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Lepidoptera diversity, richness, and distribution in semi-urban farmland and other habitats around Lumbini, Rupandehi

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Abstract
This study comprehensively examined Lepidoptera diversity in the semi-urban agricultural landscapes of Lumbini, Nepal, documenting 30 moth species from six families and 39 butterfly species from five families over 14 days. Field methods included moth traps with 50-watt LED lights inside a box lined with egg cartons for moth trapping, as well as butterfly transect surveys across various habitats, including grasslands, shrublands, and agricultural areas, for recording butterfly species. The Erebidae family dominated moth populations, while Nymphalidae led butterfly diversity, showing resilience in disturbed habitats influenced by environmental factors such as weather patterns, lunar phases, and habitat characteristics. Statistical analyses using Simpson's Diversity Index, Shannon-Wiener Diversity Index, Pielou's Evenness Index, and Margalef's Richness Index revealed that shrubland and agricultural habitats supported the highest species richness and evenness, while grasslands hosted fewer species. The study highlighted the importance of agricultural and shrubland ecosystems for biodiversity, emphasizing ongoing monitoring to understand how Lepidoptera populations respond to environmental changes, offering essential insights for future conservation efforts.

Keywords: Distribution patterns, Environmental factors, Habitat, Lepidoptera, Semi-urban farmland, Species diversity

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Introduction
Lepidoptera, comprising moths and butterflies, are among the most diverse and ecologically significant insect orders, with over 160,000 species recorded globally (Perveen and Khan, 2017). Characterized by their scaled wings and specialized proboscis, these insects undergo complete metamorphosis, progressing through the stages of egg, larva, pupa, and adult (Gibb,

2015). Moths represent the majority of Lepidoptera diversity, classified into over 30 superfamilies, with Noctuidae (35,000 species) and Geometridae (21,000 species) being the most diverse (New, 2004). Butterflies, though more conspicuous, comprise fewer species but are ecologically prominent, with families such as Nymphalidae and Lycaenidae dominating in the tropics (Iqbal *et al*., 2016).

Ecologically, Lepidoptera function as pollinators, herbivores, prey, and nutrient recyclers (Wilson and Maclean, 2010). Moths, particularly nocturnal species, pollinate a variety of night-blooming plants, while butterflies contribute to the genetic mixing of angiosperms through long-distance pollen dispersal (Pradhan *et al*., 2024; Goldstein, 2017). Their feeding habits and plant specificity render them highly sensitive to environmental disturbances, making them effective bio-indicators of ecosystem health (Dar and Jamal, 2021). Furthermore, their vulnerability to climate shifts, due to limited dispersal and habitat specialization, places many species at conservation risk (Wilson and Maclean, 2010).

Despite these roles, Lepidoptera remain understudied in Nepal's landscapes. National biodiversity strategies have historically prioritized charismatic megafauna such as tigers and rhinos (Jnawali *et al*., 2011; Fitzmaurice *et al*., 2021), while invertebrates, including moths and butterflies, have received relatively little research attention. This has resulted in significant gaps in taxonomic and ecological data, particularly regarding moth diversity and distribution.

Nepal's altitudinal and climatic gradients, ranging from tropical terai lowlands to alpine Himalayan meadows, host a wide array of lepidopteran communities (Choudhary and Chishty, 2020). These ecosystems, from dense Sal forests in the south to temperate oak forests and alpine meadows in the north, support species with diverse ecological adaptations (Slade *et al*., 2013). Yet even modified landscapes, such as urban gardens and agricultural fields, play important roles as refuge habitats. Currently, Nepal has a record of 663 butterfly species (Sapkota, KC and Pariyar, 2020) and 6,000 macro-moth species (Smith, 2010), though the accurate species richness is likely higher due to lack of sampling across diverse regions.

Most existing Lepidoptera studies in Nepal have focused on butterflies or specific protected areas, with moths receiving limited survey efforts. Although early taxonomic work (e.g., Owada, 1981; Khanal and Shrestha, 2022) laid groundwork, comprehensive studies on moth distribution, diversity, and habitat preferences remain very scarce. This limits our understanding of how these species respond to environmental changes across Nepal's fragmented landscapes.

Lumbini, located in Nepal's subtropical Terai, provides a unique setting for studying Lepidoptera due to its diverse land-use types, including agricultural fields, wetlands, forests, and shrublands (Baral, 2018). These habitats support a variety of floral resources and microclimates suitable for various lepidopteran species. This region also remains largely underexplored when it comes to moth and butterfly diversity. Understanding the diversity, richness, and distribution patterns of Lepidoptera in Lumbini is crucial not just for documenting biodiversity but also for establishing a strong foundation for future research (Thomas, 2004, 2005). This groundwork will allow us to identify reliable patterns and trends over time and inform effective conservation strategies suited to human-modified landscapes.

Objectives of the Study

This study aims to examine the diversity and distribution patterns of Lepidoptera species in semi-urban farmlands and associated habitats of Lumbini, Rupandehi. The specific objectives are:

- To evaluate the species diversity and richness of Lepidoptera across different habitat types, including agricultural fields, forests, wetlands, grasslands, and shrublands.
- To analyze how different habitat types influence butterfly abundance and distribution patterns.
- To assess the relationship between moth species diversity, richness, and evenness and environmental factors, including temperature, humidity, and lunar phases.

Materials and Methods

Study Area

The study was carried out at Lumbini, in the Rupandehi district of Lumbini Sanskritik Municipality, Lumbini Province. Lumbini, the birthplace of Lord Buddha, is a site of immense historical and religious importance, housing archaeological artifacts from the third century BC. Key structures include the Shakya Tank, Maya Devi Temple, and the Ashoka pillar with Brahmi inscriptions reflecting the region's rich history (UNESCO, 2010). The study area was centered at coordinates 27°29'24" N and 83°17'47" E, approximately 100 meters above sea level. The total area of research covered was approximately 6,771.84 square meters.

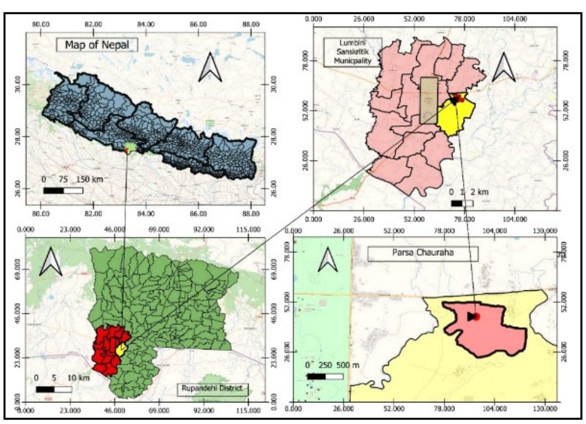

Figure 1. The study area map illustrating Lumbini Sanskritik Municipality, Rupandehi District.

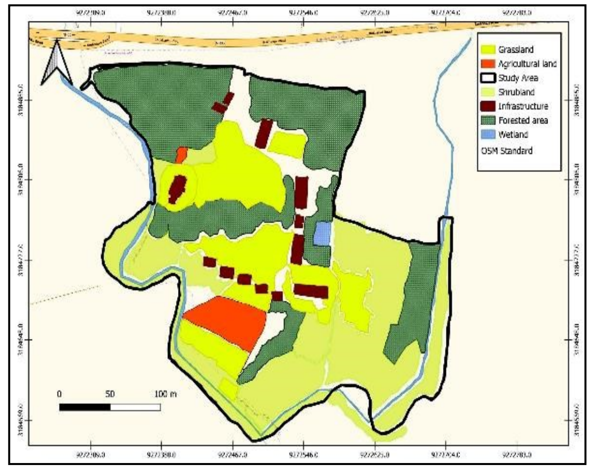

Figure 2. A polygon map of the habitat distribution across the study area

Climate and Vegetation

Lumbini experiences a tropical to subtropical climate with distinct seasons, including long, hot summers with temperatures that often exceed 40 °C, and a prolonged monsoon from June to September while winter temperatures can drop as low as 9 °C, offering a cooler period essential for agriculture. In recent years, temperatures have risen global warming (Baral, 2018), posing threats to biodiversity and potentially Lepidoptera species. Higher temperatures affect water availability and growing seasons (Malla *et al*., 2022).

Lumbini encompasses diverse habitats, including open water bodies (10 ha), forest plantations (270 ha), and grasslands (400 ha) (Baral, 2018). Lumbini Development Trust, a local authority in the area, has planted mixed types of trees, native and imported (Baral, 2018). The area supports 72 vascular plant species, mainly from the Asteraceae, Poaceae, and Fabaceae families, with Fabaceae being culturally significant due to its association with Lord Buddha (Bhattarai and Baral, 1970). However, human activities and alien species introductions have led to species decline (Siwakoti, 2008). Key nectar-rich plants include *Vernonia cinerea* and *Helianthus annuus*, while Asteraceae, Lamiaceae, and

Moraceae provide essential resources for butterflies (Siwakoti, 2008). Lumbini is also home to 421 bird species, including the globally threatened Sarus Crane (Baral, 2018) as well as mammals such as Nilgai *Boselaphus tragocamelus*, Wild Boar *Sus scrofa* and Indian Grey Mongoose *Urva edwardsii*. The Lumbini farmlands and Jagadishpur Reservoir are designated an Important Bird and Biodiversity Area of Nepal (BCN, DNPWC and DoFSC, 2023).

Data Collection

A stratified sampling approach was employed to document Lepidoptera diversity across selected habitat types in Lumbini. The study spanned a continuous 14-day period from February 19 to March 5; 2024, ensuring consistent data collection and minimizing short-term variability in species activity.

Site selection criteria

For moth sampling, a semi-urban farmland site was purposefully selected based on its transitional landscape, combining agricultural fields and human habitation. This type of setting was considered ideal for evaluating the diversity of moths influenced by mixed environmental pressures, including light pollution, habitat fragmentation, and plant diversity. For butterflies, five habitat types- grasslands, shrublands, wetlands, forest patches, and agricultural lands were identified and selected to represent the major ecological zones within the Lumbini area. These habitats were chosen to examine habitat-specific species distribution and richness across both natural and managed landscapes.

Sampling effort and replication

Each selected habitat was surveyed multiple times over the two weeks, with systematic replication to ensure representativeness. Butterfly transect walks were repeated at least three times per habitat, maintaining uniform length (500 meters) and observer effort. For moths, the light trap was deployed nightly at the same fixed location to ensure comparability across sampling nights.

Moth sampling

Moths were collected using a trap constructed from a cardboard enclosure housing a 50W LED light, with internal egg cartons and glass panes to facilitate entry and minimize harm to the moths. The LED was chosen for its broad-spectrum emission and energy efficiency, which have proven effective in attracting a wide range of moth species while minimizing environmental impact (Yun *et al*., 2023). The trap operated continuously from 18:00 to 06:30 each day and night. Captured moths in the morning were photographed under standardized lighting conditions for identification and behavior documentation. This extended overnight sampling enabled detection of species with varying activity peaks, offering advantages over passive or sporadic nocturnal sampling.

Butterfly sampling protocol

Butterfly data were collected via line transect and direct observation methods. Initial monitoring occurred from sunrise to sunset to establish daily activity patterns, followed by focused sampling during peak activity hours from 12:00 to 15:00. A single 500-meter transect was laid out in each habitat type and walked slowly while recording species. Observations were made under favorable weather conditions (sunny to partially cloudy, wind <15 km/h), and habitat visits were alternated to reduce bias due to daily variation.

Species identification and data integrity

All Lepidoptera observed or photographed were identified using digital tools (iNaturalist) and authoritative field guides by Smith (2010, 2011) and Gurung *et al*. (2024). When identification to species level was uncertain, genus-level classification was applied. Daily weather variables were also recorded to explore connections between environmental conditions and moth activity.

Figure 3. Moth sampling setup using a light trap (left), designed to attract and document nocturnal moth species, and butterfly survey conducted through systematic visual observation along transects (right), used for recording diurnal butterfly diversity.

Figure 4. The selected habitats for the butterfly surveys included: (aa) wetland, (ab) forested area, (ad) grassland, (ae) shrubland, and (af and ag) agricultural land.

The observed Lepidoptera species were classified into four abundance categories: Very Rare (VR) for 1-2 individuals, Rare (R) for 3-10, Fairly Common (FC) for 11-30, and Common (C) for more than 30 individuals. This systematic classification helped assess species prevalence within the study area (Shrestha *et al*., 2018).

Data analysis

To evaluate Lepidoptera diversity, richness, and distribution across different habitats, four biodiversity indices were selected based on their ecological relevance and complementarity. These indices provide quantitative insights into species abundance, richness, and evenness, which are essential for understanding community composition in different habitats.

Simpson's Diversity Index (D)

Simpson's Diversity Index (D) was used to quantify species diversity, determined by the formula:

$$\mathbf{D = 1-(\sum n(n-1)/ N(N-1))}$$

Where,
n = Number of individuals of a species
N= The total number of individuals of all species
D= Simpson's Diversity Index

This formula measures the likelihood that two randomly selected individuals belong to different species. Index values range from 0 to 1, with higher values indicating higher diversity (Somerfield, Clarke and Warwick, 2008).

Shannon-Weiner Diversity Index (H')

The Shannon-Wiener Diversity Index (H') was also used to assess both species richness and evenness:
The formula for the Shannon-Weiner Diversity Index (H') is:

$$\mathbf{H' = \Sigma\ S\ (i=1)\ Pi*ln\ (pi)}$$

Where,
S= Total number of species

pi = the proportion of individuals of species iii relative to the total number of individuals (i.e., pi=ni\N ,
where ni is the number of individuals of species i, and N is the total number of individuals)
ln(pi) represents the natural logarithm of pi. The Shannon-Wiener index accounts for both species richness and evenness, with higher H′ values indicating greater diversity (Bollarapuk *et al*., 2021).

Pielou's Evenness Index (J')

The evenness was calculated to reveal the relative abundance of species distributed using Pielou's Evenness Index (Equitability) (J').
The formula for the Pielou's evenness index (J') is:

$$J' = H'/\ln(S)$$

Where,
H′ = Shannon-Wiener diversity index,
S = the total number of species, and
ln(S) = natural logarithm of S.

Pielou's Evenness Index assesses how equally species are distributed among species in a group. It has a range of 0 to 1, with values closer to 1 suggesting more evenly distributed species (Heip, 1974).

Margalef's Richness Index (Dmg)

Margalef's Richness Index was calculated to measure species richness by adjusting for the total number of individuals obtained, giving an accurate comparison across several habitats.
The formula for the Magalef's Richness Index (Dmg) is:

$$Dmg = S-1/Ln\ (N)$$

Where,
S = Total number of species.
N = Total number of persons.
ln(N) = The natural logarithm of the total number of species.

Margalef's index quantifies species richness, with higher values reflecting greater richness relative to sample size (Gamito, 2010).

Analyses were performed using Microsoft Excel 2013 for basic data organization and R Studio (version 4.3.2) for statistical analysis and data visualization. Habitat and study area maps were generated using QGIS 3.22.

Results

Moths

A total of 30 moth species from six families and 26 different genera were recorded. The Erebidae family was the most prevalent, comprising 44 individuals, followed by Noctuidae with 29 individuals. Other families, including Geometridae, Crambidae, Pyralidae, and Spilomelinae, contributed 5, 4, 3, and 1 individuals, respectively.

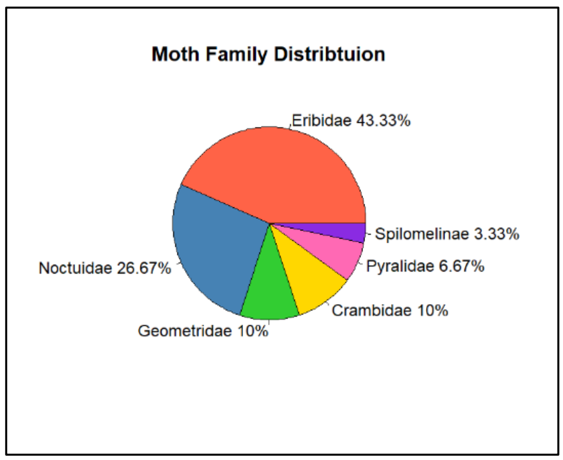

Figure 5. The distribution of moths by the families in percentage

Spilosoma strigatula (Erebidae) and *Sesamia inferens* (Noctuidae) were identified as dominant species, classified as "Fairly Common" (FC), with 25 and 18 individuals observed respectively. These species exhibited the highest relative abundances (0.3 and 0.23), indicating their ecological dominance within the community

Table 1. A Checklist of Moth Species and Their Abundance, Categorized By their Family, and Status Recorded. A dash (—) indicates that the common name was not known or not available.

S.N	Common Name	Scientific Name	Status	Abundance
A) Eribidae				
1	Tiger moth	*Spilosoma strigatula*	FC	25
2	*Asura-Miltochrista*- group spp	*Asura-Miltochrista*	R	4
3	Grizzled tussock	*Dasychira*	VR	1
4	Sober tabby	*Ericeia inangulata*	VR	1
5	Clouded tiger moth	*Cretonotos transiens*	VR	1
6	Bihar hairy moth	*Spilosoma obliqua*	VR	2
7	—	*Eressa confinis*	VR	1
8	Common hairy moth	*Spilarctia*-genera sps1	VR	2
9	—	*Spilosoma*-genera sps	R	3
10	—	*Lymantria ampla*	VR	1
11	—	*Spilarctica*-genera sps 2	VR	2
12	Baphomet moth	*Creatonotos gangis-interrupta*	VR	1
13	—	*Pandesma*-genera sps	VR	1
		Total		**45**
B) Noctuidae				
14	Asiatic pink stem borer	*Sesamia inferens*	FC	18
15	—	*Athetis*-genera sps	VR	1
16	Northern armyworm	*Mythimna separata*	VR	2
17	False army worm	*Leucania loreyi*	R	3
18	Lily borer	*Brithys crini*	VR	1
19	—	*Caradrina*-genera sps	VR	1
20	—	*Spodoptera*-genera sps	VR	1
21	Dark-mottled willow	*Spodoptera cilium*	VR	2
		Total		**29**
C) Crambidae				
22	Hydrilla leafcutter	*Parapoynx diminutalis*	VR	2
23	Banded pearl	*Sameodes cancellalis*	VR	1
24	—	*Uresiphita*- genera sps	VR	1
		Total		**4**
D) Pyralidae				
25	Snout moths	*Pyralidae-genera* sps	VR	1
26	Indian meal moth	*Plodia interpunctella*	VR	2
		Total		**3**
E) Geometridae				
27	—	*Idaea*-genera sps	VR	2
28	—	*Chorodna strixaria*	VR	1
29	—	*Scopula emissaria*	VR	2
		Total		**5**
F) Spilomelinae				
30	—	*Bradina lederer*	VR	1
		Total	VR	1
		Sum total		87

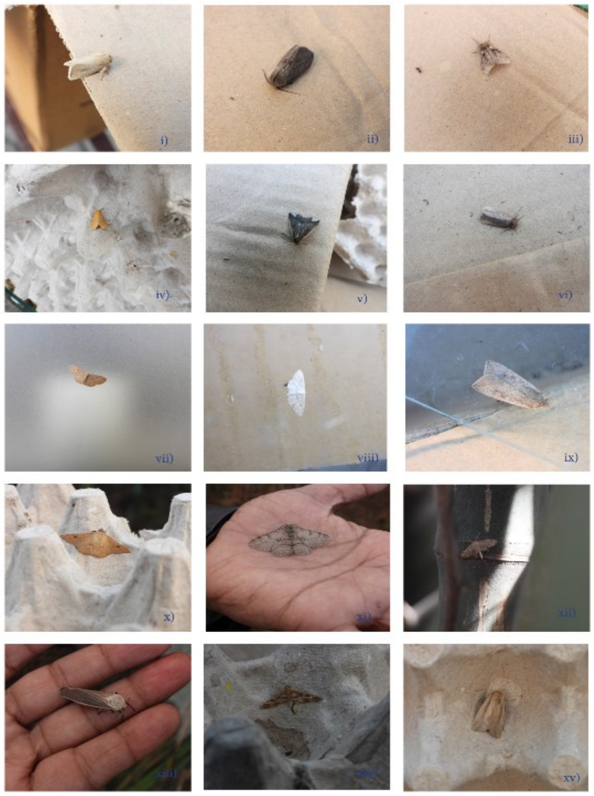

Figure 6. The moth species captured through the moth survey/ light trapping;

i) *Sesamia inferens,* ii) *Spilosoma strigatula,* iii) *Dasychira,* iv) *Asura-Miltochrista* group sps, v) *Pyralidae*-genera sps., vi) *Athetis* genera sps., vii) *Idaea* genera sps., viii) *Scopula emissaria*, ix) *Mythimna separate*, x) *Ericeia inangulata,* xi) *Chorodna strixaria,* xii) *Bradina lederer*, xiii) *Creatonotos transiens*, xiv) *Sameodes cancellalis*, xv) *Leucania loreyi.*

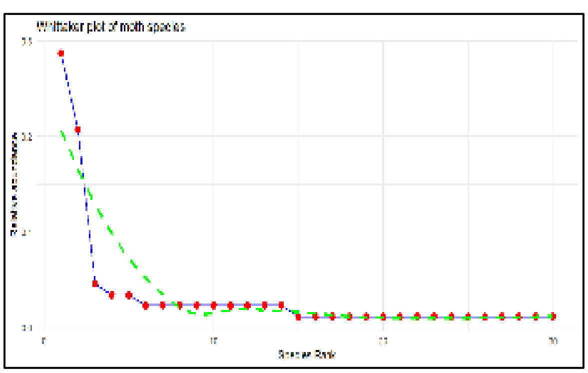

Figure 8. Rank-abundance plot of moth species observed

Figure 7. Moth species recorded through light trapping during the moth survey:

xvi) *Spilarctia obliqua*, xvii) *Eressa confinis*, xviii) *Spilarctia*- genera sps, xix) *Brithys crini*, xx) *Caradrina*-genera sps, xxi) *Lymantria ampla*, xxii) *Spodoptera* sps, xxiii) *Spodoptera cilium*, xxiv) *Creatonotos gangis*–interrupta, xxv) *Parapoynx diminutalis*, xxvi) *Uresiphita*-genera sps, xxvii) *Pandesma*- genera sps, xxviii) *Plodia interpunctella*, xxix) *Spilosoma*- genera sps 1, xxx) *Spilosoma*-genera sp 2.

A clear pattern of uneven species distribution among moths was found (Figure 6). *Spilosoma strigatula* and *Sesamia inferens* appeared dominant, with approximately 0.3 and 0.23 relative abundances, respectively. Following these dominant species, there is a sharp drop in abundance, with *Asura-Miltochrista* group sps. The mid-ranked species, such as *Dasychira* and *Parapoynx diminutalis*, exhibited varying levels of abundance, ranging from 0.034 to 0.023. Species such as *Creatonotos gangis-interrupta* and *Eressa confinis* had the lowest abundance.

Table 2. The Shannon-Weiner index (H'); Simpson's Diversity Index (D); Margalef's Richness Index (Dmg); Pielou's Evenness (J') and Species Richness (S) of all six families and their total

Family	H'	D	Dmg	J'	S
Eribidae	1.73	0.67	3.15	0.67	13
Noctuidae	1.36	0.59	2.08	0.66	8
Crambidae	1.04	0.63	1.44	0.95	3
Pyralidae	0.64	0.44	0.91	0.92	2
Geometridae	1.05	0.64	1.24	0.96	3
Spilomelinae	0	0	0	0	1
Total	2.66	0.86	6.49	0.78	30

The overall moth community diversity was moderate, with Erebidae having the highest diversity (H' = 1.73), species richness (Dmg = 3.15), and dominance (D = 0.67). Noctuidae exhibited moderate richness (Dmg = 2.08) and diversity (H' = 1.36) with lower dominance (D = 0.59) and evenness (J' = 0.66). Geometridae and Crambidae showed similar diversity values, while Pyralidae showed low diversity (H' = 0.64) and richness (Dmg = 0.91) but high evenness (J' = 0.92).

Butterflies

A total of 39 butterfly species from five families and 31 genera were recorded. Pieridae was the most abundant family, contributing 969 individuals, followed by Lycaenidae with 720 individuals. Other families included Papilionidae (227), Nymphalidae (199), and Hesperiidae (3). The most common species were *Pieris canidia* (578 individuals) and *Zizina otis* (536), both categorized as "Common".

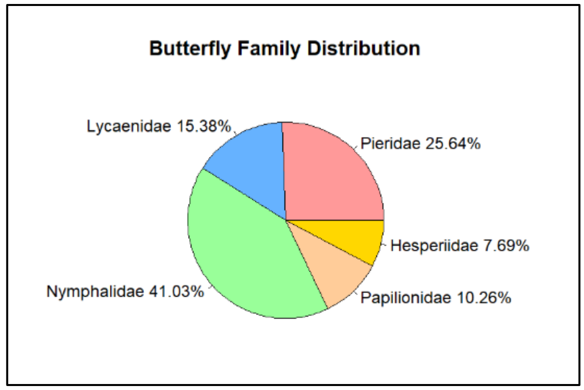

Figure 9. The distribution of the butterflies by the families in percentage

Despite Pieridae being numerically dominant, Nymphalidae showed the highest species-level diversity, contributing 16 species. The overall butterfly community exhibited substantial richness (H' = 2.317) but showed uneven distribution, with a few species dominating the majority of the population.

Nymphalidae was the most dominant butterfly family as per diversity, comprising 41.03% of the total population, indicating its significant presence across the various habitats such as grasslands, shrublands, agricultural field, wetland and forest (Figure 7). Pieridae represented 25.64% of the population, reflecting its relatively high abundance. Lycaenidae accounted for 15.38%, while Papilionidae and Hesperiidae were less prevalent, making up 10.26% and 7.69%, respectively.

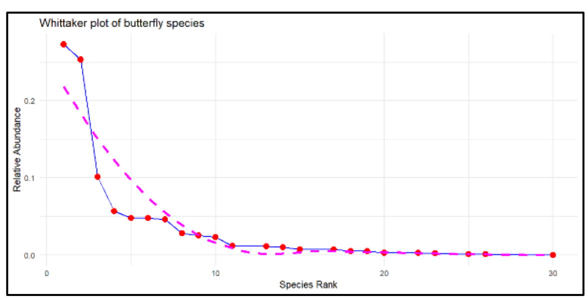

Figure 10. Rank-abundance plot of butterfly species observed

Table 3. The List of the Butterfly Species Recorded Categorized in the Total Number of Families, and Individuals Found in Various Habitats such as; AgR=Agriculture land; ShR= Shrubland; GsR=Grassland; FsR=Forest; WtL= Wetland; T=Total; ST= Sum Total

SN	Common Name	Scientific Name	Status	AgR	ShR	GsR	FsR	WtL	Total	Sum total
A.	**Pieridae**									
1	Common Gull	*Cepora nerissa*	FC	7	8	0	8	0	23	969
2	Indian Cabbage White	*Pieris brassicae*	*C*	51	35	0	34	0	120	
3	Small Grass Yellow	*Eurema brigitta*	*FC*	0	0	15	0	0	15	
4	Common Brimstone	*Gonepteryx rhamni*	*C*	39	59	0	0	0	98	
5	Large Cabbage White	*Pieris canidia*	*C*	0	280	0	275	23	578	
6	Common Wanderer	*Pareronia valeria*	*C*	11	38	0	0	0	49	
7	Common Emigrant	*Catopsilia pomona*	*FC*	6	9	0	0	0	15	
8	Caper White	*Pionner belenois aurota*	*R*	0	3	7	0	0	10	
9	Wandering Psyche	*Leptosia nina*	*C*	0	19	40	0	0	59	
10	Common Grass Yellow	*Eurema hecabe*	*VR*	0	0	2	0	0	2	
B.	**Lycaenidae**									
11	Lesser Grass Blues	*Zizina otis*	*C*	0	65	412	52	7	536	720
12	Plain Cupid	*Luthrodes pandava*	*VR*	0	0	2	0	0	2	
13	Common Pierrot	*Castalius rosimon*	*C*	38	64	0	0	0	102	
14	Pea Blue	*Lampides boeticus*	*VR*	1	0	0	0	0	1	
15	Pale Grass Blues	*Pseudozizeeria maha*	*FC*	0	0	25	0	0	25	
16	Black-spotted Pierrot	*Tarucus balcanicus nigra*	*C*	0	0	28	26	0	54	
C.	**Nymphalidae**									
17	Common Tiger	*Danaus genutia*	*C*	25	43	0	33	0	101	199
18	Great Eggfly	*Hypolimnas bolina*	*FC*	3	0	0	22	0	25	
19	Common Crow	*Euploea core*	*FC*	0	21	0	0	0	21	
20	Blue Glassy Tiger	*Ideopsis vulgaris*	*R*	3	4	0	0	0	7	
21	Commander	*Moduza procris*	*FC*	0	5	0	9	0	14	
22	Common Leopard	*Phalanta phalantha*	*R*	0	3	0	1	0	4	
23	Plain Tiger	*Danaus chrysippus*	*R*	2	4	0	0	0	6	
24	Dark Evening Brown	*Melanitis phedima*	*VR*	0	0	0	1	0	1	
25	Peacock Pansy	*Junonia almana*	*VR*	0	0	0	2	0	2	
26	Grey Pansy	*Junonia atlites*	*VR*	0	0	1	0	0	1	
27	Common Mapwing	*Cyrestis thyodamas*	*VR*	0	0	0	2	0	2	
28	Bamboo Tree Brown	*Lethe europa*	*VR*	0	0	0	0	1	1	
29	Common Evening Brown	*Melanitis leda*	*VR*	0	0	1	0	0	1	
30	Great Evening Brown	*Melanitis zitenius*	*VR*	0	0	1	0	0	1	
31	Oriental Blue Tiger	*Tirumala limniace*	*FC*	0	0	11	0	0	11	
32	Plain Sailer	*Neptis cartica*	*VR*	1	0	0	0	0	1	
D.	**Papilionidae**									
33	Common Mormon	*Papilio polytes*	*C*	64	54	30	61	4	213	227
34	Common Mime	*Papilio clytia*	*R*	1	3	0	0	0	4	
35	Common Rose	*Pachliopta aristolochiae*	*R*	0	0	0	5	2	7	
36	Lime Swallowtail	*Papilio demoleus*	*R*	1	0	2	0	0	3	
E.	**Hesperiidae**									
37	Indian Grizzled Skipper	*Spialia galba*	*VR*	1	0	0	0	0	1	3
38	Common Dartlet	*Oriens gola*	*VR*	0	1	0	0	0	1	
39	Formosan Swift	*Borbo cinnara*	*VR*	0	1	0	0	0	1	
									Total abundance =	**2118**

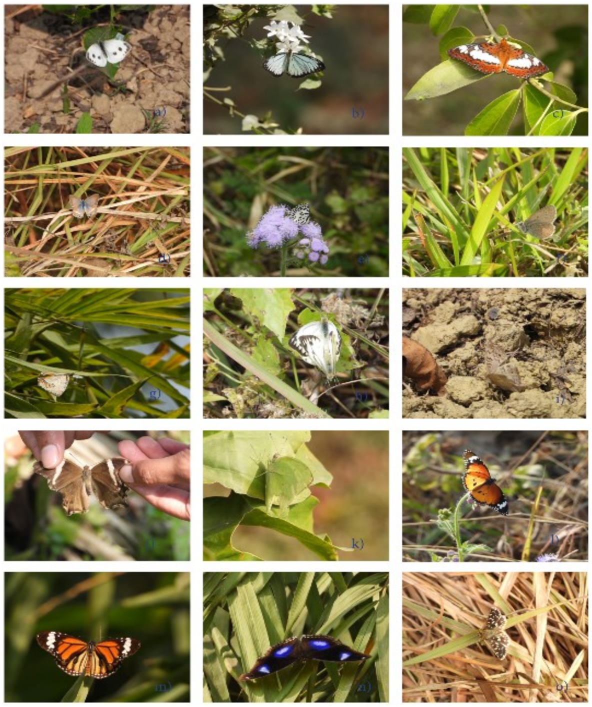

Figure 11. Butterfly species recorded during the transect survey,
a) *Pieris brassicae,* b) *Pareronia valeria,* c) *Moduza procris* , d) *Lampides boeticus,* e) *Castalius rosimon,* f) *Zizina Otis*, g) *Cyrestis thyodamas,* h) *Cepora nerissa,* i) *Junonia atlites*, j) *Lethe europa,* k) *Gonepteryx rhamni,* l) *Neptis cartica,* m) *Danaus genutia,* n) *Hypolimnas bolina,* o) *Spialia galba*

Table 4. The diversity indices calculation of five different butterfly families

Family	H'	D	Dmg	J'
Pieridae	1.398	0.611	1.309	0.607
Lycaenidae	0.833	0.419	0.760	0.465
Nymphalidae	1.759	0.707	2.831	0.634
Papilionidae	0.295	0.118	0.553	0.213
Hesperiidae	1.099	0.667	1.820	1.000
Total	2.317	0.839	4.962	0.633

Species such as *Pieris canidia*, *Zizina Otis,* and *Papilio polytes* had higher abundances compared to others (figure 10). After the top five dominant species, abundance declined steeply for others indicating that only a few species were numerically dominant, such as the *Danaus genutia* and *Gonepteryx rhamni*. Species ranked beyond 10 contributed very little to the overall population such as the *Hypolimnas bolina* and *Cepora nerissa*, suggesting that a large portion of the butterfly groups comprised of rare species.

Figure 12. Butterfly species recorded during the transect survey,
p) *Ideopsis vulgaris*, q) *Papilio demoleus*, r) *Papilio polytes,* s) *Leptosia nina,* t) *Junonia almanac*, u) *Melanitis zitenius,* v) *Pieris canidia,* w) *Oriens gola*, x) *Tarucus balcanicus nigra,* y) and ab) *Pseudozizeeria maha,* and z) *Neptis cartica*

Nymphalidae demonstrated the highest Shannon-Wiener index (H' = 1.759), richness (Dmg = 2.831), and evenness (J' = 0.634). Pieridae also showed high diversity (H' = 1.398) and evenness (J' = 0.607) across 10 species. Lycaenidae, Papilionidae, and Hesperiidae had lower diversity values, with Papilionidae showing the lowest evenness (J' = 0.213).

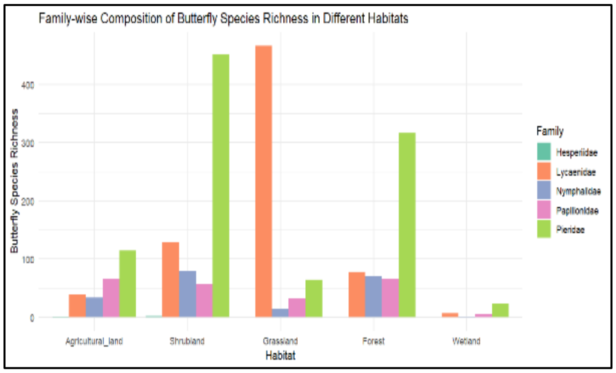

Figure 13. The family-wise categorization of butterfly richness in 5 different habitats

Butterflies were categorized across five habitats: grasslands, shrublands, wetlands, forests, and agricultural lands. Grasslands had the highest species richness, dominated by Pieridae and Lycaenidae. Shrublands and forests showed moderate richness, primarily composed of Nymphalidae and Pieridae.

Table 5. The Shannon Diversity Index (H') and Pielou's Evenness Index of the overall butterfly richness in 5 different habitats.

Habitat	Shannon Diversity Index (H')	Pielou's Evenness Index (J)
Agricultural land	2.0628	0.7281
Shrubland	2.0263	0.7010
Grassland	1.1779	0.4463
Forest	1.7242	0.6367
Wetland	1.4195	0.6827

Agricultural lands displayed high diversity (H' = 2.0628) and evenness (J' = 0.7281), while wetlands had lower richness but a balanced composition with high evenness (J' = 0.6827). Grasslands were the least even and diverse (H' = 1.1779; J' = 0.4463), with dominance by a few species.

Table 6. The total vegetation recorded with its origin and the butterfly species that visited the most

SN	Name of the Plant	Origin of the Plant	Butterfly Species Observed
1	*Clerodendrum viscosum*	Native	*Danaus genutia*
2	*Trachelospermum jasminoides*	Alien	*Papilio polytes, Pareronia valeriar, Hypolimnas bolina, Danaus genutia, Gonepteryx rhamni, and Papilio demoleus*
3	*Acmella uliginosa*	Native	*Zizina otis, Oriens gola, Pieris brassicae, Tarucus balcanicus nigra and Castalius rosimon*
4	*Phyllostachys aurea*	Native	*Junonia almana*
5	*Pogostemon heyneanus*	Native	*Tarucus balcanicus nigra, Danaus genutia, and Papilio polytes*
6	*Raphanus raphanistrum*	Planted	*Gonepteryx rhamni, Hypolimnas bolina, Papilio demoleus, and Pieris brassica*
7	*Dendrocalamus*	Native	*Danaus genutia, Pachliopta aristolochiae, Cyrestis thyodamas, and Danaus chrysippus*
8	*Mikania micrantha*	Invasive	*Pieris canidia, Pieris brassicae, Gonepteryx rhamni, Castalius rosimon, Papilio demoleus, and Catopsilia pomona*

9	*Citrus limon*	Introduced /Planted	*Ideopsis vulgaris, Tirumala limniace, Papilio demoleus, Danaus chrysippus, Papilio polytes, Catopsilia pomona, Pieris brassicae, Pieris canidia, Borbo cinnara and Gonepteryx rhamni*
10	*Ageratum houstonianum*	Weed	*Castalius rosimon, Pieris canidia, , Danaus chrysippus and Ideopsis vulgaris*
11	*Oxalis corniculata*	Weed	*Belenois aurota, Pieris canidia, Pieris brassicae, Eurema brigitta, Eurema hecabe, Tarucus balcanicus nigra*
12	*Rungia pectinata*	Weed	*Pieris brassicae, Papilio polytes, Castalius rosimon*
13	*Citrus grandis*	Planted	*Hypolimnas bolina*
14	*Bidens pilosa*	Weed/ Invasive	*Leptosia nina, Pseudozizeeria maha*
15	*Evolvulus nummularius*	Weed/ Invasive	*Castalius rosimon*
16	*Morus nigra*	Planted	*Danaus genutia, Papilio polytes, Ideopsis vulgaris, Papilio clytia, Euploea core, and Danaus chrysippus*
17	*Lippia alba*	Invasive	*Papilio polytes, Pieris brassicae, Leptosia nina*
18	*Caryota mitis*	Native	*Moduza procris, Hypolimnas bolina*
19	*Brassica oleracea*	Planted	*Papilio polytes, Papilio clytia,* and *Tarucus balcanicus nigra*

Butterfly species were found to associate differently with native, alien, planted, invasive, and weedy plant types. Native plants such as *Clerodendrum viscosum* and *Dendrocalamus* attracted species like *Necrophora chinense* and *Pachliopta aristolochiae*. Invasive species, including *Mikania micrantha*, were frequently visited by *Papilio polytes* and *Hypolimnas bolina*. Planted species like *Citrus limon* attracted *Gonepteryx rhamni*, while common weeds such as *Oxalis corniculata* supported species like *Pieris brassicae*.

Discussion

Considering the time of the year and the limited timeframe for the study, findings of 30 moth species from six families, covering 26 genera, and 39 butterfly species from five families, spanning 31 genera, highlight a very rich Lepidoptera diversity in Lumbini. This diversity represents **5.88%** of butterflies and **0.5%** of moths found in Nepal.

Diversity and dominance of moth species

The dominance of Erebidae (44 individuals) and Noctuidae (29 individuals), comprising over 70% of the total moths recorded, with findings from the Agastyamalai Biosphere Reserve in Kerala (Sondhi *et al*., 2018) and Mahamaya Reserve Forest in Assam (Ahmed *et al*., 2024), where Erebidae was also the most abundant family. This dominance may be attributed to their ecological adaptability; both families contain generalist species with broad larval host ranges and a high capacity for surviving in disturbed or semi-urban environments (Zhang *et al*., 2025). Erebidae, in particular, includes species known for their high fecundity and nocturnal habits, allowing them to be more susceptible to artificial light traps (MacGreggor, *et al*, 2014).

The semi-urban agricultural habitat of the lemon agriculture field in Lumbini, dominated by native and invasive plants like *Imperata cylindrica* and *Mikania micrantha*, may provide favorable conditions for such generalist moths (Robinson *et al*., 2023; Hussain *et al*., 2022). Studies by Merckx (2015) and Kadlec *et al*. (2009) support the idea that moths thriving in plant communities are often disturbance-tolerant species capable of adapting to such environments and conditions. Despite this dominance, the moth community exhibited notable diversity, with 30 species from six families. The most abundant species, *Spilosoma strigatula* and *Sesamia inferens*, are also recognized agricultural pests, which may explain their prevalence in farmlands. Conversely, families such as Geometridae, Crambidae, and Pyralidae contributed fewer individuals but exhibited high evenness. Although the Pyralidae family has a low number of individuals, its high evenness value (J' = 0.92) means that the few species present are represented in similar numbers. This suggests a stable balance among these species within a specific, limited habitat or niche.

Species richness and abundance were influenced by environmental variables. For instance, moth diversity decreased during the full moon (24 February 2024), likely due to reduced light trap attractiveness under strong natural light. According to Williams and Singh (1951) when strong lights are used to attract insects at night, the number of species captured is substantially more during the new moon compared to the full moon. This is because when there is no moonlight during a new moon, artificial light is more appealing to insects, but when there is a full moon, artificial light is less effective and attracts comparatively fewer insects. Similarly, during nights with complete cloud cover, unlike the nights with a full moon, a greater diversity of moths was observed, with seven distinct species identified. Studies by Watkins (2024) found a positive correlation between more cloud cover and high moth activity. This is most likely because clouds may cover natural light sources like moonlight, which makes the light traps stand out and attracts moths looking for a dependable source of light during the dark (Nowinszky, 2010). Additionally, cloud cover may help trap the heat of the day, making night's warmer, therefore increasing moth movement (Yela and Holyoak, 1997)

The rank-abundance curve illustrates a typical ecological pattern; few dominant species and many rare ones; which often reflects the species' uneven habitat preferences, reproductive strategies, or competitive abilities (Slade *et al*., 2013). Very Rare (VR) species like *Cretonotos transiens* may be habitat specialists (Thomas, 2004), with narrow environmental tolerances. Their presence adds to ecosystem complexity and highlights the need for targeted research to understand their specific habitat requirements and conservation needs.

Diversity and dominance of butterfly species

Butterfly diversity was also high, with 39 species from five families. Nymphalidae and Pieridae accounted for 67% of the total, a common findings that are consistent across different altitudes and regions in Nepal (Paudel *et al*., 2024; Sharma, 2021; Shrestha *et al*., 2020). Their dominance may be due to traits like wide host plant ranges, high dispersal ability, and resilience to anthropogenic disturbances (Khyade *et al*., 2018).

Pieris canidia and *Zizina otis* were the most abundant species in the study area, each making up over 25% of the total butterfly count. The prominance of *P. canidia* is supported by earlier studies in the Kathmandu Valley (Shrestha *et al*., 2018). However, the absence of other prominent species such as *Aglais cashmerensis*, is most likely due to seasonal effects; this species hibernates during the winter months and emerges later in spring (Riyaz and Sivasankaran, 2021), suggesting a need for year-round monitoring and recording of the butterfly species. According to Priyadarshana *et al*. (2023), *Pieris canidia* and *Pieris brassicae* thrive in farmlands as important pests of cruciferous crops. Additionally, field edges and blooming weeds provide extra nutrients and habitat, further increasing their abundance (Curtis *et al*., 2015). Grasslands supported the highest species richness, especially of Lycaenidae and Pieridae, due to abundant nectar sources and sun exposure. Open habitats like grassland offer ample nectar and host plants, providing the sunny environments essential for Pieridae butterflies like *Eurema brigitta* and *Leptosia nina*, which rely on plants such as *Oxalis corniculata* and *Lippia alba* (Table 4). Shrublands and agricultural lands had higher diversity and evenness, likely due to a mix of native and cultivated plants providing varied resources and microhabitats. Species such as *Zizina otis* and *Castalius rosimon* benefit from diverse host plants like *Rungia pectinata* and *Acmella uliginosa*, commonly found in such habitats (Alsterberg *et al*., 2017).

Interestingly, agricultural areas showed high species diversity despite being manmade habitats. This may be because the surveyed areas were free from harmful pesticides and herbicides. Studies like those by Tiple and Khurad (2012) and Curtis *et al*. (2015) support the role of unmanaged field edges and diverse floral patches in promoting butterfly abundance. In contrast, previous studies such as by (Paudel, Shah and Bashyal, 2024) that found forests to be more diverse may have surveyed larger and less fragmented forest patches, whereas the forested portions in this study were very limited.

Methodological limitations

This study had several limitations**.** Firstly, its short duration, restricted to the February–March period, likely excludes species that emerge later in the season, particularly butterflies that appear in late spring and early summer. Secondly, butterfly observations and transect walks were conducted by only two individuals, which may have reduced the likelihood of detecting all present species. Thirdly, the reliance on light trapping for moth collection in a single habitat type introduced sampling bias. Although the study originally aimed to cover multiple habitats, budget constraints limited data collection to agricultural fields. As a result, the findings may be skewed toward phototactic moth species, potentially underrepresenting non-phototactic species or those adapted to other habitats through camouflage or behavioral traits. Finally, the limited representation of forested areas may have affected estimates of species richness and evenness.

Future directions and applications

To build on the findings of this study and address its limitations, future research should adopt a broader temporal, spatial, and methodological scope. Extending the study period to include late spring and early summer months would allow for the inclusion of additional Lepidoptera species that emerge outside the February–March window, providing a more complete picture of seasonal diversity. Increasing the number of observers during transect walks could also improve species detection, particularly for butterflies that may be easily overlooked by a small team.

Future moth surveys should incorporate multiple habitats, including forested, grassland, and wetland areas, to reduce habitat-specific bias and better represent species with varying ecological preferences. The use of complementary sampling techniques, such as bait traps, malaise traps, or daytime surveys, would help capture non-phototactic moths and those with camouflage or alternative behavioral adaptations, thus enhancing taxonomic and ecological coverage.

Conclusion

This study documents a surprisingly rich diversity of Lepidoptera in the semi-urban farmlands surrounding Lumbini, with 30 moth species from six families and 39 butterfly species from five families recorded within a short timeframe. These findings demonstrate the ecological importance of landscapes such as agricultural lands, shrublands, and grasslands in supporting diverse insect populations.

Dominant moth families like Erebidae and Noctuidae, and butterfly families such as Nymphalidae and Pieridae, were well-represented, reflecting their adaptability to anthropogenic environments. However, the presence of many Very Rare (VR) and Rare (R) species indicates the ecological sensitivity and richness of the region. Species distribution was strongly influenced by habitat type, plant diversity, and weather conditions.

Enhancing floral diversity, reducing chemical use, and protecting marginal habitats like field edges can help sustain both generalist and specialist species, thereby preserving the ecological balance and pollination services these insects provide. Developing a more comprehensive dataset on Lepidoptera diversity in different seasons and habitat types would greatly strengthen biodiversity monitoring and conservation planning, not only within the Terai region but also across Nepal's hilly and Himalayan landscapes. Such data would be especially valuable for detecting ecological shifts driven by land-use changes or climate variability. Emphasis should be placed on accurate species-level identification, particularly for moths, and on conserving diverse habitats such as shrublands, wetlands, forests, and grassland areas. Promoting pollinator-friendly agricultural practices would further support the presence of these ecologically vital species. Additionally, involving citizen scientists and local communities in long-term monitoring could make future research more cost-effective, consistent, and sustainable, while fostering broader awareness and appreciation for Lepidoptera and the native habitats they rely on.

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