Index and UPGMA algorithm.

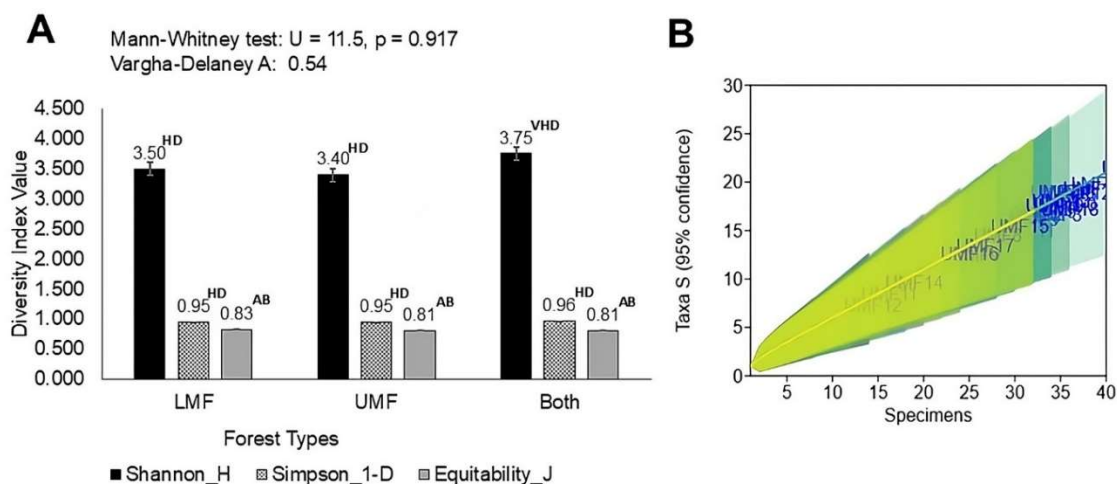
Seven (7) species appear in the IUCN Red List, including three Endangered species (*Shorea astylosa*, *Phoebe glabrifolia*, and *Magnolia pubescens*) and four Vulnerable taxa (*Saurauia copelandii*, *Clethra tomentella*, *Xanthostemon bracteatus*, and *Dendrocnide subclausa*) (Table 1).

At the national level, 21 species are recognized as threatened under DAO 2017-11, comprising nine as Vulnerable, one as Endangered, and two as Critically Endangered. Sixty three species are categorized as Other Wildlife Species, while nine are categorized as Other Threatened Species (Table 1). In this listing, *Madhuca betis* was the sole species listed as Endangered, while *S. astylosa* and *X. bracteatus* were classified as Critically Endangered.

These threatened species, either international or nationally categorized, belong to the families Dipterocarpaceae, Lauraceae, Magnoliaceae, Sapotaceae, and Myrtaceae each represented by at least one threatened species. These include *S. astylosa* (yakal), *P. glabrifolia* (kaburo), *M. pubescens* (hangilo), *M. betis* (betis), and *X. bracteatus* (mapilig), respectively. Most of these species are Philippine endemics, except for *M. betis* which is considered native. Overall, Mt. Kampalili supports a high number of endemic and threatened tree species underscoring its conservation importance.

### Tree species similarity in two montane forests

The dendrogram reveals five distinct clusters, reflecting variation in species assemblages between and within the two forest types (Fig. 5). Notably, sampling plots generally clustered according to forest type, with spatially proximate plots along the elevational gradients often grouping together. Clusters A and B correspond to lower montane forest (LMF) plots. Cluster A (LMF plots 1–9) is dominated by the families Lauraceae (*Litsea philippinensis*), Phyllanthaceae (*Bischofia javanica*), Sapotaceae (*Palaquium luzoniense*), Fagaceae (*Lithocarpus caudatifolius*), and Elaeocarpaceae (*Elaeocarpus sp.*), whereas Cluster B (LMF plots 10–19) is characterized by the dominance of Fagaceae (*Lithocarpus caudatifolius*), Sapotaceae (*Palaquium luzoniense*), Podocarpaceae (*Dacrycarpus imbricatus*), Myrtaceae (*Xanthostemon bracteatus*), and Phyllanthaceae (*Bischofia javanica*). In contrast, clusters C and D represent upper montane forest (UMF) plots. Most UMF plots are grouped under Cluster C, while Cluster D is restricted to plots 10–12 only but both are by the dominance of the gymnosperm families Podocarpaceae (*Dacrycarpus imbricatus*) and Araucariaceae (*Agathis philippinensis*). Meanwhile, the distinct position of the first LMF (LMF00) plot in the dendrogram is attributed to the presence of the unique species *Pipturus arborescens*,



**Fig. 6.** Comparison of tree diversity in the lower (LMF) and upper (UMF) montane forests of Mt. Kampalili using the Shannon-Wiener, Simpson's, and Pielou's evenness indices. **A.** Diversity indices for each forest type. **B.** Individual rarefaction per plot in two forest types. Superscripts HD high diversity; VHD very high diversity; AB almost balanced. Interpretations of indexed values are based on Fernando (1998), Guajardo (2015), and Napaldet (2023) for Shannon, Simpson, and Pielou's indices, respectively.

**Table 2.** Interpretation of diversity index values and the number of sampling plots for each category.

Index Values	Interpretation	Number of Plots	
<b>A. Shannon-Wiener Index (<math>H'</math>)</b>			
		LMF	UMF
3.50 – above	Very high	0	0
3.00 – 3.49	High	0	0
2.50 – 2.99	Moderate	5	5
2.00 – 2.49	Low	9	12
0.00 – 1.99	Very low	6	3
<b>B. Pielou's Evenness Index (<math>J</math>)</b>			
$\geq 0.96$ - $<1.00$	balanced	7	1
$\geq 0.75$ - $<0.95$	almost balanced	12	19
$\geq 0.5$ - $<0.75$	semi-balanced	0	0
$\geq 0.25$ - $<0.50$	less balanced	0	0
$\leq 0.25$	unbalanced	1	0
<b>C. Simpson's index (<math>1-D</math>)</b>			
1.00	perfect diversity	0	0
$\geq 0.80$ - $<1.00$	high diversity	19	18
$\geq 0.60$ - $<0.80$	moderately high diversity	0	2
$\geq 0.41$ - $<0.60$	moderate diversity	0	0
$\geq 0.01$ - $<0.40$	low diversity	1	0
0.00	homogenous	0	0

**Note:** Interpretations of indexed values are based on A: Fernando (1998), B: Napaldet (2023), and C.: Guajardo (2015). LMF= lower montane; UMF= upper montane.

which occurs exclusively in this plot. Overall, species exhibiting broad elevational ranges from lower to upper montane forests include *Lithocarpus caudatifolius* and the gymnosperm *Dacrycarpus imbricatus*, reflecting their ecological adaptability across various montane habitats.

### Diversity of trees in two forest types

Diversity analyses revealed that the two forest types of Mt. Kampalili supports a high level of tree diversity with a relatively even distribution of species altogether. The Shannon–Wiener diversity index ( $H' = \geq 3.40$ ) and

Simpson's Diversity Index ( $1-D = \geq 0.95$ ) both reflect this high diversity between forest types and in the pooled datasets (Fig. 6A). Pielou's Evenness Index ( $J = \geq 0.81$ ) further suggests an almost equitable distribution of individuals among species, indicating minimal dominance and a balanced tree community structure in both forest types and the entire mountain ecosystem. Closer examination of diversity metrics shows slightly higher tree diversity in the lower montane forest (LMF) compared to the upper montane forest (UMF). Individual-based rarefaction curves for both LMF and UMF (Fig. 6B) show a consistent increase in species richness with increasing numbers of individuals, without reaching a clear asymptote, suggesting that the sampling effort captured general richness trends but that additional sampling would likely detect more tree taxa in both forest types.

Moreover, with regard to the plot-level diversity (Table 2; Fig. 7), Shannon–Wiener suggests that most sampling plots in both forest types were classified as having low to very low diversity, with only five plots per forest type rated as highly diverse (Table 2). This relatively low Shannon–Wiener score may be attributed to several factors, such as a high proportion of rare or unique species occurring in only a few plots, low species richness and abundances across sampling sites, or localized dominance by certain taxa that reduces the logarithmic contribution of less common species to the index. In contrast, both Simpson's and Pielou's evenness indices showed an opposite trend, whereby most plots in both montane forests exhibited 'high diversity' and 'almost balanced' status. Despite these differences, the Mann–Whitney U test ( $U = 11.5$ ,  $p = 0.917$ , Vargha–Delaney A = 0.54) indicated no significant difference in diversity between the two forest types (Fig. 6). This means that the LMF and UMF have statistically comparable average diversity, despite substantial variation in diversity among individual plots.

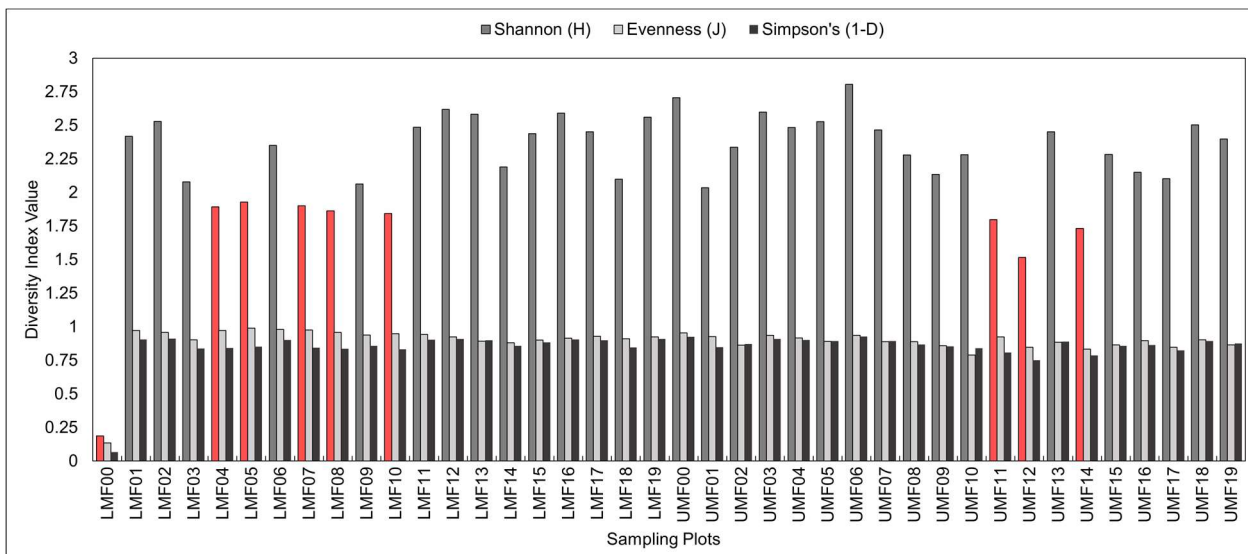


Fig. 7. Plot-level comparison of tree diversity in the lower (LMF) and upper (UMF) montane forests of Mt. Kampalili. Red bars indicate plots with 'very low' Shannon-Wiener diversity index.

Table 3. Vegetation analysis using the top five tree species by Species Importance Value (SIV) in lower and upper montane forests of Mt. Kampalili, Davao de Oro, Philippines.

Forest type/ Species Name	RF (%)	RD (%)	RD'(%)	SIV
<b>Both</b>				
<i>Dacrycarpus imbricatus</i>	4.98	7.10	37.38	16.49
<i>Lithocarpus caudatifolius</i>	5.98	11.38	14.74	10.70
<i>Cinnamomum mercadoi</i>	4.18	6.22	10.33	6.91
<i>Palaquium luzoniense</i>	4.38	5.15	4.99	4.84
<i>Bischofia javanica</i>	4.18	4.09	5.07	4.45
Others	76.29	66.06	27.49	56.62
<b>Lower montane</b>				
<i>Lithocarpus caudatifolius</i>	7.11	11.03	20.71	12.95
<i>Dacrycarpus imbricatus</i>	4.89	4.53	25.98	11.80
<i>Palaquium luzoniense</i>	7.11	8.63	11.00	8.91
<i>Bischofia javanica</i>	6.22	7.07	12.95	8.75
<i>Xanthostemon bracteatus</i>	3.11	0.00	11.48	6.04
Others	71.56	64.36	17.68	50.96
<b>Upper montane</b>				
<i>Dacrycarpus imbricatus</i>	5.11	9.24	32.75	15.70
<i>Cinnamomum mercadoi</i>	6.20	10.15	22.41	12.92
<i>Lithocarpus sp.</i>	5.11	11.40	15.58	10.70
<i>Agathis philippinensis</i>	2.55	8.78	8.50	6.61
<i>Lithocarpus caudatifolius</i>	2.55	4.90	7.01	4.82
Others	78.47	55.53	13.75	49.25

Note: RF= relative frequency; RD: relative density; RD': relative dominance; SIV: species importance value

Tree community structure

Table 3 summarizes the five tree species with the highest Species Importance Values (SIVs) for each forest type and across the combined lower and upper montane forests. In both forest types, the most ecologically dominant species were *Dacrycarpus imbricatus* (igem), *Lithocarpus caudatifolius* (ulayan), *Cinnamomum mercadoi* (kalingag), *Palaquium luzoniense* (red nato), and *Bischofia javanica* (tuai). Collectively, these species

account for a substantial proportion of the total SIV (43.38), underscoring their central role in shaping the structure and composition of Mt. Kampalili's montane forests. Moreover, *Xanthostemon bracteatus* (mapilig) was recorded exclusively in the lower montane forest of Mt. Kampalili.

Among these taxa, *D. imbricatus* recorded the highest SIV when both forest types were combined, reflecting its strong contribution to forest dominance and structural prominence in Mt. Kampalili. Meanwhile, *L. caudatifolius* ranked highest in relative density and frequency, indicating its widespread occurrence and consistent presence across sampling plots. This contrast suggests how species can attain ecological importance through different pathways, either through high abundance and broad distribution or through structural dominance.

With regard to dominance in each forest type, in the lower montane forest, *L. caudatifolius* was the most widespread and abundant species, whereas *D. imbricatus* had the highest contribution to the basal area. Other species, including *P. luzoniense*, *B. javanica*, and *X. bracteatus*, contributed smaller proportions to the total SIV. In the upper montane forest, *D. imbricatus* again had the highest dominance, followed by *C. mercadoi* and *Lithocarpus sp.* Across both forests, the "other" species collectively accounted for a large proportion of SIV, indicating high species richness and a diverse tree assemblage beyond the dominant taxa.

DISCUSSION

**Tree composition:** The tree species richness documented in Mount Kampalili is comparatively lower than that reported for mountain ranges such as Mt. Candalaga, Mt. Hamiguitan, and Mt. Apo. For example,



Baslot *et al.* (2013) recorded 141 tree species in unburned areas and 103 species in burned sites of Mt. Candalaga, both exceeding the 101 species identified in the present study. Similarly, Amoroso *et al.* (2009) reported 184 tree species across multiple forest types in the Mt. Hamiguitan Range Wildlife Sanctuary (MHRWS), including dipterocarp, montane, typical mossy, and mossy-pygmy forests. Notably, the montane (920–1160 masl) and typical mossy (1160–1350 masl) forests of MHRWS, which is comparable in elevation to Mt. Kampalili's lower and upper montane zones, had an average species richness of 27 and 14 species, respectively. In contrast, Mt. Kampalili's average was markedly lower at 11 species for lower montane forest and 13 for upper montane forest.

Species richness in Mt. Kampalili is also lower than in Mt. Apo Natural Park (MANP), where Zapanta *et al.* (2019) documented 136 tree species. While in comparison with other studies on tree diversity in the Philippines, Mt. Kampalili has higher tree species richness than Initao Libertad Protected Landscape and Seascape with 36 tree species (Canencia and Daba, 2015) and in Mt. Malinao, Albay in Luzon with 70 tree species (de Guzman *et al.*, 2014).

However, direct comparisons require caution due to differences in forest type representation, sampling intensity, and plot design. The MANP study employed five 2-kilometer transects spanning a broader range of habitats, including lowland forests, montane agroforests, and secondary-growth stands. In contrast, the MHRWS survey of Amoroso *et al.* (2009) involved 32 plots (20 × 20 m each) distributed across four forest types, with greater replication in dipterocarp forests. These broader habitat coverages and higher sampling efforts likely increased species detectability, leading to higher reported richness.

The comparatively lower richness in Mt. Kampalili may therefore reflect a combination of ecological and methodological factors. Ecologically, its montane-dominated vegetation may inherently support fewer tree species than lowland and mixed-forest systems, consistent with global patterns of declining species richness with increasing elevation (Peters *et al.*, 2016; Berhanu *et al.*, 2017; Cirimwami *et al.*, 2019; Lasway *et al.*, 2023). Methodologically, the narrower habitat scope, smaller sampling effort, and differences in plot configuration could have limited species detection, potentially underestimating true richness. Future surveys incorporating a wider range of forest types, increased replication, and standardized plot sizes would improve comparability with neighboring mountain ranges and refine estimates of Kampalili's biodiversity standing.

**Endemicity and conservation status:** The number of endemic tree species recorded in this study is notably higher than that reported in Mt. Apo Natural Park (MANP), where 19 endemic species were documented along elevational gradients ranging from 636 masl to 1250 masl (Zapanta *et al.*, 2019). Direct comparisons

with Mt. Hamiguitan are limited, as Amoroso and Aspiras (2011) reported 163 endemic plant species across all life forms, with tree-specific counts not explicitly reported. Mt. Kampalili also harbors more endemic tree species than Mt. Tapulao, Zambales (456-1910 masl), with only 10 endemic tree species (Rivera and Paz-Alberto, 2020), and the Mt. Tago Range, Mindanao, which supports 16 endemic tree species (Coritico *et al.*, 2020). Even compared to lower elevation, non-montane forests, Mt. Kampalili shows higher endemics, exceeding the 18 endemic tree species documented in Mt. Agad-agad in Iligan, Mindanao (maximum elevation 520 masl) by Medicilo-Guiang *et al.* (2022).

The results of this study do not fully align with the established ecological theories regarding elevational gradients in species richness and endemism. Previous studies suggest that species richness tends to decrease with increasing elevation, while species endemism often increases at higher elevations due to greater environmental specialization and isolation (Alexander *et al.*, 2010; McCain and Grytnes, 2010; da Costa *et al.*, 2015). However, the present study found near-equal species richness between the lower and upper montane forests (LMF=64 vs. UMF=63), along with a slight decrease in endemism at higher elevations (LMF=16 vs. UMF=14), deviating from these expected patterns.

Such deviations may be attributed to a complex interplay of abiotic factors (e.g., climate, soil, topography) and biotic interactions (e.g., competition, dispersal limitation) that shape species distributions across elevations. These factors often interact in taxon-specific ways and may obscure broad elevational trends, particularly in tropical montane forests (Herzog *et al.*, 2013; Trigas *et al.*, 2013). Furthermore, sampling effort, plot size, and forest condition such as illegal logging and abaca cultivation observed in the area, may also influence the observed patterns, underscoring the importance of context-specific analyses when evaluating elevational biodiversity dynamics. Anthropogenic disturbances, particularly illegal logging and the conversion of native forests to agricultural plantations, can reduce endemic species by degrading habitat quality, altering microclimatic conditions, and favoring generalist species, consistent with documented biodiversity losses in disturbed tropical forests (Alroy, 2017).

The reported number of threatened species (n=26) herein is considerably higher than that reported for Mt. Hamiguitan (10 species; Amoroso and Aspiras, 2011) and Mt. Apo (19 species; Zapanta *et al.*, 2019). The number of threatened species is nearly evenly distributed between the two forest types. Notably, nine species were shared between the two, indicating that both forest types are of comparable conservation value in terms of supporting populations of threatened trees. It must be noted, however, that the LMF was closer to the community and thus more exposed to agricultural and other anthropogenic activities.



A substantial proportion of the threatened species identified in this study, particularly dipterocarp species (Dipterocarpaceae), are subject to anthropogenic pressure due to their high commercial timber value (Fernando *et al.*, 2009; Khoo *et al.*, 2022). Other economically valuable and similarly threatened taxa including *D. dao* (dao), *K. pinnatum* (amugis), *C. luzonicum* (piling-liitan), *C. mercadoi* (kalingag), *T. decorticata* (malabayabas), and *X. bracteatus* (mapilig), are likewise highly susceptible to illegal logging (Chiu, 2023). In addition, *P. luzoniense* (red nato) and *A. philippinensis* (almaciga) are extensively harvested for resin and latex products, further compounding their conservation risk (Razal *et al.*, 2021; Buot Jr *et al.*, 2022).

Illegal logging remains a major driver of deforestation in Davao de Oro, the province encompassing Mt. Kampalili. Between 2010 and 2020, Davao de Oro recorded the second highest forest loss in Mindanao and the highest within the Davao Region (Chiu, 2023). Several municipalities such as Laak and Nabunturan, have been identified as illegal logging hotspots (FMB-DENR, 2022). This ongoing habitat loss in the province further exacerbates the threatened status of the endemic species in the study area, emphasizing the urgency of implementing effective protection and management measures to ensure their persistence in the wild (Medecilo-Guiang *et al.*, 2021).

With Mt. Kampalili's relatively high number of endemic and threatened tree species, conservation of this area is of critical importance. As part of the Eastern Mindanao Corridor, this finding highlights the urgent need for targeted conservation strategies, particularly in light of ongoing habitat degradation and forest conversion. Both forest types contribute substantially to the persistence of threatened species, reinforcing the need of elevating this area's protection status, enhancing forest law enforcement, and supporting community-based conservation initiatives.

### Tree species similarity in two montane forests

The cluster dendrogram analysis produced a cophenetic correlation coefficient of 0.8021, suggesting a strong goodness-of-fit and indicating that the dendrogram reliably represents the similarity structure among the sampled plots (Bray and Curtis, 1957). This further demonstrates strong agreement between the hierarchical clustering and the Bray-Curtis dissimilarity structure and confirming that the resulting clusters represent ecologically meaningful compositional differences among plots as influenced by ecological factors rather than clustering artifacts (Wellenbeck *et al.*, 2024). The resulting species groupings are consistent with well-documented ecological patterns in Philippine montane forests. For example, members of the genera *Lithocarpus* spp. have been reported to exhibit broad elevational ranges, often dominating from lower montane forests

through transitional zones approaching upper montane environments (ERDB, 2012; Castillo *et al.*, 2021; Coritico *et al.*, 2022). Consistent with this, *Lithocarpus* spp. occurred abundantly across multiple clusters in the analysis which primarily comprised lower- to high-elevation plots in both montane forests. This suggests that these taxa may play a key role in maintaining canopy structure across a broad elevational gradient.

On the other hand, high-elevation specialists, including gymnosperms such as *Dacrycarpus imbricatus* and *Agathis philippinensis*, were concentrated in upper-elevation plots (1,374–2,012 masl), reflecting adaptation to much cooler conditions (Khan *et al.*, 2023; Clemente, 2024). *D. imbricatus* occurred from lower montane forest plots to high-elevation UMF plots, reaching its uppermost occurrence at 2,012 masl, while *A. philippinensis* was abundant in the upper half of the transect (1,694–2,012 masl). The consistent presence of these conifers in cooler, high-elevation plots highlights their role as structurally dominant and widely distributed species, as well as potential bioindicators of upper montane ecological conditions in Mt. Kampalili. This pattern aligns with the findings of Coritico *et al.* (2020) in the Mt. Tago Range, Philippines.

Cluster analysis revealed clear compositional and ecological gradients along the elevational transect, with elevation strongly influencing tree species assemblages in Mt. Kampalili's montane forests. Elevation integrates multiple abiotic factors such as temperature, moisture, and microclimate, which filter species distributions and drive turnover along the altitudinal continuum (Athamanakath *et al.*, 2025). Distinct assemblages emerged between lower and upper montane plots, reflecting shifts in species pools and functional traits with elevation. Although the similarity index used was weighted for abundance, which may reduce sensitivity to dominance-driven patterns, the clustering results align with established elevational structuring in other tropical montane forests, where species composition shifts predictably with altitude due to environmental filtering and niche differentiation (Culmsee *et al.*, 2011; Coritico *et al.*, 2020). These patterns highlight the biogeographical significance of Mt. Kampalili, which harbors broadleaf tropical taxa alongside cold-adapted gymnosperms and other montane forest tree specialists whose distributions are shaped by climate and topography. Turnover along the elevational gradient contributes to the diversity, a critical component of regional biodiversity that enhances the conservation value of these montane landscapes. Additionally, elevational gradients can concentrate unique species combinations and endemic taxa in restricted bands, a pattern documented in other Southeast Asian montane systems where elevationally structured communities are hotspots of endemism and conservation priority (Brambach *et al.*, 2017). Protecting the full elevational range (both LMF and UMF) in Mt. Kampalili



would ensure representation of these gradients, increasing resilience against climatic change and habitat loss.

### Diversity of trees in two forest types

The tree diversity in Mt. Kampalili is comparable to, and in some cases exceeds, that of other recognized biodiversity hotspots in the Philippines, despite differences in sampling design and effort. The Shannon–Wiener index ( $H' = 3.75$ ) exceeds values reported for Mount Lantoy ( $H' = 3.5$ ; Lillo *et al.*, 2021) and Balbalasang–Balbalan National Park ( $H' = 3.25$ ; Malabrigo, 2013), and is substantially higher than lower- and upper-montane forests of Mt. Hamiguitan ( $H' = 1.70$  and  $1.27$ , respectively; Amoroso *et al.*, 2009). This high diversity, paired with Pielou's evenness ( $J = 0.81$ – $0.83$ ), indicates that species coexist with minimal dominance, suggesting structurally complex and ecologically stable forest communities capable of supporting diverse functional niches (Ampoorter *et al.*, 2020; Loreau *et al.*, 2021).

Analysis of individual plots confirms this pattern (Table 2; Fig. 7). While some plots contained sparsely represented species, overall evenness remained high, as reflected in Simpson's diversity index ( $1-D = 0.95$ ). Notably, lower montane plots exhibited slightly higher Shannon diversity ( $H' = 3.50$ ) and evenness ( $J = 0.83$ ) than upper montane plots ( $H' = 3.40$ ;  $J = 0.81$ ), suggesting a marginally more equitable distribution of individuals among species at lower elevations. The convergence of Simpson's values across forest types highlights the sensitivity of this index to dominant species rather than richness, whereas Shannon's  $H'$  captures both richness and evenness, making it more responsive to small variations in rare species abundance (Daly *et al.*, 2018; Schulze *et al.*, 2019).

Rarefaction analyses further support these findings. Curves for both forest types increased consistently with sampling effort and did not reach asymptotes, indicating that general richness trends are well-captured but additional species are likely to occur with further sampling. Mann–Whitney U tests confirmed that differences in diversity between lower and upper montane forests were not statistically significant, reinforcing that total species richness is relatively stable across the elevational gradient, even though composition shifts markedly. This pattern aligns with observations in tropical montane systems where environmental filtering drives turnover in dominant taxa without substantially reducing overall species richness (Culmsee *et al.*, 2011; Khan *et al.*, 2023).

Elevational patterns in diversity also suggest a mid-elevation peak (LMF10–UMF10; 1,376–1,705 masl), consistent with the mid-domain effect (MDE), where geometric constraints in bounded domains produce maximal species overlap at intermediate elevations (Colwell *et al.*, 2004). Although the MDE remains a debated mechanism (Letten *et al.*, 2013), the observed pattern may result from a combination of spatial

constraints and ecological factors, including moderate temperatures and resource availability that favor coexistence of both lowland and high-elevation taxa. Anthropogenic disturbance appears to influence diversity patterns, particularly in lower montane plots adjacent to agricultural zones (e.g., LMF00), which exhibited low richness (4 species) and high dominance by *Pipturus arborescens*. This indicates that localized human activity can depress diversity and evenness, emphasizing the importance of considering disturbance regimes alongside elevational effects.

Collectively, these results suggest that while species composition shifts along the elevation gradient, total tree diversity remains resilient. Widespread species such as *Lithocarpus caudatifolius* and the gymnosperm *Dacrycarpus imbricatus* maintain broad elevational ranges, while high-elevation specialists (*Agathis philippinensis*, *D. imbricatus*) dominate cooler upper montane plots. These structural and compositional patterns enhance ecosystem stability and underscore the conservation value of maintaining the full elevational continuum. Protecting Mt. Kampalili's gradient ensures representation of both generalist and habitat-specific taxa, preserves mid- and high-elevation biodiversity hotspots, and buffers species against climate-induced range shifts (Brambach *et al.*, 2017; Athamanakath *et al.*, 2025).

### Tree community structure

The analysis of Species Importance Values (SIVs) shows that the majority of high-SIV species recur across both lower and upper montane forest plots (Table 3), consistent with the cluster analysis that revealed shared dominant species among multiple plot groupings. This recurring dominance suggests that these taxa function as ecological generalists or are well-adapted to the relatively uniform environmental conditions along the elevational gradient of Mt. Kampalili (Cabrera *et al.*, 2019; Coritico *et al.*, 2020). Their widespread presence across plots highlights both structural and compositional contributions, underscoring their role in shaping forest architecture and community assembly.

Beyond their ecological functions, the high-SIV species hold substantial biodiversity and conservation significance. All five species, *D. imbricatus*, *L. caudatifolius*, *P. luzoniense*, *X. bracteatus*, and *C. mercadoi* are native to the Philippines, with four being endemic (Pelsner *et al.*, 2011). Several are also recognized as threatened under both the IUCN Red List (2025-2) and the Department Administrative Order (DAO 2017-11). For instance, *X. bracteatus* is listed as Vulnerable by IUCN and Critically Endangered under DAO 2017-11, while both *P. luzoniense* and *A. philippinensis* are Vulnerable under DAO framework. Their threatened status is primarily due to logging, agricultural expansion, and mining activities (IUCN, 2025). The persistence of these species at high SIVs across both forest types indicates that Mt. Kampalili



maintains a structurally mature and ecologically intact forest, capable of supporting the ecological functions of these key taxa. Comparable patterns have been documented in Sipit Watershed, Mt. Makiling (Castillo *et al.*, 2021) and the Mount Hamiguitan Range Wildlife Sanctuary (Amoroso and Aspiras, 2011), highlighting that structurally intact forests continue to sustain endemic and threatened species even amid regional habitat loss.

Quantitative comparisons reveal functional differences among the dominant taxa. *D. imbricatus* recorded the highest SIV (16.49) and relative dominance (RD = 37.38%), indicating a disproportionate contribution to total basal area, whereas *L. caudatifolius* exhibited the highest relative density and frequency, reflecting broad spatial distribution and consistent abundance across plots. Despite lower abundance, the emergent stature and larger diameter of *D. imbricatus* (average DBH = 67 cm; maximum = 78.66 cm) amplify its ecological influence on canopy structure, light penetration, and microclimate regulation. In contrast, *L. caudatifolius*, as an understory-to-subcanopy species (average DBH = 12.41 cm; maximum = 38.2 cm), contributes primarily through numerical dominance and spatial ubiquity rather than structural impact. These contrasting strategies (structural dominance vs. widespread abundance) demonstrate that ecological importance in Mt. Kampalili's montane forests arise from multiple pathways, reflecting niche complementarity and functional diversity among tree species.

From a conservation perspective, the co-occurrence of endemic, threatened, and structurally influential species across both lower and upper montane forests supports Mt. Kampalili's high ecological and biogeographical value. The presence of these species along broad elevational ranges contributes to the mountain's role as a reservoir of regional biodiversity, providing critical ecosystem services such as carbon storage, microclimate stabilization, and habitat for associated flora and fauna. Given an ongoing deforestation and habitat degradation in other Philippine montane systems (Pang *et al.*, 2021; Daipan, 2021; Pito *et al.*, 2019; Zapanta *et al.*, 2019), these findings highlight the urgency of site-specific conservation strategies that maintain both species richness and structural integrity across the full elevational gradient.

## CONCLUSION

This study provides the first comprehensive assessment of tree diversity, composition, and structure across Mount Kampalili's lower and upper montane forests, revealing 101 species, including numerous Philippine endemics and threatened taxa. High diversity, evenness, and structurally intact forests indicate both ecological resilience and functional complexity across elevations.

Species shift along the elevational gradient reflects strong environmental filtering, with generalist taxa (*Lithocarpus caudatifolius* and *Dacrycarpus imbricatus*) persisting across forest types and sustaining essential structural and functional roles. This pattern illustrates that both lower and upper montane forests can sustain overall richness even as community composition shifts, emphasizing the necessity of conserving the entire elevational gradients to protect both widespread and habitat-restricted species.

The presence of endemic and threatened species with strong ecological influence highlights Mt. Kampalili as a conservation priority. These findings support the enhanced protection of the mountain system through the development of site-specific management strategies. Addressing ongoing threats such as logging, agricultural encroachment (abaca cultivation), and habitat fragmentation through monitoring, community engagement, and policy integration is critical to preserving the mountain's biodiversity, ecosystem function, and regional significance as a Philippine montane forest stronghold.

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