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First Survey of Land Snails in Mount Hamiguitan: Biodiversity and Environmental Insights from a UNESCO World Heritage and ASEAN Heritage Park in the Philippines

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Mount Hamiguitan, a UNESCO World Heritage Site and a biodiversity hotspot in the Philippines, supports diverse and unique ecosystems. This study presents the first comprehensive assessment of land snail diversity across five vegetation types: agro-ecosystem, dipterocarp forest, montane forest, mossy forest, and mossy-pygmy forest. A total of 96 individuals, representing 20 species from 6 families, were recorded. The mossy forest exhibited the highest diversity (1-D = 0.85, H' = 2.03), while the agro-ecosystem and mossy-pygmy forest had lower diversity, attributed to habitat disturbance and extreme environmental conditions. Canonical Correspondence Analysis (CCA) revealed that environmental factors, including leaf litter depth, relative humidity, soil pH, and temperature, influenced land snail distributions. Axis 1 (31.85% constrained inertia) showed a gradient favoring generalist species (*Tanychlamys* sp.) in disturbed, warmer habitats and specialist species (*Hemiplecta* sp.) in cooler, humid environments. Axis 2 (30.91%) emphasized humidity and leaf litter depth, associating montane forests and species like *Trochomorpha* sp. 2 with high moisture conditions. The Bray-Curtis similarity index revealed distinct ecological compositions among vegetation types. The agro-ecosystem formed a separate cluster with low species diversity and specialized communities. The mossy-pygmy forest shared similarities with the mossy forest, both characterized by high humidity and dense vegetation. A strong similarity was observed between the dipterocarp and montane forests, suggesting similar environmental conditions and overlapping species. This study underscores the vital ecological role of the mossy forest as a biodiversity refuge and provides critical data for conservation strategies aimed at preserving Mount Hamiguitan's unique ecosystems. It also advocates for targeted conservation efforts to mitigate human disturbances and enhance ecological resilience in this globally significant hotspot.

Key words: Land snails, Biodiversity, Mt. Hamiguitan, Vegetation types, Habitat disturbance

BACKGROUND

The Philippines is renowned for its exceptional biodiversity and high levels of endemism (Ambal et al. 2012; Agduma et al. 2023), hosting some of the world's largest remaining forests. These forests are home to an extraordinary array of unique plants (Batuyong et al. 2021; Aureo et al. 2020; Meñiza et al. 2024) and animals (Mohagan et al. 2019), many of which are found nowhere else on Earth. Among the country's biodiverse

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regions, the forested landscapes of Mindanao stand out for their rich and diverse flora (Coritico et al. 2020; Madjos and Ramos 2021) and fauna (Sanguila 2020; Quibod et al. 2021), ranging from towering dipterocarp trees to ecologically significant land snails. However, this biodiversity faces numerous threats, including deforestation, habitat fragmentation, and climate change (Pang et al. 2021). These pressures endanger species survival and undermine critical ecosystem services essential for both biodiversity and human well-being (Shroff and Cortés 2020; Oguh et al. 2021).

Mount Hamiguitan, located in Mindanao, exemplifies the region's ecological richness as a UNESCO World Heritage Site and ASEAN Heritage Park. This mountain range supports diverse ecosystems, including agro-ecosystem, dipterocarp forest, montane forest, mossy forest, and mossy-pygmy forest (Amoroso et al. 2009; Amoroso and Aspiras 2011; Dizon et al. 2018), each with species adapted to specific environmental conditions. This pristine environment offers a unique opportunity to explore lesser-known organisms, such as land snails, which play crucial roles in ecosystem processes. Land snails are particularly diverse and exhibit specialized behaviors, including distinct feeding strategies, microhabitat preferences, and moisture-seeking adaptations that enable them to thrive in challenging and heterogeneous habitats (Gheoca et al. 2023). These characteristics highlight their ecological significance and emphasize their potential as bioindicators for assessing ecosystem health and stability.

Globally, there are an estimated 35,000 to 40,000 species of land snails (Barker 2001), encompassing both described species and many yet to be discovered or formally classified. In the Philippines, around 1,213 species are known (Faustino 1930), although this number is likely an underrepresentation due to the country's vast, unexplored habitats. Continuous research, especially in biodiversity hotspots like Mt. Hamiguitan, is essential to uncovering the full diversity of land snails, underscoring the need for comprehensive biodiversity assessments.

Land snails play indispensable roles in ecosystems, contributing significantly to nutrient recycling (Němec et al. 2021), litter decomposition (Wehner et al. 2021; de la Torre and Villarruel-Oviedo 2023), and soil calcium concentration (Sundalian et al. 2021). They also serve as a vital food source for other animals (Woo et al. 2022), highlighting their importance across various trophic levels. Furthermore, land snails act as valuable environmental indicators (Baroudi et al. 2020) and biodiversity predictors (Stanisic et al. 2024), with their short life spans and limited dispersal abilities making them ideal for monitoring climate change (Dhiman and Pant 2021). Recent studies highlight their role in detecting environmental shifts and providing insights into ecosystem health and stability (Gheoca et al. 2021). These ecological functions emphasize the importance of preserving land snail populations to maintain biodiversity and ecological balance.

Beyond their ecological importance, land snails hold significant cultural, economic, and nutritional value in the Philippines. The native delicacy "bayuko" (*Ryssota ovum*) is a rich source of protein and is commonly prepared in coconut milk, a dish known as "ginataang bayuko" (Paclibar and Tadiosa 2020). Additionally, snails play a role in traditional medicine, utilized by indigenous communities, and in folk healing practices. Their shells also hold historical and artistic significance, often featured in local art and jewelry (Fadul 2012), highlighting their cultural and economic relevance. Therefore, conserving land snail populations is crucial not only for maintaining environmental health but also for preserving cultural heritage and ensuring food security in the Philippines.

Despite their ecological and cultural importance, land snails in the Philippines remain understudied, with limited research interest and expertise (Parcon et al. 2021). To the best of our knowledge, this is the first study to examine land snails across five distinct vegetation types in the Philippines, encompassing agro-ecosystem, dipterocarp forest, montane forest, mossy forest, and mossy-pygmy forest. This pioneering work addresses a critical research gap by exploring the species composition, abundance, and distribution of land snails in these diverse habitats. Additionally, this study assesses key environmental parameters, including leaf litter depth, humidity, soil pH, and temperature, to evaluate how these factors influence land snail diversity and habitat preferences. By integrating species data with environmental variables, the research provides a more holistic understanding of the ecological roles of land snails and their relationships with their habitats. By identifying the species present and understanding their ecological roles, this research will inform conservation strategies, promote biodiversity, and support local community engagement. Furthermore, it aims to contribute to global biodiversity goals, inspire further research, and advocate for the conservation of these essential yet often overlooked species.

MATERIALS AND METHODS

Study Area

The study was conducted within the Mt. Hamiguitan Range Wildlife Sanctuary, located in

Davao Oriental, Southeastern Mindanao, Philippines (Fig. 1; Table 1). The sanctuary encompasses a range of ecosystems, from lowland agro-ecosystem to high-elevation mossy-pygmy forests, covering an altitudinal gradient from approximately 241 to 1,312 meters above sea level (m.a.s.l.). Five distinct vegetation types were identified and surveyed for this study: agro-ecosystem (AE), dipterocarp forest (DF), montane forest (MF), mossy forest (MoF), and mossy-pygmy forest (MPF) (Fig. 2).

The agro-ecosystem is a mixed-use landscape dominated by cultivated species, including *Cocos nucifera* (coconut) and *Mangifera indica* (mango). Scattered remnants of dipterocarp species, primarily *Shorea* spp. (*e.g.*, tanguile, yakal), are present, indicating the area's historical classification as a dipterocarp forest prior to its conversion for agricultural use. These remnants serve as ecological vestiges of

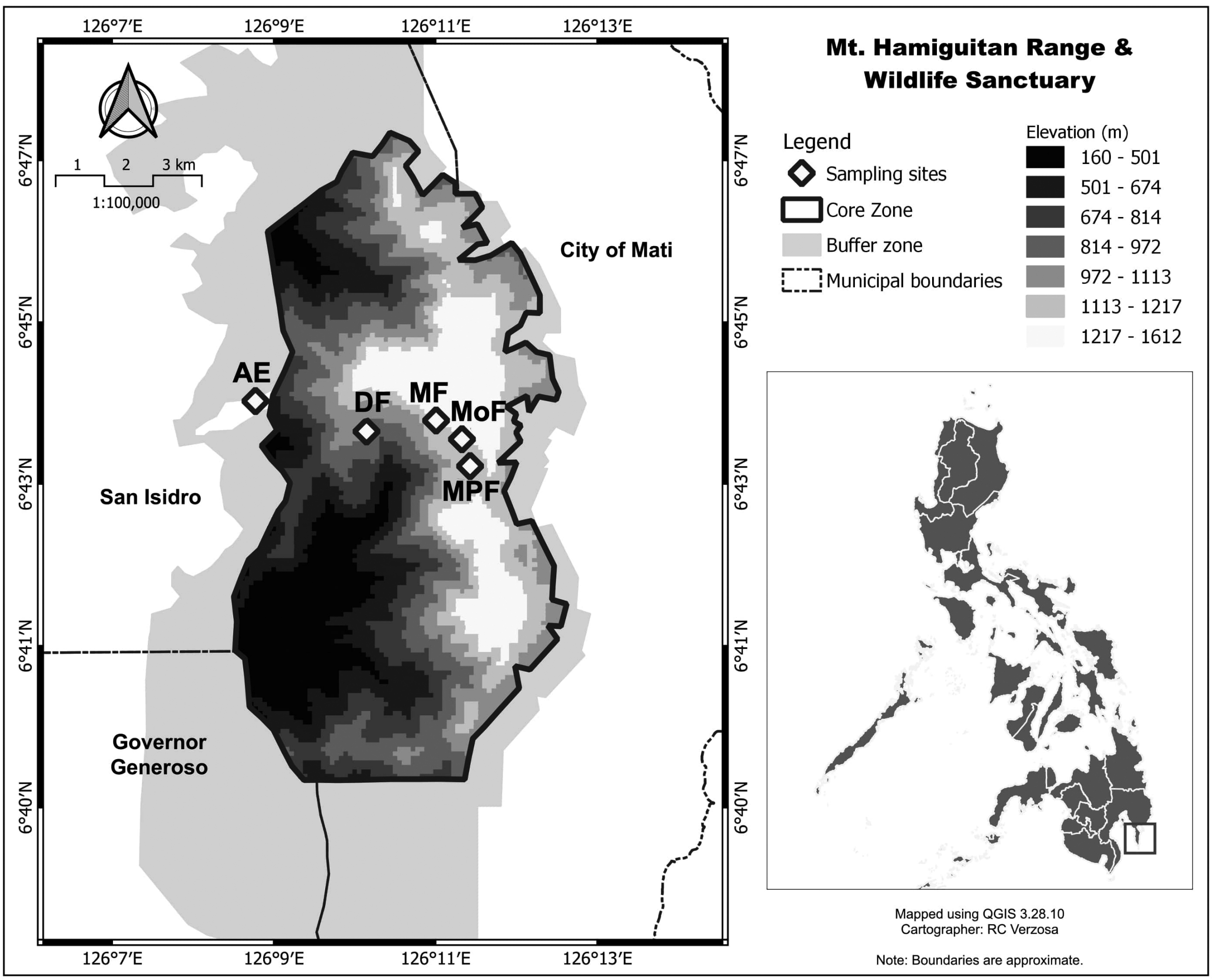

Fig. 1. Geographical locations of study sites within Mt. Hamiguitan Range, Davao Oriental, Philippines.

Table 1. Specimen collection data, with station numbers corresponding to those shown in figure 1

Station	Vegetation types	Coordinates	Elevation (m.a.s.l.)
AE	Agro-ecosystem	6.73539° N, 126.14658° E	241–362
DF	Dipterocarp forest	6.72976° N, 126.16718° E	526–540
MF	Montane forest	6.73179° N, 126.18008° E	938–951
MoF	Mossy forest	6.72831° N, 126.18488° E	1,205–1,227
MPF	Mossy-pygmy forest	6.72334° N, 126.18639° E	1,147–1,312

the site's original forest composition, highlighting the anthropogenic influence on this landscape.

The dipterocarp forest is dominated by tall, straight-trunked tree species, such as *Shorea* spp., which form a prominent upper canopy layer. This canopy provides critical shading and microclimatic regulation, supporting the diverse assemblage of flora in the lower strata. The forest is further characterized by a stratified understorey, consisting of shrubs, vines, epiphytes, ferns, and orchids. This complex vertical structure contributes to the forest's high biodiversity and ecosystem functionality, offering diverse habitats for various taxa across multiple layers.

The montane forest, situated at mid-elevation, is characterized by its cool, humid conditions, which promote high levels of epiphytism and the proliferation of mosses and lichens. The dominant tree species include *Agathis philippinensis* (Philippine agathis) and various *Nepenthes* spp. (pitcher plants), which are well adapted to the unique conditions of this ecosystem. The understorey is rich and diverse, comprising shrubs, ferns, and epiphytes, including orchids and mosses. These elements create a multilayered and visually lush forest structure, which supports a wide range of ecological processes.

The mossy forest, occurring at higher elevations, is defined by its dense moss coverage, which blankets tree trunks, branches, and the forest floor. This forest is characterized by stunted, gnarled trees heavily draped with mosses, lichens, and ferns, shaped by the persistent mist and high moisture levels in this habitat. The dense moss growth gives the forest a carpet-like appearance, reflecting the high humidity and constant condensation at this elevation. Prominent tree species include *Calophyllum blancoi* (Blanco's calophyllum) and *Dacrydium elatum* (mountain dacrydium), which are adapted to these conditions.

The mossy-pygmy forest, found at the highest elevations, is characterized by its extreme environmental conditions and unique vegetation structure. Trees in this forest are stunted and twisted, with an average height ranging from 0.5 to 3 meters, despite their advanced age, with some individuals believed to be centuries old. Dominant species include *Leptospermum* spp. (tea trees), *Weinmannia* spp., and *Dacrydium* spp. The cold, humid, and misty conditions at this elevation foster prolific growth of mosses, and lichens, which blanket the vegetation and forest floor. This unique ecosystem supports a specialized assemblage of flora that has adapted to nutrient-poor, acidic soils and the harsh conditions of high-altitude environments, contributing significantly to its ecological uniqueness.

Sample collection and identification

All necessary permits, including a Wildlife Gratuitous Permit (No. XI-2018-16) from the Department of Environment and Natural Resources

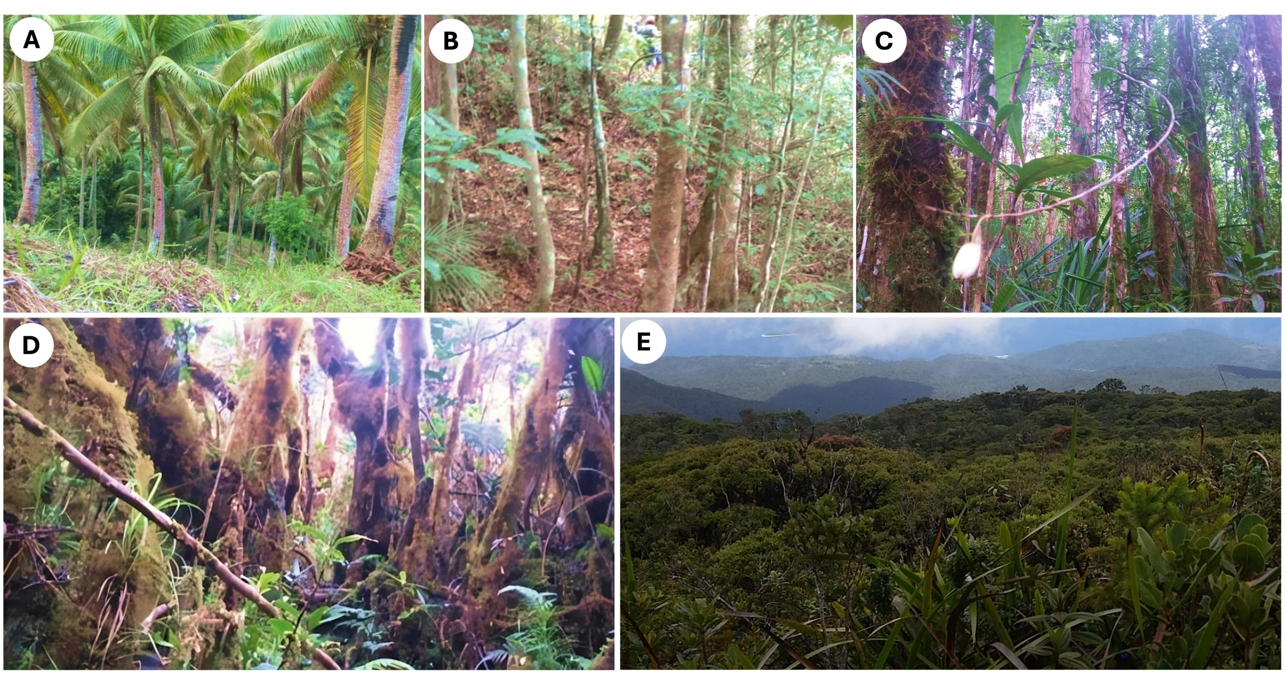

Fig. 2. Locations of sampling stations in Mt. Hamiguitan, Davao Oriental, representing different vegetation types: A, Agro-ecosystem; B, Dipterocarp forest; C, Montane forest; D, Mossy forest; E, Mossy-pygmy forest.

(DENR), were obtained to ensure compliance with regulatory requirements. Sampling was conducted in March 2018 across different vegetation types in Mt. Hamiguitan. A 360-meter transect line was established horizontally in each vegetation type, with three 20 × 20 m (400 m^2) quadrats placed at 100-meter intervals. Quadrats were positioned at least 5 meters from the main trail to minimize edge effects.

Land snails were collected by hand-picking both live individuals and empty shells, with samples from each vegetation type kept separate for abundance analysis. Representative specimens were photographed, preserved in 70% ethanol, and identified using AmScope microscopy based on morphological structures and body sizes. Identification was confirmed using the World Mollusc Species Database (WMSDB) and cross-referenced with published literature, including works by Bartsch (1909), Smith and Kershaw (1979), Springsteen and Leobrera (1986), Cowie et al. (2017), and Bouchet et al. (2017).

Environmental Parameters

To assess the potential influence of environmental factors on land snail distribution, selected parameters were measured systematically within each quadrat using standardized methods to ensure consistency and comparability across all sampling sites. Leaf litter depth, a key determinant of habitat quality and substrate availability for land snails (Gheoca et al. 2021), was measured using a calibrated metal stick at three random points within each quadrat. The average depth, recorded in centimeters, provided critical insights into the structural complexity of the forest floor, which serves as a refuge and feeding ground for land snails.

Relative humidity, a vital factor affecting the physiological and ecological requirements of moisture-sensitive species (Zimmermann et al. 2024), was measured using a psychrometer. Three readings were taken at different times throughout the day within each quadrat, and the average value was recorded as a percentage to reflect the microclimatic moisture conditions of each habitat.

Soil pH was assessed to determine the chemical properties of the substrate, which play a crucial role in land snail survival, particularly in calcium availability for shell formation (Mustapha and Marshall 2021). Soil samples weighing 1 kg were randomly collected within each quadrat using a sterilized trowel, ensuring the integrity of the samples. These samples were stored in labeled plastic bags and transported to the Davao Oriental State University (DOrSU) Science Laboratory, where soil pH was measured using a calibrated pH meter. The readings were replicated three times per sample, and the average pH value for each quadrat was recorded.

Air temperature was measured in degrees Celsius (°C) using an alcohol thermometer at each sampling station. Four readings were taken at different times of the day to capture diurnal variations in temperature, and the average was calculated for each quadrat.

Data Analysis

Species relative abundance and density of land snails across the study area were calculated using Microsoft Excel, based on the number of individuals observed in each quadrat. Rarity was defined as species contributing less than 0.5% of the total individual counts, in line with the criteria set by Perez et al. (2023), which helps to identify less common species in the community. To assess sampling completeness and species richness, species accumulation curves were generated using iNext software, providing insight into the adequacy of the sampling effort across different vegetation types and their respective habitats (Chao et al. 2023).

The biodiversity and community structure of land snails were analyzed using multiple diversity indices and ecological composition metrics, calculated with Paleontological Statistics (PAST) software version 4.15 (Hammer and Harper 2001). Simpson's Diversity Index (1-D) was employed to estimate the probability that two randomly selected individuals belong to different species, with higher values indicating greater diversity. Similarly, the Shannon-Wiener Index (H') quantified overall species diversity, where higher values reflected a more diverse community. To examine the distribution patterns of species, Pielou's Evenness Index (J') was used to assess whether species were evenly distributed or dominated by a few, while the Dominance Index (D) measured the relative abundance of the most common species, providing a more nuanced understanding of community structure within each vegetation type.

This study applied the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm to analyze the relationships between various samples based on a similarity matrix. The matrix was generated using the Bray-Curtis similarity index (BC), which quantified the degree of similarity in species composition and environmental conditions across different vegetation types. By applying this classical hierarchical clustering method, the research visually represented the similarities and differences between the samples, providing insights into the ecological patterns and relationships among vegetation types. Canonical Correspondence Analysis (CCA) was also performed to investigate the influence of environmental factors, including leaf litter depth, relative humidity, soil pH, and air temperature, on land snail distribution and community structure.

RESULTS

Species Composition, Abundance, and Rarity

The investigation of land snails across five distinct forest types in Mt. Hamiguitan yielded a total of 96 individuals, representing 20 species from 6 families (Table 2; Figs. 3–5). Species richness varied among the habitats, with the mossy forest hosting the highest species richness (9 species), followed by the dipterocarp forest with 7 species. The montane forest and agro-ecosystem exhibited relatively lower species richness, with 4 and 2 species, respectively. Notably, the mossy-pygmy forest harbored the least species richness and abundance, with only a single species, *Hemiplecta* sp., represented by 3 individuals.

Cyclophoridae emerged as the most species-rich family, contributing 8 species, followed by Camaenidae and Helicinidae, each with 3 species. The families Ariophantidae, Euconulidae, and Trochomorphidae each contributed 2 species. In terms of abundance, Helicinidae dominated, accounting for 36 individuals (37.50%), followed by Cyclophoridae (21 individuals, 22.88%) and Ariophantidae (16 individuals, 16.67%). The remaining families exhibited much lower abundances, with individual contributions below 15% of the total.

At the species level, *Sulfurina* sp. 3 was the most dominant species, contributing 28.13% of the total individuals, with its population entirely concentrated in the dipterocarp forest (27 individuals). Similarly, *Tanychlamys* sp. and *Trochomorpha* sp. 2 were among

Table 2. Relative abundance, density, and rarity of land snails in the study areas

Family & Species	AE	DF	MF	MoF	MPF	Total	RA (%)	RD (400 m^2)
Pulmonata								
Ariophantidae								
Hemiplecta sp.				1	3	4	4.17	0.01
Tanychlamys sp.	12					12	12.5	0.03
Camaenidae								
Helicostyla smaragdina	1					1	1.04	0.00
Tricheulota sp.		1				1	1.04	0.00
Tricheulota spinosissima			2			2	2.08	0.01
Euconulidae								
Coneuplecta sp.				4		4	4.17	0.01
Euconulus sp.				2		2	2.08	0.01
Helicinidae								
Sulfurina sp.1				6		6	6.25	0.02
Sulfurina sp.2				3		3	3.13	0.01
Sulfurina sp.3		27				27	28.13	0.07
Trochomorphidae								
Trochomorpha sp.1				1		1	1.04	0.00
Trochomorpha sp.2			12			12	12.5	0.03
Prosobranchia								
Cyclophoridae								
Alycaeus sp.		1	2			3	3.13	0.01
Cyclotus variegatus		1				1	1.04	0.00
Leptopoma perlucidum		3				3	3.13	0.01
Leptopoma signatum				3		3	3.13	0.01
Leptopoma sp.1			4			4	4.17	0.01
Leptopoma sp.2		2				2	2.08	0.01
Leptopoma sp.3				3		3	3.13	0.01
Leptopoma sp.4		1		1		2	2.08	0.01
Total number of individuals	**13**	**36**	**20**	**24**	**3**	**96**		
Number of species	**2**	**7**	**4**	**9**	**1**	**20**		

AE, Agro-ecosystem; DF, Dipterocarp forest; MF, Montane forest; MoF, Mossy forest; MPF, Mossy-pygmy forest; RA, Relative abundance; RD, Relative density.

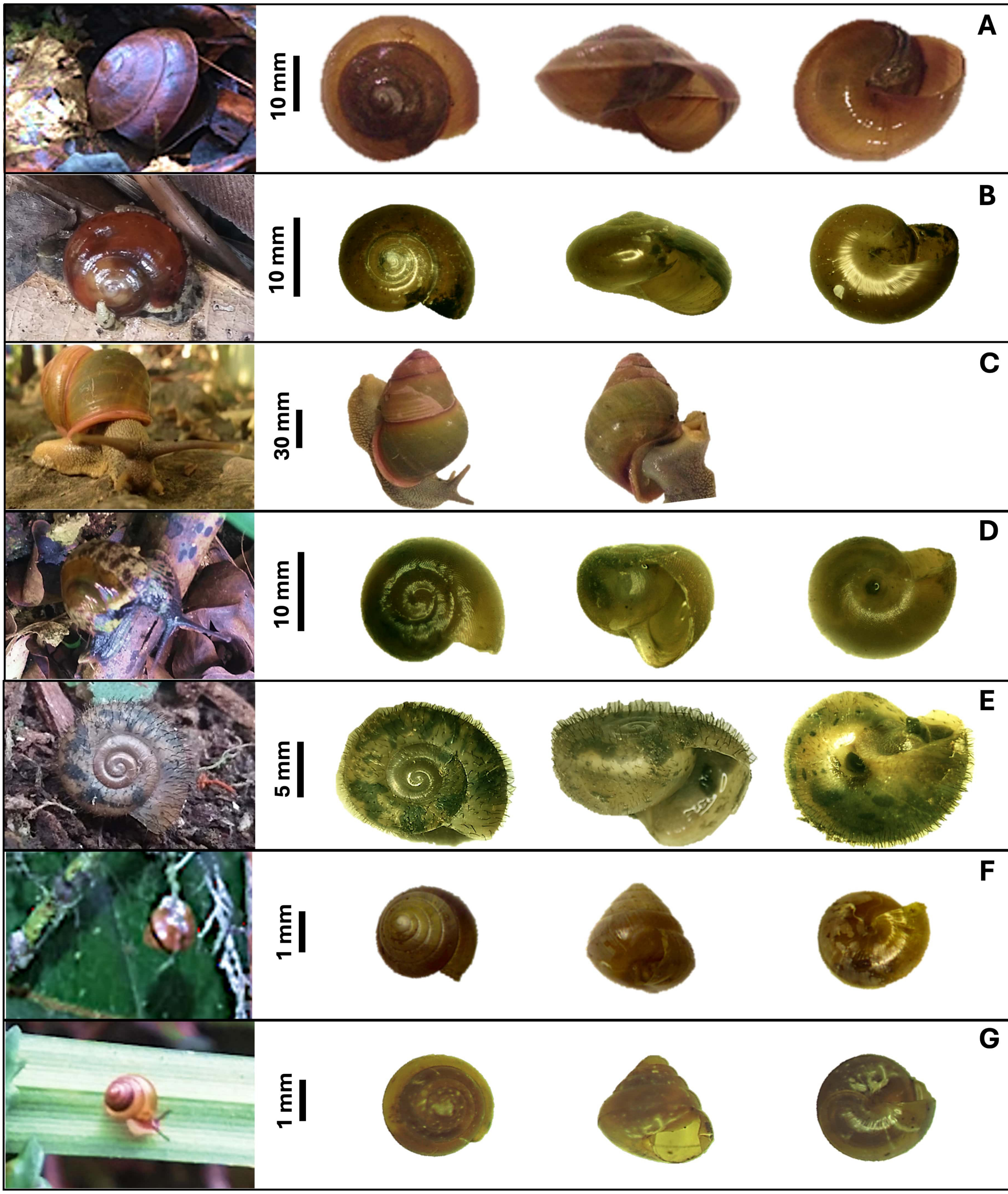

Fig. 3. Land snails recorded in Mt. Hamiguitan: Pulmonata, Ariophantidae (A, *Hemiplecta* sp.; B, *Tanychlamys* sp.), Camaenidae (C, *Helicostyla smaragdina*; D, *Tricheulota* sp.; E, *Tricheulota spinosissima*), Euconulidae (F, *Coneuplecta* sp.; G, *Euconulus* sp.).

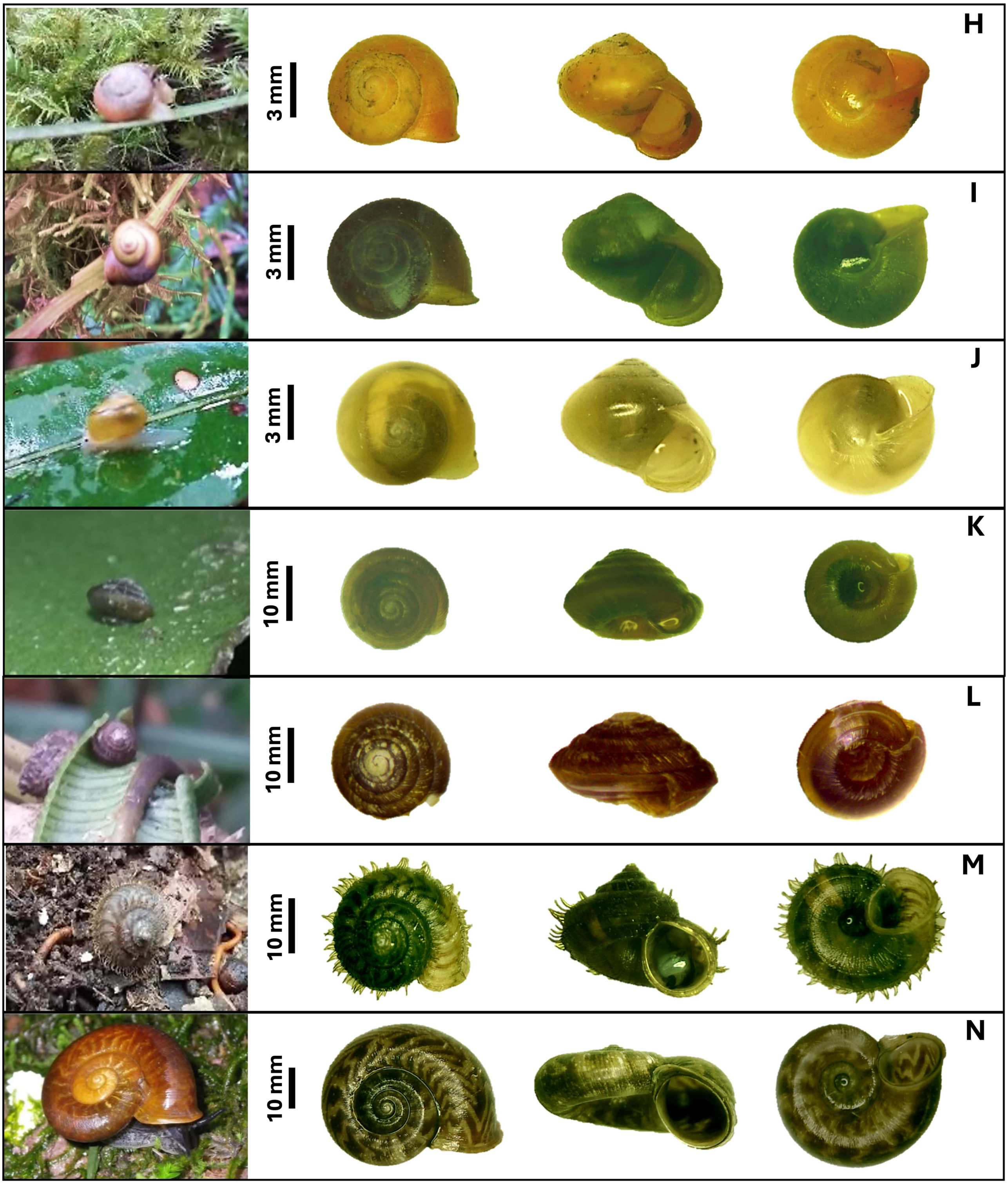

Fig. 4. Land snails recorded in Mt. Hamiguitan: Pulmonata, Helicinidae (H, *Sulfurina* sp.1; I, *Sulfurina* sp.2; J, *Sulfurina* sp.3), Trochomorphidae (K, *Trochomorpha* sp.1; L, *Trochomorpha* sp.2), Prosobranchia, Cyclophoridae (M, *Alycaeus* sp.; N, *Cyclotus variegatus*).

the more abundant species, each comprising 12.5% of the total individuals, although these were largely restricted to specific habitats. Notably, no species were classified as relatively rare across the surveyed habitats.

Species accumulation curve

Land snail diversity across Mt. Hamiguitan exhibited substantial variation among five distinct assemblages, with significant disparities observed in sampling completeness, species richness, and community diversity (Table 3). Sampling completeness varied across vegetation types, with the mossy-pygmy forest achieving full sampling, while the agro-ecosystem exhibited high sampling completeness (SC). The montane and dipterocarp forests showed moderate sampling completeness, whereas the mossy forest displayed the lowest level of completeness.

Species richness was relatively low in both the agro-ecosystem and mossy-pygmy forest, while

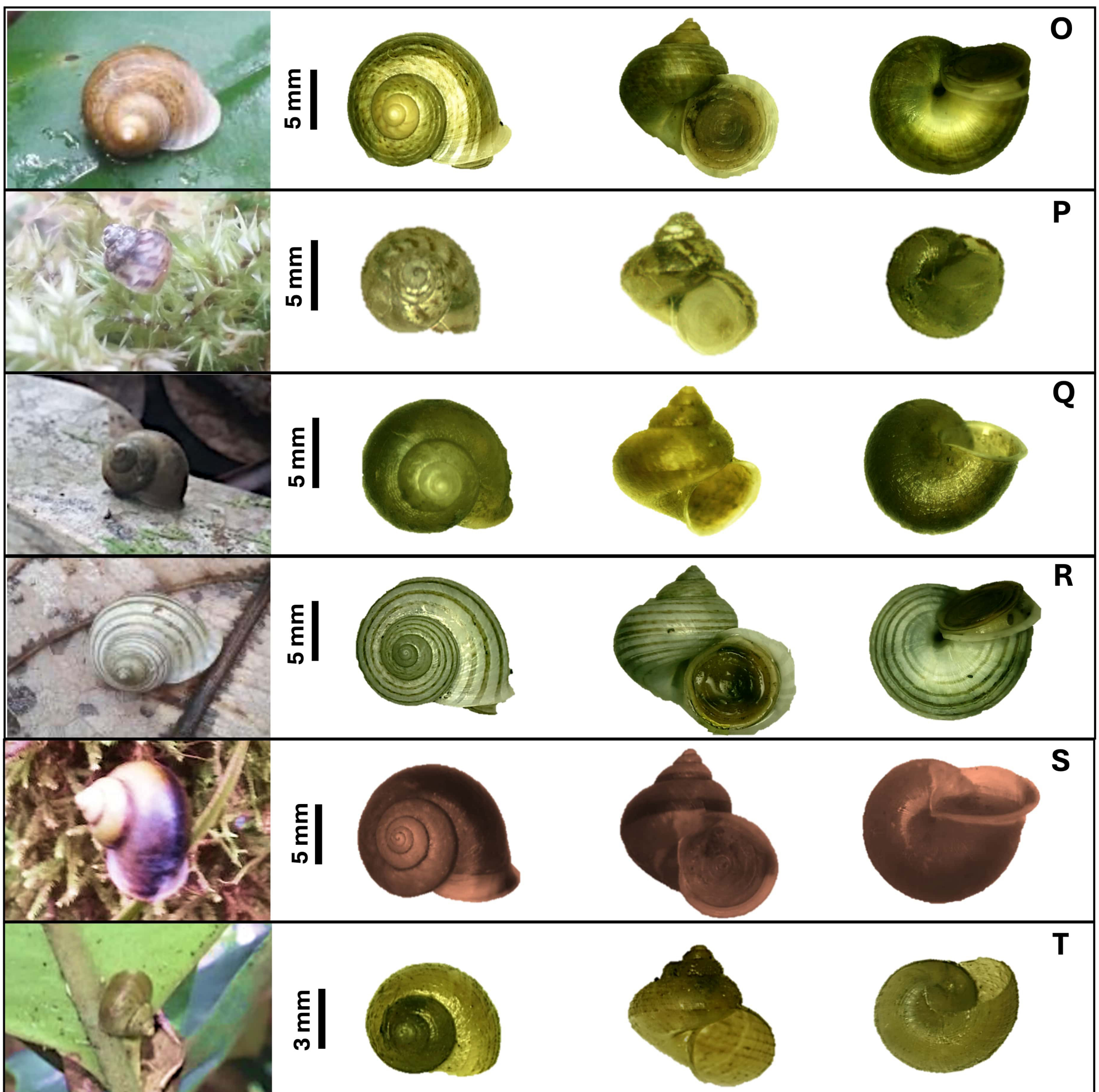

Fig. 5. Land snails recorded in Mt. Hamiguitan: Prosobranchia, Cyclophoridae (O, *Leptopoma perlucidum*; P, *Leptopoma signatum*; Q, *Leptopoma* sp.1; R, *Leptopoma* sp.2; S, *Leptopoma* sp.3; T, *Leptopoma* sp.4).

the montane and dipterocarp forests exhibited moderate species richness. Notably, the mossy forest demonstrated the highest species richness among all assemblages. Shannon diversity indices revealed considerable variation in community structure across the assemblages. The mossy-pygmy forest exhibited the lowest diversity, followed by the agro-ecosystem. Moderate diversity was observed in the montane and dipterocarp forests, whereas the mossy forest displayed the highest diversity.

Rarefaction (solid lines, observed) and extrapolation (dashed lines, expected) curves were employed to assess sampling adequacy and estimate species richness (Fig. 6). The species accumulation curves for the mossy forest exhibited the steepest slopes, followed by those for the dipterocarp forest, suggesting that additional species may be encountered with continued sampling in these vegetation types. In contrast, the accumulation curves for the remaining three vegetation types showed shallower slopes as they approached an asymptote, indicating that species richness estimates were nearing saturation. Furthermore, the accumulation curve for the Shannon diversity index revealed that the mossy forest exhibited the steepest slope, further suggesting the likelihood of encountering additional species with continued sampling. In contrast, the other four vegetation types displayed shallower slopes, indicating that their diversity estimates were approaching a saturation point. These findings underscore the importance of continued sampling to fully capture the land snail diversity across Mt. Hamiguitan.

Diversity Indices

Biodiversity indices exhibited significant variation across the five vegetation types surveyed on Mt. Hamiguitan, highlighting pronounced differences in community structure and ecological stability (Table 4). The mossy forest demonstrated the highest diversity, characterized by a well-balanced community with minimal species dominance. The montane forest exhibited moderate biodiversity, while the dipterocarp forest was marked by lower diversity, reflecting a less even species distribution. In contrast, the agro-ecosystem displayed the lowest diversity among the forested areas, with a high dominance index indicative of an imbalanced community structure. The mossy-pygmy forest, in contrast, showed no measurable diversity, characterized by complete species dominance.

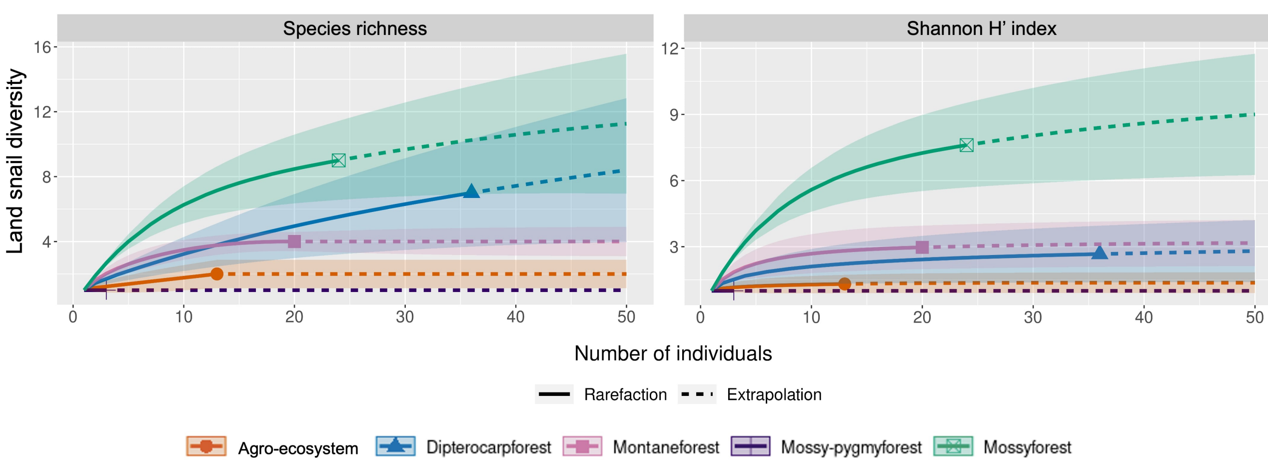

Fig. 6. Diversity accumulation curves of land snails across five survey sites in Mt. Hamiguitan, generated using iNEXT with 95% confidence intervals. The curves represent Hill numbers for species richness (q = 0) and Shannon diversity (q = 1), illustrating diversity patterns among the sites.

Table 3. Sampling completeness, species richness, and Shannon diversity of land snails were estimated using iNEXT across various vegetation types

Vegetation	Sampling Completeness (SC)	Species Richness (qD)	Shannon Diversity (qD)
Agro-ecosystem	0.923	1.24–1.73	1.16–1.28
Dipterocarp Forest	0.563–0.786	1.00–2.41	1.00–1.86
Montane Forest	0.389–0.804	1.00–2.83	1.00–2.37
Mossy Forest	0.112–0.502	1.00–4.56	1.00–4.21
Mossy-Pygmy Forest	1.00	1.00	1.00

Bray-Curtis Similarity Index

The Bray-Curtis similarity index analysis revealed distinct patterns in the species composition of land snails across various ecosystems (Fig. 7). The Dipterocarp and Montane forests were closely clustered, indicating a high degree of similarity in their land snail communities. This grouping is supported by their elevated Bray-Curtis similarity index values, suggesting that these two forest types share a significant number of common land snail species. In contrast, the Mossy forest and Mossy-pygmy forest, while grouped together, showed a greater distance between them compared to the Dipterocarp and Montane forests. This indicates a lower degree of similarity in their species compositions, as reflected by their more moderate similarity index values. Additionally, the Agro-ecosystem was positioned more distantly from all the forest types, suggesting a greater dissimilarity in land snail species composition.

Canonical Correspondence Analysis

The analysis yielded two canonical axes with eigenvalues of 0.9749 and 0.9459 for Axis 1 and Axis 2, respectively. Axis 1 explained 31.85% of the constrained inertia (28.72% of total inertia), while Axis 2 contributed 30.91% of the constrained inertia (27.86% of total inertia). Together, the first two axes captured 62.76% of the total variation in species-environment relationships.

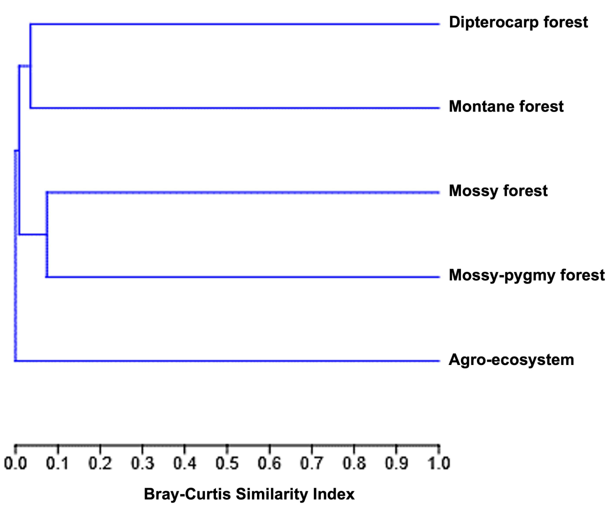

Fig. 7. Clustering analysis of all sample sites based on the Bray-Curtis similarity index.

The species-environment relationships revealed by the CCA indicate distinct gradients along the canonical axes (Fig. 8). Axis 1 primarily represented a gradient of increasing temperature and soil pH, along with decreasing humidity and leaf litter depth. Species such as *Tanychlamys* sp. and *H. smaragdina*, along with vegetation types like the agro-ecosystem, were positively associated with this axis. This association highlights their preference for warm, low-humidity habitats characterized by thinner leaf litter and less acidic soils. In contrast, *Hemiplecta* sp., along with vegetation types such as the mossy-pygmy forest, were negatively associated with Axis 1, indicating their adaptation to cooler, more humid environments with thicker leaf litter and more acidic soils.

Axis 2, on the other hand, primarily reflected a gradient of increasing humidity, along with decreasing leaf litter depth and soil pH. The montane forest and species such as *Trochomorpha* sp. 2 displayed strong positive associations with this axis, indicating their preference for humid environments with relatively low leaf litter depth. Conversely, the agro-ecosystem, *Tanychlamys* sp., and *H. smaragdina* were negatively associated with Axis 2, suggesting their affinity for habitats with thicker leaf litter. These relationships underscore the differential responses of species and vegetation types to the underlying environmental gradients. Additionally, while Axis 1 and Axis 2 captured the largest proportion of variation, their associated p-values (0.754 and 0.431, respectively) indicated that these axes were not statistically significant.

DISCUSSION

Habitat heterogeneity plays a crucial role in shaping the diversity, abundance, and distribution of land snails. In the mossy forest, the highest species

Table 4. Diversity indices of land snails in Mt. Hamiguitan, Davao Oriental

Vegetation type	Simpson (1-D)	Shannon (H’)	Dominance (D)	Evenness (J’)
Agro-ecosystem	0.14	0.27	0.86	0.66
Dipterocarp forest	0.42	0.98	0.58	0.38
Montane forest	0.58	1.09	0.42	0.74
Mossy forest	0.85	2.03	0.15	0.86
Mossy-pygmy forest	0.00	0.00	1.00	0.00

richness and abundance were observed, highlighting its ecological role as a biodiversity hotspot. This forest's stable microhabitats, characterized by high humidity, thick leaf litter, and dense vegetation, provide optimal conditions for moisture-sensitive species, making it a critical refuge for species that require stable, undisturbed environments (Wronski et al. 2014; Criscione and Köhler 2016). The mossy forest thus supports a high diversity of taxa, indicating its role in preserving specialized species and maintaining ecosystem functions like nutrient cycling and detritus decomposition. In contrast, the agro-ecosystem exhibited the lowest species richness and abundance, reflecting the profound ecological degradation caused by anthropogenic disturbances. Agricultural practices, habitat fragmentation, and reduced canopy cover create a less hospitable environment, which limits the species diversity and abundance that can thrive (Galindo et al. 2022). This highlights the agro-ecosystem's diminished ecological role in sustaining diverse land snail communities, emphasizing the need for restoration efforts to mitigate biodiversity loss. The mossy-pygmy forest, with its extreme environmental conditions (Chen et al. 2024), supports a limited community of highly specialized species, underscoring its ecological fragility and the narrow ecological niche it offers for land snails. The dipterocarp forest, with its moist soils and organic-rich substrates, provides a relatively stable habitat for Helicinidae species, playing an important role in supporting nutrient cycling and ecosystem stability. The montane forest, serving as a transitional zone, provides a critical ecological function by maintaining connectivity between highland and lowland ecosystems, supporting species that may move between different elevations due to climatic or environmental changes (Moradi et al. 2020).

The absence of rare species in this study may be attributed to the fact that, although the surveyed habitats were extensive, they may not have encompassed extreme or isolated environments typically associated with the occurrence of truly rare species, such as highly specialized ecological niches (Xiao et al. 2023). Furthermore, the stable environmental conditions within the forests likely facilitated population stability, thereby mitigating the fluctuations that commonly give rise to species rarity. Competitive dynamics within these habitats may also have favored the persistence of more dominant species (Chapuis et al. 2023), such as *Sulfurina* sp. 3, potentially limiting the establishment of less abundant species. Additionally, while the survey was comprehensive in its scope, the possibility remains that rare or cryptic species may have been overlooked. Consequently, future research employing more targeted methodologies, including advanced genetic techniques or sampling in more extreme environments, may uncover patterns of rarity not captured in the present survey.

The species accumulation curves further highlight

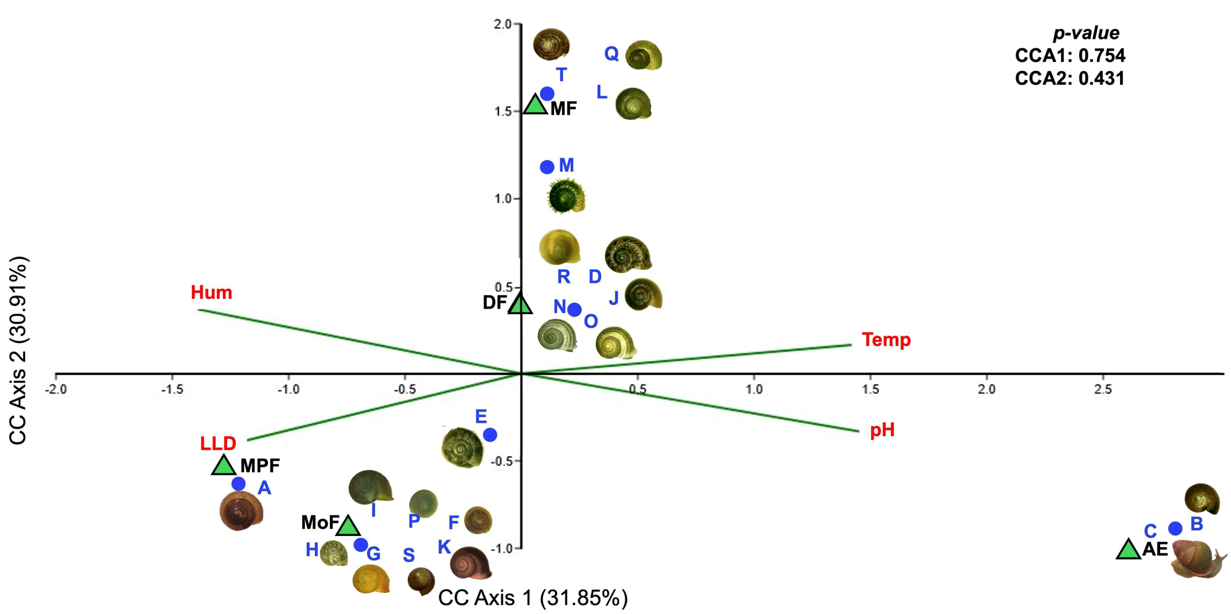

Fig. 8. Canonical Correspondence Analysis (CCA) illustrating the associations between land snail species and environmental variables across study sites. The biplot depicts land snail species (blue circles with representative images) and environmental variables (green vectors), including leaf litter depth (LLD), relative humidity (Hum), soil pH (pH), and temperature (Temp). Study sites are represented as follows: agro-ecosystem (AE), dipterocarp forest (DF), montane forest (MF), mossy forest (MoF), and mossy-pygmy forest (MPF). The land snail species are labeled A–T, as shown in figures 3–5.

the ecological roles of the different vegetation types, reflecting both observed and extrapolated species richness and offering insights into community diversity. The mossy forest, with its steep rarefaction curve, indicates not only high observed species richness but also a high likelihood of encountering additional species with continued sampling. This reinforces the forest's role as a stable, diverse habitat with significant ecological importance for biodiversity support and habitat complexity. Similarly, the dipterocarp forest, with its steep accumulation curve, suggests that additional species remain to be discovered, underlining the potential for further research to better understand its ecological value in supporting biodiversity and ecosystem resilience. In contrast, the agro-ecosystem and mossy-pygmy forest displayed shallower slopes in their accumulation curves, suggesting that species richness in these areas is nearing saturation, likely due to habitat simplification and disturbance in the agro-ecosystem, and the extreme environmental conditions in the mossy-pygmy forest that limit species' capacity to thrive. The montane forest, with its moderate accumulation curve slope, demonstrated that it plays an important role in sustaining diverse communities while acting as a buffer zone between higher and lower elevation ecosystems. These findings underscore the need for continued sampling to fully capture the diversity of land snails across Mt. Hamiguitan, with further exploration of the dipterocarp and mossy forests potentially revealing additional species and improving the understanding of the ecological dynamics at play.

The diversity indices provide critical insights into the ecological stability of each habitat. The mossy forest stands out for its high diversity and low dominance, reflecting its ecological resilience and balanced species composition. This high evenness suggests that the forest supports a diverse range of species with minimal competitive exclusion, playing an important role in maintaining ecological stability and species coexistence. The montane forest showed moderate diversity and evenness, which indicates that, although not as ecologically stable as the mossy forest, it still plays an important role in connecting diverse habitats across elevations. The dipterocarp forest displayed a more uneven community structure, with higher dominance, suggesting that it may be more vulnerable to disturbances, such as selective logging (Atikah et al. 2021). Despite this, it still supports valuable ecological functions, such as nutrient cycling and habitat provision for species like Helicinidae. The agro-ecosystem, with its low diversity and high dominance, underscores the consequences of anthropogenic activities, where habitat degradation reduces ecological functions like species support and ecosystem resilience (Bohada-Murillo et al. 2020; Andersson et al. 2021). The mossy-pygmy forest exhibited extreme dominance by a few species, highlighting its role as a specialized, though fragile, ecosystem where only highly adapted species can survive, serving as an example of the limits of biodiversity under harsh ecological conditions.

The clustering patterns of land snail communities across the five vegetation types highlight the degree of ecological connectivity and isolation among these habitats. The agro-ecosystem stands out due to its complete isolation, underscoring the detrimental effects of habitat fragmentation and anthropogenic disturbance on biodiversity. In contrast, the dipterocarp forest and montane forest exhibit strong ecological similarities, particularly due to their shared moderate humidity and organic-rich substrates. These similarities suggest that both habitats offer comparable ecological niches for land snails, thereby playing complementary roles in sustaining biodiversity and supporting diverse communities across the landscape. The mossy forest, which has the highest species richness, is a key biodiversity hotspot. Its stable, humid conditions with thick leaf litter and complex vegetation support a wide range of species, making it a critical habitat for land snails. While the mossy-pygmy forest has lower biodiversity due to its extreme environmental conditions, such as low temperatures, poor nutrient availability, and harsh growing conditions, it shares ecological similarities with the mossy forest, particularly in its high humidity and dense vegetation. However, the mossy-pygmy forest remains a more marginal habitat for land snails, supporting only a few specialized species adapted to such challenging conditions. Despite its limited species richness, the mossy-pygmy forest holds significant ecological value by providing a refuge for these specialized species.

CCA results suggest that environmental variables such as leaf litter depth, humidity, soil pH, and temperature play important roles in shaping land snail distributions. The observed patterns reflect the ecological gradients between disturbed and undisturbed habitats, with species such as *Tanychlamys* sp. and *H. smaragdina* adapted to warmer, disturbed environments, while others, like *Hemiplecta* sp., are specialized for cooler, more humid forests. These gradients underline the role of environmental factors in structuring land snail communities and highlight the complex interplay between habitat conditions and species distribution. The lack of statistical significance may be due to unmeasured environmental factors that could provide additional insights into these patterns. Nevertheless, the findings reinforce the importance of habitat conditions in supporting land snail communities and maintaining ecosystem balance.

CONCLUSIONS

This study highlights the rich biodiversity of land snails in Mount Hamiguitan, a UNESCO World Heritage Site and ASEAN Heritage Park in the Philippines. The findings reveal distinct ecological patterns shaped by the varying conditions across five vegetation types: agro-ecosystem, dipterocarp forest, montane forest, mossy forest, and mossy-pygmy forest. The mossy forest stands out as the most biodiverse habitat, supporting the highest species richness and abundance due to its stable microclimate, thick leaf litter, and high humidity. These characteristics make it an ecological refuge for a wide variety of land snail species. In contrast, the agro-ecosystem exhibited the lowest biodiversity, which can be attributed to human-induced disturbances and habitat alteration. It formed an isolated cluster in the cluster analysis, distinct from the other vegetation types due to its reduced species diversity and specialized communities. The dipterocarp and montane forests, on the other hand, exhibited strong ecological similarity, reflecting their shared environmental conditions and overlapping species compositions. These forests appear to play complementary roles in supporting land snail biodiversity, particularly by maintaining connectivity between higher and lower elevations.

The mossy-pygmy forest, despite its lower biodiversity due to harsh conditions such as cold temperatures and nutrient-poor soils, shared ecological similarities with the mossy forest. Both are characterized by high humidity, dense vegetation, and similar environmental factors. Key environmental drivers of species distribution included leaf litter depth, humidity, soil pH, and temperature. Generalist species thrived in disturbed habitats, while specialist species were associated with cooler, more humid forests with thick leaf litter and acidic soils. The distinct patterns of species composition between forest types further underscore their unique ecological characteristics and the need for targeted conservation strategies.

This study provides foundational data for understanding the ecological roles of land snails in Mount Hamiguitan and highlights their potential as bioindicators for monitoring ecosystem health. Further research with expanded sampling efforts and the inclusion of additional environmental variables is necessary to deepen our understanding of the ecological dynamics shaping land snail communities. Ultimately, the findings advocate for integrated conservation strategies that protect biodiversity, maintain ecosystem functions, and support the sustainable use of natural resources in Mount Hamiguitan and beyond.

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