


Lepidopteran diversity and seasonal variations in a mountainous scrubland ecosystem of Kumaun Himalaya, India

Surabhi Bisht  and Manoj Kumar Arya* 

Insect Biodiversity Laboratory, Department of Zoology, D.S.B. Campus, Kumaun University, Nainital-263001, Uttarakhand, India

*Corresponding author : dr.manojkumar19@rediffmail.com

Citation: Bisht, S. and Arya, M. K. (2024). Lepidopteran diversity and seasonal variations in a mountainous scrubland ecosystem of Kumaun Himalaya, India. *Journal of Animal Diversity*, 6 (4): 38–50. <https://dx.doi.org/10.22034/JAD.2024.6.4.4>

Abstract

Research on insect fauna is crucial for assessing ecosystem health and understanding the impacts of human activities on natural resources. A comprehensive inventory of species diversity, particularly within the order Lepidoptera, is therefore essential. The understudied scrub region of Nainital District in the Kumaun division of Uttarakhand, in the Western Himalaya, represents a significant gap in our knowledge, particularly regarding the state's Lepidopteran diversity. We quantitatively analysed the diversity and seasonal dynamics of Lepidopteran species in this scrubland habitat. The study documented 65 species belonging to 55 genera and 11 families, recorded during the survey period from March 2022 to February 2023. Although no new species records were found, the study provides important baseline data for this biotope, which contributes to understanding the Lepidopteran diversity. Family Nymphalidae exhibited the highest richness, with 21 species, whereas Riodinidae and Nolidae each had a single species. Despite threats from habitat degradation, fragmentation, and fire suppression, the estimated Shannon diversity index ($H' = 4.03$) indicates high species richness and evenness, suggesting a well-balanced ecosystem in terms of observed diversity. Further taxonomic documentation of the Lepidopteran fauna from the region is vital for assessing ecological status and pressures such as habitat fragmentation and anthropogenic disturbances.

Editor-in-Chief: Dr. Ali Gholamifard

Associate Editor: Professor Christopher Tudge

Subject Editor: Dr. Reza Zahiri

Received: 12 September 2024

Revised: 29 November 2024

Accepted: 22 December 2024

Published online: 31 December 2024

Key words: Biodiversity, habitat fragmentation, seasonal fluctuation, species richness, Western Himalaya

Introduction

Scrublands are terrestrial ecosystems characterized by a mix of shrubs and degraded forest vegetation. Shrubs in such habitats typically range from 10 cm to 2 m in height, and are adapted to survive environmental stressors such as drought, nutrient-poor soils, and frequent fires (McArthur and Kitchen, 2007; Lugo et al., 2019). They are usually multi-stemmed and possess flexible growth forms that enable regeneration after disturbances (Francis, 2004). Despite their ecological importance, scrublands remain underappreciated compared with more prominent ecosystems. Lepidopteran insects (butterflies and moths),

functioning as pollinators, herbivores, and prey, are widely regarded as bioindicators of ecological health due to their sensitivity to habitat disturbances, seasonal variations, food availability, and vegetation cover (Erhardt, 1985; Scoble, 1992; Bonebrake et al., 2010; Naik et al., 2022). They also contribute significantly to ecological balance and biodiversity, particularly within scrubland ecosystems (Wagner et al., 2003; Özden and Hodgson, 2011; Zecharia et al., 2018).

The Himalayas, recognized as one of the world's biodiversity hotspots, harbour rich Lepidopteran diversity across multiple altitudinal zones, including alpine scrublands, where vegetation is sparse (Sanyal

et al., 2011; Dey et al., 2017; Mallick, 2021). Approximately 13,124 Lepidopteran species, classified into 101 families and 31 superfamilies, are recorded from the Indian subcontinent (Singh et al., 2024). The Indian Himalayan region contains approximately 1,249 butterfly species (Das et al., 2018) and about 4,107 moth species belonging to 1,726 genera, 62 families, and 153 subfamilies (Sanyal et al., 2018). The Kumaun region of the Western Himalaya has long been a subject of interest in Lepidopteran research, with notable studies documenting butterfly and moth diversity (Smetacek, 2004, 2008; Verma and Arya, 2018; Bandyopadhyay et al., 2019; Arya et al., 2020; Bisht et al., 2021; Singh and Sahu, 2022; Chandra et al., 2023; Joshi and Joshi, 2023). However, much of the existing research focuses on protected areas, whereas mountainous scrublands remain largely overlooked despite their importance in supporting high insect diversity. Recent studies from eastern India have emphasized the need for systematic documentation of Lepidoptera, mainly butterflies, in hill-scrub and forest-edge mosaics (Mandal and Roy, 2022; Mukherjee et al., 2023). Although a few studies from the Garhwal region of Uttarakhand have examined the ecological potential of scrub-dominated landscapes for moth fauna, the present work is the first systematic attempt to document Lepidopteran diversity from a scrubland biotope in the Kumaun division. Monitoring Lepidoptera populations is therefore essential for understanding and preserving the ecological integrity of scrubland habitats in the Kumaun Himalaya. To address this gap, the present study was undertaken on the slopes of a scrubland biotope in the Kumaun Himalaya, contributing valuable data on Lepidopteran diversity and providing insights into the ecological health of these ecosystems. This dataset provides a baseline for future studies aimed at conserving and managing these unique and vital ecosystems.

Understanding the seasonal dynamics of Lepidoptera is crucial, as they help assess the impact on an ecosystem. Because no extensive study has examined the systematic composition and seasonal patterns of these insects in Kumaun scrublands, the present work aims to investigate species diversity and seasonal patterns across the region.

Material and Methods

Study area

This study was conducted in a mountainous scrubland system covering approximately 8-10 sq km near the slopes of a remote hamlet known as Alookhet, located about 3 km from the city of Nainital. Nainital is a hill station in the Kumaun Himalayan range of the state of Uttarakhand. The study site is situated at approximately 1,800 m above mean sea level (MSL) (Google Earth, 2023) at 29°22'13" N, 79°29'44" E. The area experiences an

average annual rainfall of 6.3 mm (November) and 310.6 mm (July). Climatic data were obtained from the Indian Meteorological Station at Tallital, Nainital. The scrubland extends across undulating hill slopes, with the terrain comprising a mix of gentle to moderate slopes typical of the region. Microhabitats include open low-scrub patches, transitional zones with sparse trees, and areas of dense undergrowth. Figure 1 provides an overview map of the scrubland patch within the study area. Dry deciduous scrub is interspersed with dry mixed deciduous trees, including pine and pine mixed broad-leaved oak, grasslands, and plantations. Plant species comprising more than 70% canopy were designated as the dominant community species. Field observations indicated that sparsely distributed *Pinus roxburghii* (Pine) dominated open areas, accompanied by shrubs such as *Hypericum oblongifolium*, *Spermatidictyon suaveolens*, *Lantana camara*, *Berberis* spp., and *Rubus ellipticus*.

Sampling and identification of Lepidopteran insects

Sampling to document Lepidopteran diversity and assess seasonal variations was conducted from March 2022 to February 2023. The study encompassed three seasons: summer (March to June), monsoon/rainy (July to October), and winter (November to February). To capture both diurnal and nocturnal Lepidoptera, two transects were established and surveyed monthly. Each transect measured approximately 800 m in length and 5 m in width; transects were spaced about 500 m apart to ensure comprehensive habitat coverage and minimize overlap, following a modified Pollard Walk Method (Pollard, 1977). Established trails and secondary roads provided access to sampling sites, facilitating comprehensive habitat coverage. Each transect was surveyed once per month over the 12 months, yielding 24 transect walks in total. Sampling sessions averaged approximately 6 hours per week and included both daytime and nocturnal efforts. Sampling effort was kept consistent across transects. Daytime sampling occurred between 08:00 and 11:00 hours and comprised visual surveys and netting for butterflies. Nocturnal sampling employed light traps for moths biweekly, typically between 19:00 and 22:00 hours. Light traps consisted of a 15 W ultraviolet tube bulb mounted on a white cloth approximately 2 m * 2 m to attract moths. The setup was powered by a portable generator and positioned in areas with minimal artificial lighting to maximize moth attraction.

Daytime specimens were identified in situ by direct field observation and photographic documentation using comprehensive field guides (Kehimkar, 2016; Sondhi and Kunte, 2018, for butterflies, and Shubhalaxmi, 2018, for the moths) and were released immediately to minimize disturbance. When visual identification was not possible due to overlapping morphological features, individuals were occasionally captured using insect nets. Nocturnal specimens attracted to light traps were collected for further examination. Unidentifiable specimens were

transferred to jars containing cotton soaked in 10% ethyl acetate and transported to the laboratory. These were then stretched, pinned, and preserved in insect cabinets with naphthalene balls to prevent fungal growth and pest damage, and later analysed at the Insect Biodiversity Laboratory, D.S.B. Campus, Kumaun University, Nainital. Taxonomic identification was conducted using the same field guides referenced during collection.

Data analysis

Based on observation frequency and relative abundance, each species' local status was categorized as: rare (relative abundance ≤ 0.5), uncommon ($> 0.5 - \leq 1.5$), common ($> 1.5 - \leq 2.5$), and very common ($> 2.5 - \leq 3.5$). Diversity indices, including the Shannon-Wiener for species diversity (H'), Simpson's indices for dominance (D), and Margalef diversity index for species richness (H_m), were calculated using PAST v3.4 statistical software (Hammer et al., 2001). Indices were calculated using standard formulas (Shannon, 1948, and Simpson, 1949). Diversity indices were compared descriptively across seasons to evaluate seasonal variations in species richness and abundance.

Results

Family-wise abundance of Lepidopteran insects

During the study period, 2,910 adult individuals representing 65 species and 55 genera across 11 families were recorded (Table 1). Of these, butterflies comprised 48 species in six families, whereas moths included 17 species in five families. Among butterflies, Nymphalidae was the most diverse family, contributing 43.8% of species, followed by Pieridae (27.1%), Lycaenidae (14.6%), Papilionidae (8.3%), Hesperidae (4.2%), and Riodinidae (2.1%). Among moths, the highest number of species belonged to Geometridae and Erebidae (29.4% each), followed by Noctuidae (23.5%), Crambidae (11.8%), and Nolidae (5.9%). Figure 2 (A-L) illustrates representative Lepidopteran species recorded during the study period.

Species distribution indicated that 10 species were very common, 17 were common, 34 were uncommon, and four were rare (Table 1). Species such as *Heliophorus sena* (Lycaenidae), *Aglais caschmirensis* (Nymphalidae), several Pieridae species, including *Eurema hecabe*, *E. laeta*, *Catopsilia pomona*, *C. pyranthe*, *Pieris canidia*, and *P. brassicae*, *Papilio polytes* (Papilionidae), and *Mythimna separata* (Noctuidae) were very common, accounting for 31.87% of all individuals recorded. Conversely, species of *Risoba* (Nolidae), *Euthalia* (Nymphalidae), *Everes lacturnus* (Godart) (Lycaenidae), and *Cepora nerissa* (Fabricius) (Pieridae), collectively represented only 1.28% of individuals and were categorized as rare. Notably, three butterfly species- *Cepora nerissa* (Fabricius), *Lampides boeticus* (Linnaeus), and *Euploea core* (Cramer)- are legally protected under different schedules of the Indian

Wildlife (Protection) Act, 1972, underscoring their conservation importance. No moth species recorded in the study was listed under any legal protection schedule. None of the recorded species is classified under any threatened categories of the IUCN Red List (2024). Although the study did not yield new species records for the Kumaun region of the Western Himalaya, it represents the first formal documentation of Lepidopteran diversity from this scrubland biotope, contributing important baseline data for future biodiversity assessments.

Species diversity and sampling adequacy

The total Shannon-Weiner Diversity Index (H') was 4.034, indicating high diversity in the study area. Nymphalidae exhibited the highest species diversity (2.921) and species richness (2.984) (Table 2). Simpson's Dominance Index ranged from 0.497 to 0.940, indicating dominance by certain species within major families. Insects were fairly evenly distributed, as reflected by Pielou's evenness ($J = 0.869$). Overall, Shannon's diversity ($H_s = 4.034$), Margalef richness ($H_m = 8.024$), and Simpson's dominance ($D = 0.98$) were high. Individual-based rarefaction curves generated from total abundance data showed an asymptotic pattern, indicating that most species were captured during sampling. Figure 3 presents the individual-based rarefaction curve for all Lepidopteran species recorded during the study period.

Seasonal fluctuation in the Lepidopteran assemblage

Temporal patterns in Lepidopteran occurrence showed substantial fluctuations among families throughout the study period. Abundance was highest in summer (1,534 individuals), followed by the rainy season (1,182 individuals) and winter (884 individuals). Calculated diversity indices further reflected these seasonal patterns. The Shannon diversity index (H') indicated higher diversity in summer ($H' = 4.03$) than in winter ($H' = 3.39$), reflecting greater species richness and evenness. Margalef's richness index (H_m) was highest during the rainy season ($H_m = 8.90$), indicating that different species coexist, even though their total population sizes aren't as large or diverse as in summer. Similarly, Simpson's diversity index showed a marked decline during the winter months ($D = 0.95$), underscoring reduced ecological interactions in this period. A one-way ANOVA revealed significant differences in Shannon diversity ($F = 6.06$; $p = 0.02$) and Margalef richness ($F = 0.003$; $p = 0.01$) across seasons. Statistical analysis at a 5% significance level indicated significant variation among Lepidopteran families across seasons. Table 3 presents diversity indices for Lepidopteran species across seasons, illustrating variation in species richness and evenness. Warmer temperatures enhance insect activity and metabolic rates, leading to increased foraging and reproductive success. Additionally, summer provides stable and abundant nectar sources and host plants, whereas the rainy season can disrupt habitats and reduce resource accessibility.

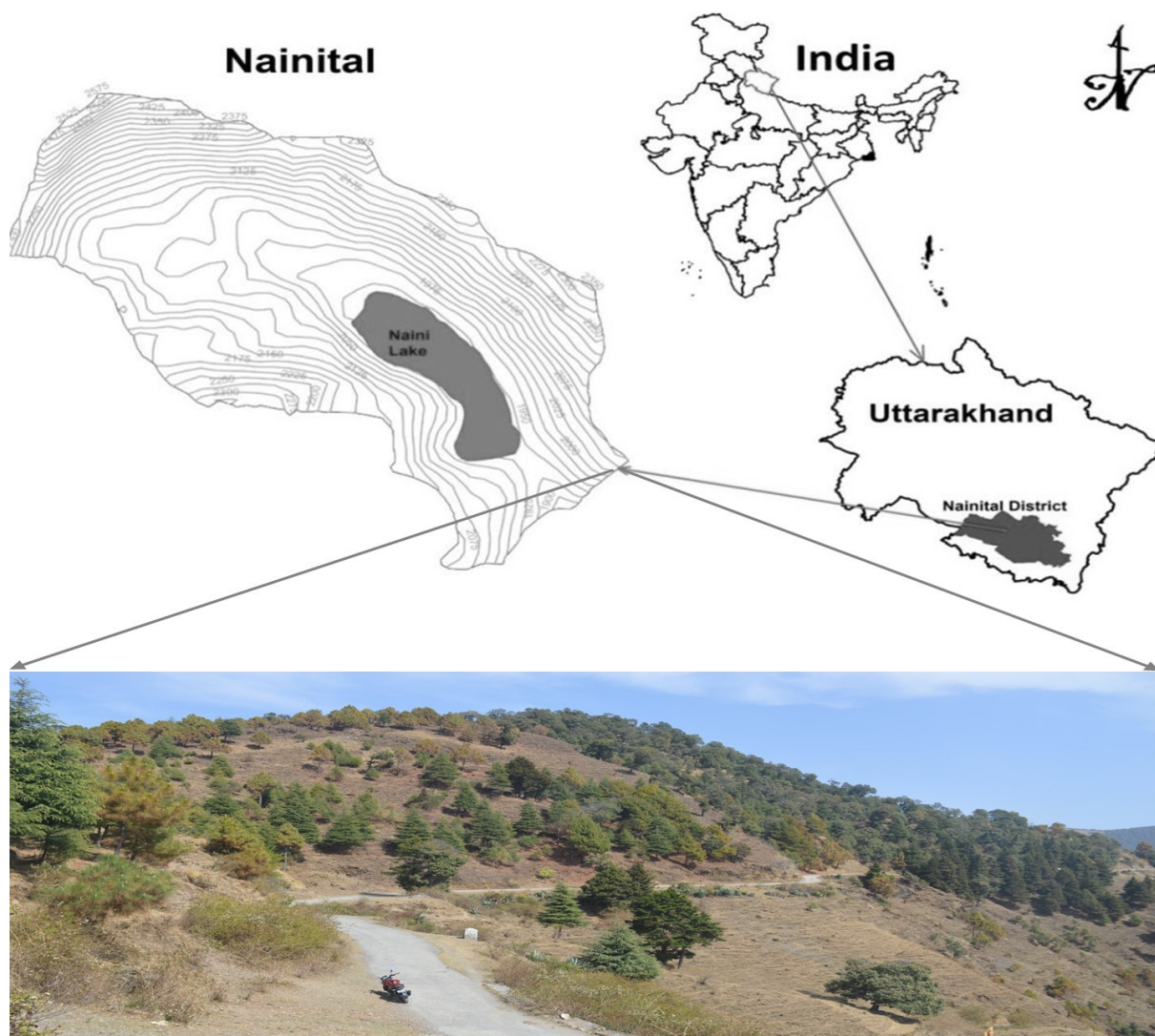


Figure 1: Overview map showing the location of the scrubland patch within the study area in the Kumaun Himalaya, India. The top right panel shows the position of the Nainital district within Uttarakhand and India. The top left panel presents the topographic map of Nainital town, showing contour elevation lines and the nearby slopes where the transects were laid (Source: Google Earth Pro).

Table 1: Species composition, relative abundance and seasonal distribution of different species of Lepidoptera recorded from scrubland, Kumaun Himalaya, India.

S. No.	Families / Species	Relative abundance	Seasons			Status
			Summer	Rainy	Winters	
Papilionidae (S= 4)						
1.	<i>Graphium sarpedon</i> (Linnaeus)	1.47	•	•	-	UC
2.	<i>Papilio machaon</i> Linnaeus	0.68	•	•	-	UC
3.	<i>Papilio polytes</i> Linnaeus	2.57	•	•	•	VC
4.	<i>Papilio protenor</i> Cramer	1.2	•	•	-	UC
Pieridae (S= 13)						
5.	<i>Aporia agathon</i> (Gray)	1.92	•	•	-	C
6.	<i>Belenois aurota</i> (Fabricius)	1.3	•	•	-	UC
7.	<i>Catopsilia pomona</i> (Fabricius)	2.92	•	•	•	VC
8.	<i>Catopsilia pyranthe</i> (Linnaeus)	2.74	•	•	•	VC
9.	<i>Cepora nerissa</i> (Fabricius)	0.37	•	•	-	R
10.	<i>Colias fieldii</i> Menetries	1.92	•	•	•	C
11.	<i>Delias belladonna</i> (Fabricius)	1.37	•	•	-	UC
12.	<i>Eurema blanda</i> (Boisduval)	2.4	•	•	-	C
13.	<i>Eurema hecabe</i> (Linnaeus)	3.16	•	•	•	VC
14.	<i>Eurema laeta</i> (Boisduval)	3.02	•	•	•	VC
15.	<i>Gonepteryx nepalensis</i> Doubleday	1.95	•	•	•	C
16.	<i>Pieris brassicae</i> (Linnaeus)	2.74	•	•	•	VC
17.	<i>Pieris canidia</i> (Sparmann)	2.92	•	•	•	C

Table 1: (Continued).

S. No.	Families / Species	Relative abundance	Seasons			Status
			Summer	Rainy	Winters	
Nymphalidae (S= 21)						
18.	<i>Aglais caschmerensis</i> (Kollar)	3.16	●	●	●	VC
19.	<i>Argynnis hyperbius</i> (Linnaeus)	0.61	●	●	-	UC
20.	<i>Aulocera swaha</i> Kollar	0.82	●	●	●	UC
21.	<i>Callerebia annada</i> (Moore)	1.2	●	●	-	UC
22.	<i>Cyrestis thyodamas</i> Doyere	0.61	●	●	-	UC
23.	<i>Danaus chrysippus</i> (Linnaeus)	1.78	●	●	●	C
24.	<i>Euploea core</i> (Cramer)	1.16	●	●	-	UC
25.	<i>Euthalia</i> sp.	0.34	●	-	-	R
26.	<i>Junonia almana</i> (Linnaeus)	1.85	●	●	●	C
27.	<i>Junonia iphita</i> (Cramer)	1.37	●	●	●	UC
28.	<i>Lasiommata schakra</i> (Kollar)	1.54	●	●	●	C
29.	<i>Lethe verma</i> (Kollar)	0.99	●	●	-	UC
30.	<i>Neptis sappho</i> (Pallas)	1.51	●	●	-	C
31.	<i>Parantica aglea</i> (Stoll)	1.2	●	●	-	UC
32.	<i>Parantica sita</i> (Kollar)	1.37	●	●	-	UC
33.	<i>Pseudergolis wedah</i> (Kollar)	0.96	●	●	-	UC
34.	<i>Sephisia dichroa</i> (Kollar)	0.48	●	●	-	UC
35.	<i>Symbrenthia lilaea</i> (Hewitson)	0.96	●	●	-	UC
36.	<i>Vanessa cardui</i> Linnaeus	2.33	●	●	●	C
37.	<i>Vanessa indica</i> Herbst	2.47	●	●	●	C
38.	<i>Ypthima</i> sp.	1.2	●	●	●	UC
Lycaenidae (S= 7)						
39.	<i>Celastrina heugelli</i> (Moore)	1.03	●	●	-	UC
40.	<i>Everes lacturnus</i> (Godart)	0.3	●	●	-	R
41.	<i>Heliophorus epicles</i> (Godart)	0.51	●	●	-	UC
42.	<i>Heliophorus sena</i> (Kollar)	3.6	●	●	●	VC
43.	<i>Lampides boeticus</i> (Linnaeus)	2.47	●	●	●	UC
44.	<i>Lycaena panava</i> (Westwood)	1.71	●	●	●	C
45.	<i>Pseudozizeeria maha</i> (Kollar)	1.2	●	●	●	UC
Riodinidae (S= 1)						
46.	<i>Dodona durga</i> (Kollar)	1.16	●	●	●	UC
Hesperiidae (S= 2)						
47.	<i>Borbo bevani</i> (Moore)	1.68	●	●	●	C
48.	<i>Polytremis eltola</i> (Hewitson)	1.44	●	●	●	UC
Geometridae (S= 5)						
49.	<i>Hypomecis</i> sp.	1.23	●	●	●	UC
50.	<i>Lassaba albidaria</i> (Walker)	0.82	●	●	●	UC
51.	<i>Pseudopanthera himalayica</i> Kollar	0.68	●	●	●	UC
52.	<i>Psyra angulifera</i> Walker	1.03	●	●	●	UC
53.	<i>Thalossodes</i> sp.	2.23	●	●	●	C
Erebidae (S=5)						
54.	<i>Cyana</i> sp.	0.96	●	●	●	UC
55.	<i>Hypena iconicalis</i> Walker	1.44	●	●	●	UC
56.	<i>Sidyra albifinis</i> Walker	0.82	●	●	●	UC
57.	<i>Syntomoides imaon</i> (Cramer)	1.99	●	●	●	C
58.	<i>Mocis frugalis</i> (Fabricius)	1.71	●	●	●	C
Noctuidae (S= 4)						
59.	<i>Chasmina candida</i> Walker	0.79	●	●	●	UC
60.	<i>Mythimna separata</i> (Walker)	2.57	●	●	●	VC
61.	<i>Spodoptera litura</i> (Fabricius)	0.96	●	●	●	UC
62.	<i>Xestia c-nigrum</i> (Linnaeus)	0.68	●	●	●	UC
Crambidae (S= 2)						
63.	<i>Cnaphalocrocis medinalis</i> (Guenee)	1.71	●	●	●	C
64.	<i>Spoladea recurvalis</i> (Fabricius)	2.13	●	●	●	C
Nolidae (S= 1)						
65.	<i>Risoba</i> sp.	0.27	●	●	-	R

Note: S= Species richness for a family; Local status in the study area as per recorded relative abundance – VC= Very common, C= Common, UC= Uncommon, R= Rare.

● Presence of species in particular season

- Species absent



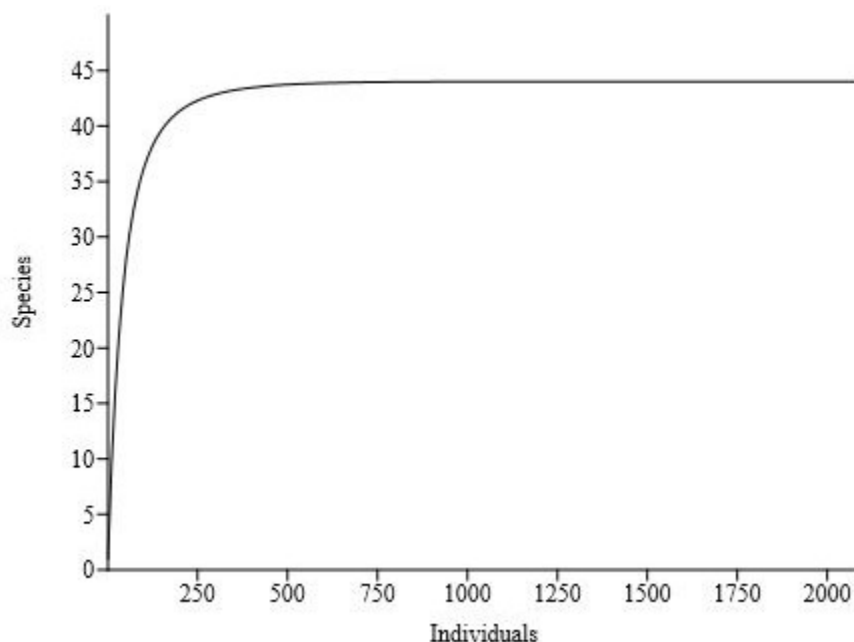
Figure 2: Species of some Lepidopteran insects recorded from the scrubland of Kumaun division: (A) *Papilio machaon*, (B) *Belenois aurota*, (C) *Colias fieldii*, (D) *Eurema laeta*, (E) *Junonia iphita*, (F) *Symbrenthia lilaea*, (G) *Ypthima* sp., (H) *Borbo bevani*, (I) *Thalossodes* sp., (J) *Mythimna separata*, (K) *Cnaphalocrocis medinalis*, and (L) *Risoba* sp.

Table 2: Diversity and abundance metrics for Lepidopteran families in the mountainous scrubland ecosystem, Kumaun Himalaya, India.

Family	Diversity Indices					
	Species	Individuals	Simpson 1-D	Shannon H	Evenness	Margalef (Hm)
Papilionidae	4	173	0.696	1.281	0.9	0.582
Pieridae	13	838	0.913	2.486	0.924	1.783
Nymphali-dae	21	815	0.94	2.921	0.883	2.984
Lycaenidae	7	316	0.788	1.708	0.788	1.042
Riodinidae	1	34	0	0	1	0
Hesperiidae	2	91	0.497	0.69	0.997	0.221
Geometri-dae	5	175	0.758	1.516	0.91	0.774
Erebidae	5	202	0.779	1.557	0.949	0.753
Noctuidae	4	146	0.655	1.222	0.848	0.602
Crambidae	2	112	0.494	0.687	0.994	0.211
Nolidae	1	8	0	0	1	0
Total	65	2910	0.98	4.034	0.869	8.024

Table 3: Diversity indices showing distribution of Lepidopteran species across different seasons during the study period in Kumaun Himalaya, India.

Diversity Indices	Season		
	Summer	Rainy	Winter
Simpson 1-D	0.98	0.98	0.95
Shannon_H	4.03	4.00	3.39
Margalef	8.72	8.90	7.59

**Figure 3:** Individual-based rarefaction curve for Lepidopteran species recorded in the scrubland ecosystem of the Kumaun Himalaya, India.

Seasonal dynamics of Lepidopteran families

Family Papilionidae: Papilionid abundance peaked in summer, particularly in April (44 individuals). Their presence declined markedly in winter, with no observations for most winter months and a single sighting in the last week of February.

Family Pieridae: Pieridae showed distinct seasonal variations, peaking in summer (April: 168; May: 140 individuals). Abundance remained substantial during the rainy season, peaking at 73 individuals in September. In winter (November-February), counts were significantly lower, with only six individuals recorded in January.

Family Nymphalidae: Nymphalids peaked in summer (April: 126; May: 121 individuals) and maintained high abundance into the rainy season (July: 104 individuals), suggesting active foraging and reproduction during these periods. Abundance declined consistently in winter, reaching a minimum in January (8 individuals).

Family Lycaenidae: Lycaenidae peaked in summer (April: 50; May: 43; summer total: 165 individuals). Presence continued into the rainy season (October: 24 individuals) but declined markedly in winter

(January: 4; February: 5 individuals), indicating reduced activity during colder months.

Family Riodinidae: *Dodona durga* was the sole Riodinidae species recorded. Counts were highest in summer (April: 4; May: 5 individuals) and peaked again in the rainy season (October: 15 individuals). No individuals were observed in January or February, indicating a winter decline.

Family Hesperidae: Hesperidae peaked in summer, with 14 individuals recorded in both May and June. Activity persisted into the rainy season (July: 14 individuals), but winter counts declined sharply, with only one individual recorded in December and one in January.

Family Geometridae: Geometrids were present throughout the year, peaking in summer (June: 32; May: 23 individuals). Abundance remained notable in the rainy season (July: 18 individuals) but declined in winter (January: 2; February: 4 individuals).

Family Erebidae: Erebidae peaked in the rainy season (October: 29 individuals). Summer peaks occurred in June (26) and May (24 individuals). Winter abundance was minimal, with December recording only one individual.

Family Noctuidae: Noctuidae abundance peaked in summer (June: 26; summer total: 62 individuals). In the rainy season, August recorded the highest count (24; rainy total: 75 individuals). Winter showed a marked decline, with one individual recorded in each of December, January, and February, indicating dormancy.

Family Crambidae: Crambidae peaked in June (19 individuals; summer total: 43). Notable activity continued into the rainy season (rainy total: 65 individuals). Winter counts declined markedly, with only two individuals recorded in

November and minimal presence in December–February, indicating dormancy.

Family Nolidae: Nolidae was represented by a single taxon, *Risoba* sp., which was more abundant during the warmer summer and rainy seasons and declined substantially in winter.

Variation in population dynamics and diversity trends among butterfly families across seasons is shown in Figure 4 (A-F); Figure 5 (A-E) illustrates seasonal abundance and richness for moth families. Overall, Lepidopteran presence peaked in summer and the rainy season and declined markedly in winter.

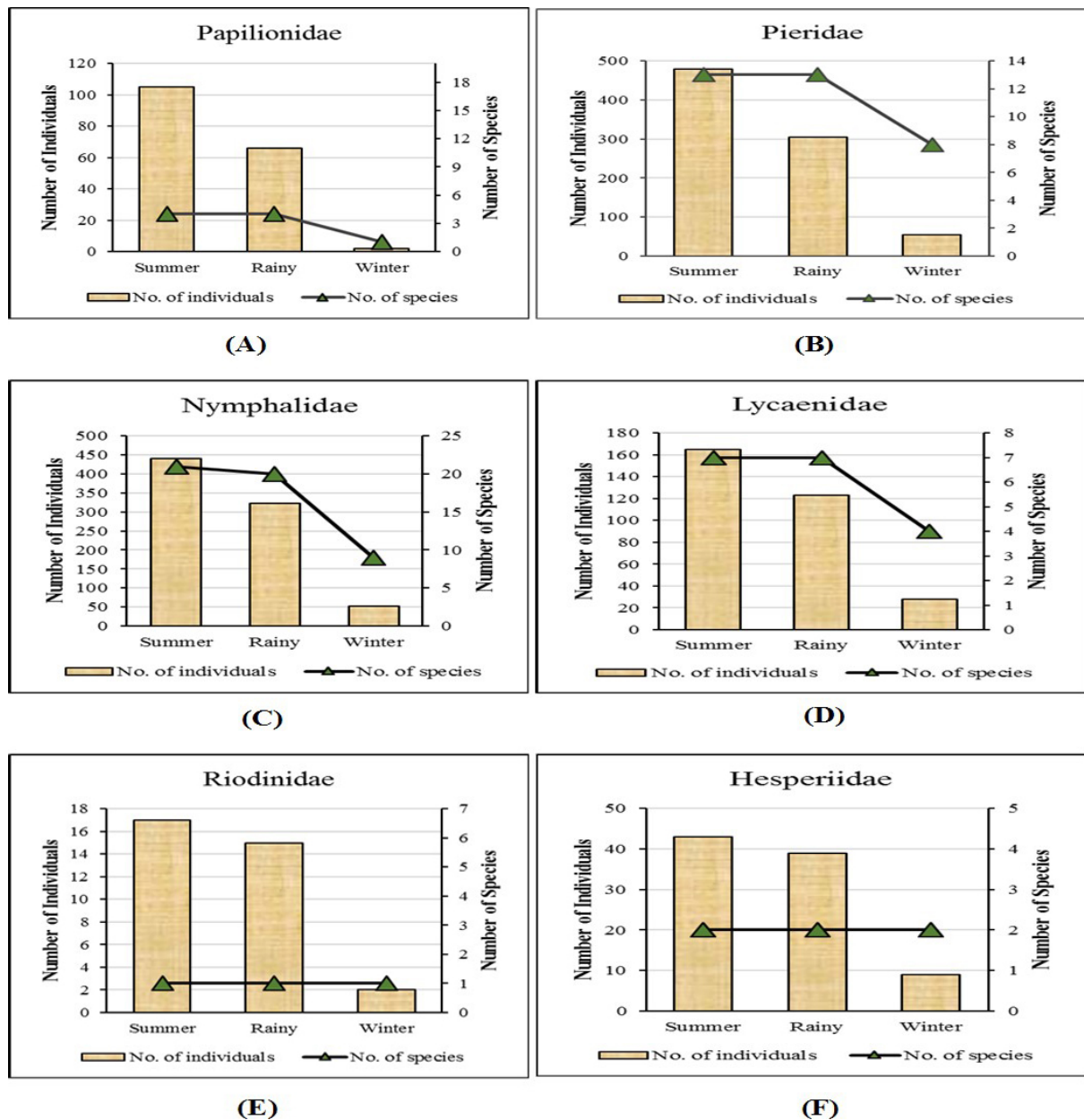


Figure 4 (A-F): Graphical representation of seasonal abundance and richness of different families of Butterflies recorded from the study area in the Kumaun Himalaya, India.

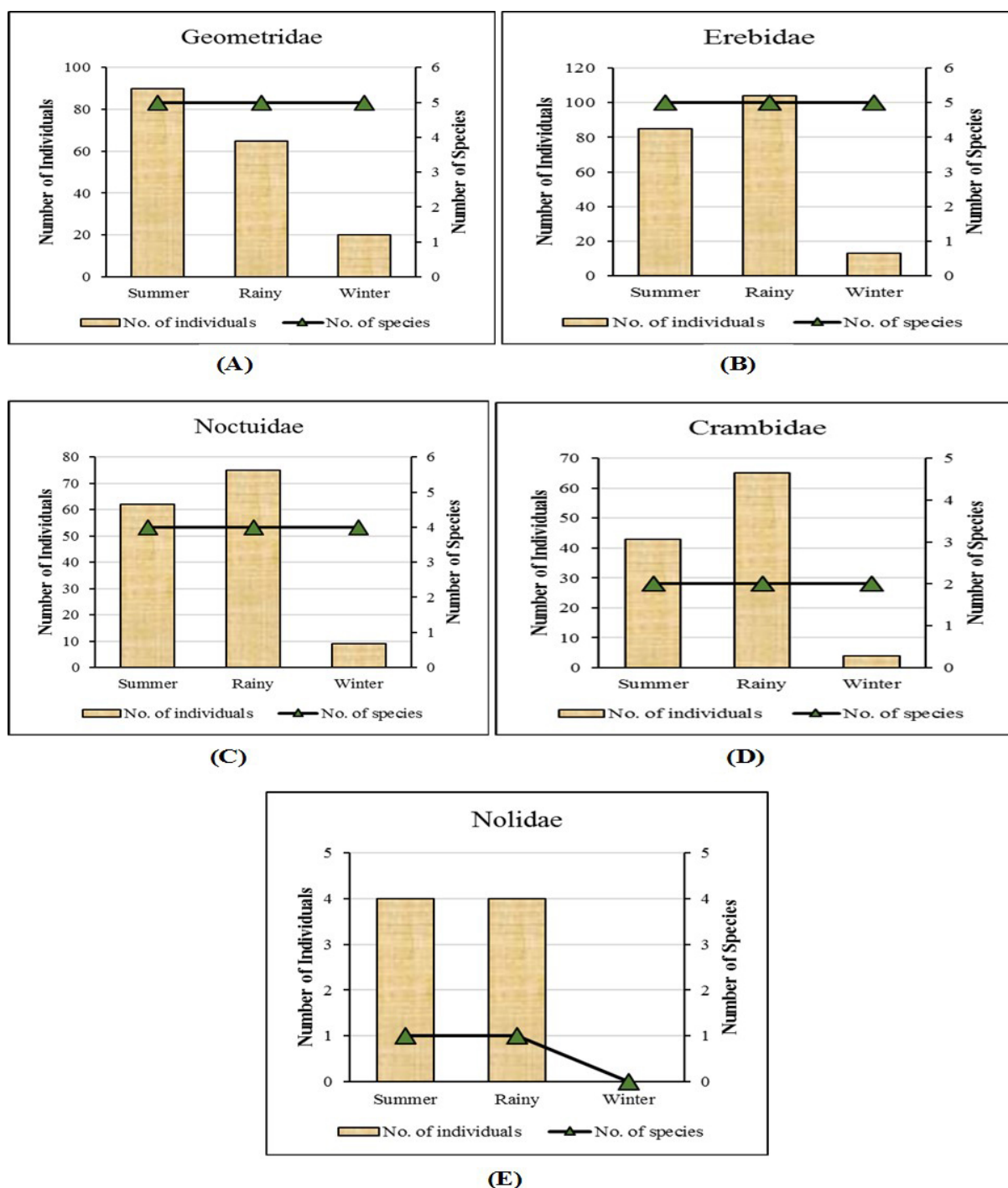


Figure 5 (A-E): Graphical representation of seasonal abundance and richness of different families of Moths recorded from the study area in the Kumaun Himalaya, India.

Discussion

This study documented 2,910 individuals representing 65 Lepidopteran species across 11 families in the scrub habitat of the Nainital District, demonstrating the rich biodiversity of this ecosystem. The study highlights marked seasonal fluctuations in Lepidopteran populations, reflecting their sensitivity to environmental changes. The Shannon diversity index ($H' = 4.034$) indicates high species richness, particularly during the summer months.

This seasonal pattern aligns with studies in similar scrub habitats, where higher temperatures and greater resource availability during warmer months enhance Lepidopteran activity (Schwartz-Tzachor et al., 2008; Kubo et al., 2009). The abundance of nectar-producing plants such as *Asclepias* spp. and *Lantana camara* during summer supports both foraging and reproduction, underscoring the link between floral resource availability and Lepidopteran diversity (Yela and Herrera, 1993). Conversely, the decline in species richness during winter suggests seasonal

dormancy or migration, consistent with strategies used by many Lepidopteran taxa in fluctuating climates (Chandekar et al., 2014). These patterns indicate that the ecological diversity of Lepidopteran populations may be similar across regions, underscoring the significance of scrublands as critical habitats (Kunte, 1997; Clausen et al., 2001). Variation in Lepidopteran abundance is therefore likely driven by microclimatic conditions and host-plant phenology.

Family-specific patterns reveal important ecological insights, particularly the dominance of Nymphalidae, a trend also reported from temperate and tropical scrub habitats (Tiple, 2012; Fileccia et al., 2015; Koneri et al., 2019; Dar et al., 2022). Their prevalence likely reflects broad environmental tolerance and diverse host-plant associations. In contrast, families such as Riodinidae and Nolidae were species-poor, possibly due to restricted host-plant availability, limited habitat distribution, or lower detectability in light-trap surveys. The lower moth abundance relative to butterflies may reflect differences in sampling efforts, diel activity patterns, or habitat preferences. Previous studies similarly report high Lepidopteran diversity in shrubland habitats, emphasizing their ecological importance (Wagner et al., 2003). For example, 56 species of conservation concern have been documented in scrub habitats of southern New England and southeastern New York. Similarly, Alagumurugan et al. (2011) recorded 65 butterfly species in a scrub jungle in Peraiyur Taluk, Madurai District, Tamil Nadu, with Nymphalidae and Pieridae contributing the highest species richness. Ozden and Hodgson (2011) reported peak butterfly abundance in late April and early May in shrub-dominated habitats of northwestern Cyprus. Uniyal et al. (2013) emphasised the importance of scrub and forest-edged habitats in supporting Lepidopteran diversity in the Gangotri landscape of Uttarakhand, noting the dominance of Nymphalidae and Geometridae. Sethy et al. (2014) further demonstrated that scrub jungle habitat in Namdapha Tiger Reserve supports high Lepidopteran diversity and highlighted the role of microhabitat variations within scrub ecosystems. Zecharia et al. (2018) examined Lepidopteran richness in scrub jungles of Chennai, Tamil Nadu, and demonstrated strong negative effects of urbanization and pollution on diversity, underscoring the group's sensitivity to environmental disturbances. In West Bengal, Mandal and Roy (2022) recorded 142 butterfly species in mixed scrub-forest mosaics of Jhargram District, reporting higher diversity than in more uniform landscapes. Mukherjee et al. (2023) similarly found that heterogeneous scrubland habitats in Purulia District support high butterfly richness. Sharma et al. (2023) recorded 54 butterfly species from five families in the Central Aravalli Hills of Rajasthan, with Nymphalidae and Pieridae showing the highest diversity. Roopha et al. (2024) documented 80 butterfly species in the Kiluvamalai scrub jungle, again identifying Nymphalidae and Pieridae as dominant families.

These findings align with the present study and underscore the importance of scrub ecosystems in supporting Lepidopteran communities. The present study area experiences moderate anthropogenic influence but retains sufficient natural habitats to sustain high butterfly and moth diversity. However, effective management is essential to preserve scrubland integrity and sustain both common and rare Lepidopteran species. The study has relevant conservation implications because several species recorded are protected under the Indian Wildlife (Protection) Act, 1972 (Amendment 2022). Species such as *Cepora nerissa* and *Lampides boeticus* (formerly listed under Schedule II) and *Euploea core* (formerly Schedule IV) have been reclassified under revised Schedules I–III following the 2022 amendment, reflecting updated protection levels. Although no endemic species were recorded, the presence of legally protected taxa highlights the need for targeted conservation, particularly given habitat changes associated with urbanization near Nainital. The present study focused primarily on macro-Lepidoptera, including butterflies and larger moths. Micromoths, which constitute a significant portion of Lepidopteran diversity, were not comprehensively sampled. Future research should incorporate micromoths to provide a more complete picture of the regional Lepidopteran community. Another limitation of this study is the lack of detailed monitoring of habitat-specific variations, such as differences between open sunny scrubland and denser vegetation patches. Future studies incorporating microhabitat variation-including elevation gradients and vegetation density along transects-would improve understanding of species distribution and habitat preferences in the region.

Conclusion

The scrubland ecosystem on the outskirts of Nainital supports a remarkably diverse Lepidopteran community, as evidenced by the 65 species and high Shannon diversity ($H' = 4.034$) recorded during the study period. Seasonal patterns were strongly pronounced, with peak abundance and diversity in summer and the monsoon season, followed by a marked reduction in winter, reflecting the sensitivity of Lepidopteran taxa to microclimatic fluctuations and resource availability. The dominance of families such as Nymphalidae, Pieridae, and Geometridae further underscores the ecological importance of scrubland vegetation in sustaining functionally significant insect groups.

As one of the first systematic assessments of Lepidopteran diversity in a Kumaun scrubland, this study provides essential baseline data for a habitat type often overlooked in regional biodiversity planning. The presence of legally protected species highlights the need for targeted conservation strategies, particularly as the landscape faces increasing pressure from forest fires, expanding human activity, and urbanization near Nainital.

Maintaining the structural heterogeneity of scrub habitats, along with continuous monitoring across seasons, will be critical for safeguarding both common and rare species. Future research incorporating microhabitat variation and the largely unsampled micromoth fauna will enable a more comprehensive understanding of Lepidopteran community structure in the region. Protecting these scrubland mosaics is vital, as ongoing habitat alteration may disrupt species' life cycles, diminish seasonal dynamics, and ultimately reduce regional biodiversity.

Acknowledgments

We extend our gratitude to the Head of the Department of Zoology at D.S.B. Campus, Kumaun University, Nainital, for providing the essential facilities that supported this research. We also thank the Editors and anonymous referees for useful suggestions regarding the manuscript.

Author contributions

The authors confirm their contribution in the paper as follows: S.B. conducted the fieldwork and collected data, and wrote the original draft of the manuscript; M.K.A. analysed the data and contributed to the results.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that there are no conflicting issues related to this research article.

References

- Alagumurugan, C., Pavaraj, M. and Rajan, M. K. (2011). Seasonal and relative abundance of butterflies in a scrub jungle habitat of Peraiyur Taluk, Madurai District, Tamil Nadu. *Journal of Research in Biology*, 1 (1): 44–50.
- Anonymous (2006). *The Wildlife (Protection) Act, 1972*. Natraj Publishers, Dehradun. 253 pp.
- Arya, M. K., Dayakrishna and Verma, A. (2020). Patterns in distribution of butterfly assemblages at different habitats of Corbett Tiger Reserve, Northern India. *Tropical Ecology*, 61 (2): 180–186. <https://doi.org/10.1007/s42965-020-00077-7>
- Bandyopadhyay, U., Das, G. N., Gayen, S., Mallick, K. and Bhattacharyya, K. (2019). Lepidopteran assemblages of selected protected areas: Askot Wildlife Sanctuary, Uttarakhand, Western Himalaya (Kumaon). In: *Assemblages of Lepidoptera in Indian Himalaya through long term monitoring plots*. Zoological Survey of India, Kolkata. 71–86.
- Bisht, S., Arya, M. K. and Farooq, F. (2021). Moth assemblages of an urban biotope in Kumaun Himalaya, Uttarakhand. *Indian Journal of Entomology*, 83 (2): 169–173. <http://dx.doi.org/10.5958/0974-8172.2021.00066.3>
- Bonebrake, T. C., Ponisio, L. C., Boggs, C. L. and Ehrlich, P. R. (2010). More than just indicators: a review of tropical butterfly ecology and conservation. *Biological Conservation*, 143 (8): 1831–1841. <https://doi.org/10.1016/j.biocon.2010.04.044>
- Chandekar, S. K., Nimbalkar, R. K. and Kuvalekar, A. A. (2014). The seasonal patterns in the abundance of butterflies, their biotopes and nectar food plants from Maval tahsil, Pune district, Maharashtra, India. *International Journal of Plant, Animal and Environmental Sciences*, 4 (1): 50–64.
- Chandra, H., Arya, M. K. and Verma, A. (2023). Biodiversity of butterflies (Lepidoptera: Rhopalocera) in the protected landscape of Nandhour, Uttarakhand, India. *Journal of Threatened Taxa*, 15 (1): 22448–22470. <https://doi.org/10.11609/jott.7519.15.1.22448-22470>
- Clausen, H. D., Holbeck, H. B. and Reddersen, J. (2001). Factors influencing abundance of butterflies and burnet moths in the uncultivated habitats of an Organic Farm in Denmark. *Biological Conservation*, 98: 167–178. [https://doi.org/10.1016/S0006-3207\(00\)00151-8](https://doi.org/10.1016/S0006-3207(00)00151-8)
- Dar, A. A., Jamal K., Shah, M. S., Ali, M., Sayed, S., Gaber A., Kesba, H. and Salah, M. (2022). Species richness, abundance, distributional pattern and trait composition of butterfly assemblage change along an altitudinal gradient in the Gulmarg region of Jammu & Kashmir, India. *Saudi Journal of Biological Sciences*, 29 (4): 2262–2269. <https://doi.org/10.1016/j.sjbs.2021.11.066>
- Das, G. N., Gayen, S., Ali, M., Jaiswal, R. K., Lenin, E. A. and Chandra, K. (2018). Insecta: Lepidoptera (Butterflies), In: *Faunal Diversity of Indian Himalaya*. Published by the Director, Zoological Survey of India, Kolkata. pp. 611–650.
- Dey, P., Uniyal, V. P. and Chandra, K. (2017). A Prefatory estimation of diversity and distribution of moths in Nanda Devi Biosphere Reserve, Western Himalaya, India. *National Academy Science Letters*, 1–5. <https://doi.org/10.1007/S40009-016-0534-1>
- Erhardt, A. (1985). Diurnal Lepidoptera: Sensitive indicators of cultivated and abandoned Grassland. *Journal of Applied Ecology*, 22 (3): 849–861. <https://doi.org/10.2307/2403234>

- Fileccia, V., Santorsola, S., Arpaia, S. and Manachini, B. (2015). Seasonal patterns in butterfly abundance and species diversity in five characteristic habitats in sites of community importance in Sicily (Italy). *Bulletin of Insectology*, 68 (1): 91–102.
- Francis, J. K. (2004). Wildland shrubs of the United States and its territories: Thamnisc descriptions, Volume 1. General Technical Report IITF-GTR-26. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, San Juan, Puerto Rico. 830 pages. <https://doi.org/10.2737/IITF-GTR-26>
- Hammer, O., Harper, D. A. T and Ryan, P. D. (2001). PAST: palaeontological statistics software package for education and data analysis, Palaeontol Electron. Version 3.04.
- IUCN Red List (2024). The IUCN Red List of Threatened Species. Version 2024-1. <https://www.iucnredlist.org/> (Accessed 20 September 2024).
- Joshi, P. and Joshi, R. (2023). The study of butterfly diversity in Bhimtal and Ramnagar region of district Nanital, Uttarakhand. *Journal of Mountain Research*, 18 (1): 153–156. <https://doi.org/10.51220/jmr.v18i1.2>
- Kehimkar, I. (2016). *The Book of Indian Butterflies*. Bombay Natural History Society-Oxford University Press, Mumbai, India. 528 pp.
- Koneri, R., Nangoy, M. J. and Siahaan, P. (2019). The abundance and diversity of butterflies (Lepidoptera: Rhopalocera) in Talaud Islands, North Sulawesi, Indonesia. *Biodiversitas*, 20 (11): 3275–3283. <https://doi.org/10.13057/biodiv/d201121>
- Kubo, M., Kobayashi, T., Kitahara, M. and Hayashi, A. (2009). Seasonal fluctuations in butterflies and nectar resources in a semi-natural grassland near Mt. Fuji, central Japan. *Biodiversity and Conservation*, 18: 229–246 <https://doi.org/10.1007/s10531-008-9471-8>
- Kunte, K. J. (1997). Seasonal patterns in butterfly abundance and species diversity in four tropical habitats in northern Western Ghats. *Journal of Biosciences*, 22 (5): 593–603. <http://dx.doi.org/10.1007/BF02703397>
- Lugo, A. E., Medina, E., Cuevas, E. and González, O. R. (2019). Ecological and physiological aspects of Caribbean shrublands. *Caribbean Naturalist*, 58: 1–35. ja_iitf_2019_lugo002.pdf (usda.gov)
- Mallick, K. (2021). Diversity and distributional pattern of family Geometridae (Lepidoptera) in Great Himalayan National Park. Ph.D. thesis. Wildlife Institute of India (Affiliated to Saurashtra University), Dehradun, India. 467 pp.
- Mandal, B. and Roy, S. (2022). Observations on Papilionoidea (Lepidoptera) fauna from heterogeneous patches of Jhargram district with new distribution reports from West Bengal, India. *Journal of Animal Diversity*, 4 (4): 59–73. <https://dx.doi.org/10.52547/JAD.2022.4.4.6>
- McArthur, E. D. and Kitchen, S. G. (2007). Shrubland ecosystems: importance, distinguishing characteristics, and dynamics, In: Sosebee, R. E., Wester, D. B. and Britton, C. M. (Eds.), *Shrubland dynamics—fire and water*. Proceedings on August 10–12, 2004; Lubbock, TX. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. RMRS-P-47. 173 pp.
- Mukherjee, A., Kumar, A., Mahato, S. and Samanta, S. (2023). An updated checklist of the butterfly fauna of Ajodhya Hills, Purulia, West India, India along with new distribution records. *Journal of Animal Diversity*, 5 (1): 65–79. <https://dx.doi.org/10.6186/JAD.5.1.65>
- Naik, D., Rao, R. S. P., Kunte, K. and Mustak, M. S. (2022). Ecological monitoring and indicator taxa: butterfly communities in heterogeneous landscapes of the Western Ghats and Malabar coast, India. *Journal of Insect Conservation*, 26: 107–119. <https://doi.org/10.1007/s10841-022-00368-5>
- Özden, O. and Hodgson, D. J. (2011). Butterflies (Lepidoptera) highlight the ecological value of shrubland and grassland mosaics in Cypriot garrigue ecosystems. *European Journal of Entomology*, 108: 431–437 <http://dx.doi.org/10.14411/eje.2011.055>
- Pollard, E. (1977). A method for assessing changes in the abundance of butterflies. *Biological Conservation*, 12 (2): 115–134. [https://doi.org/10.1016/0006-3207\(77\)90065-9](https://doi.org/10.1016/0006-3207(77)90065-9)
- Roopha, P. D., Kishore, R., Thatheyus, A. J., Dharmalingam, M. and Sonia, T. (2024). Butterfly diversity in thorn forest, Kiluvamalai, Madurai district, Tamilnadu, India. *International Journal of Entomology Research*, 9 (3): 44–50.
- Sanyal, A. K., Mallick, K., Khan, S., Bandyopadhyay, U., Mazumder, A., Bhattacharyya, K., Pathania, P. C., Raha, A. and Chandra, K. (2018). Insecta: Lepidoptera (Moths), In: Chandra, K., Gupta, D., Gopi, K.C., Tripathi, B. and Kumar, V. (eds.), *Faunal Diversity of Indian Himalaya*. Published by the Director, Zoological Survey of India, Kolkata. pp. 651–726.
- Sanyal, A. K., Uniyal, V. P., Chandra, K. and Bhardwaj, M. (2011). Diversity and indicator species of moth (Lepidoptera: Heterocera) assemblages in different vegetation zones in Gangotri Landscape, Western Himalaya, India. *ENVIS Bulletin: Arthropods and their Conservation in India (Insects and Spiders)*, 14 (1): 114–129.

- Schwartz-Tzachor, R., Izhaki, I. and Perevolotsky, A. (2008). The role of seasonality and climatic factors in shaping the community composition of Mediterranean butterflies. ... *Journal of Ecology and Evolution*, 54 (1): 105–110.
<https://doi.org/10.1560/IJEE.54.1.105>
- Scoble M. J. (1992). *The Lepidoptera: form, function and diversity*. Oxford University Press, Natural History Museum, USA. 404 pp.
- Sethy, J., Behera, S. and Chauhan, N.S. (2014). Species diversity of butterflies in South-Eastern part of Namdapha Tiger Reserve, Arunachal Pradesh, India. *Asian Journal of Conservation Biology*, 3 (1): 75–82.
- Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27 (3): 379–423.
<https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>
- Sharma, B., Choudhary, R., Sharma, V., Dutta, S. and Chandra, S. (2023). Community composition and dynamics of butterflies in different microhabitats of Central Aravalli hill regions of Ajmer district, Rajasthan, India. *Asian Journal of Biology*, 19 (3): 13–20.
<https://doi.org/10.9734/ajob/2023/v19i3368>
- Shubhalaxmi, V. (2018). *Field Guide to Indian Moths*. First Edition. Birdwing Publishers, India. VI+ 461 pp.
- Simpson, E. (1949). Measurement of diversity. *Nature*, 163: 688.
<https://doi.org/10.1038/163688a0>
- Singh, A. P. and Sahu, L. (2022). First site record of the Burnet Moth *Milleria adalifa* (Doubleday, 1847) (Lepidoptera: Zygaenidae: Chalcosiinae) from Uttarakhand, Western Himalaya, India. *Journal of Bombay Natural History Society*, 119 (2): 1–2.
<https://doi.org/10.17087/jbnhs/2022/v119/165077>
- Singh, N., Joshi, R., Kendrick, R. C., Pathania, P. C. and Banerjee, D. (2024). *An illustrated guide to the Lepidoptera of India: taxonomic procedures, family characters, diversity and distribution*. Zoological Survey of India, Kolkata, India. 308 pp.
- Smetacek, P. (2004). Descriptions of new Lepidoptera from the Kumaon Himalaya. *Journal of the Bombay Natural History Society*, 101 (2): 269–276.
- Smetacek, P. (2008). Moths recorded from different elevations in Nainital district, Kumaon Himalaya, India. *Bionotes*, 10 (1): 5–15.
- Smetacek, P. (2009). Additions and corrections to the list of moths recorded from different elevations in Nainital District, Kumaon Himalaya, India. *Bionotes*, 11 (4): 117–118.
- Smetacek, P. (2011). Further additions to the moths (Lepidoptera: Heterocera) of Nainital district, Kumaon Himalaya, India. *Bionotes*, 13 (4): 140–141.
- Sondhi, S. and Kunte, K. (2018). *Butterflies of Uttarakhand- A Field Guide*. Bishen Singh Mahendra Pal Singh (Dehradun), Titli Trust (Dehradun) National Centre for Biological Sciences (Bengaluru). 310 pp.
- Tiple, A. D. (2012). Butterfly species diversity, relative abundance and status in Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, Central India. *Journal of Threatened Taxa*, 4 (7): 2713–2717.
<https://doi.org/10.11609/JoTT.o2656.2713-7>
- Uniyal, V. P., Bhardwaj, M. and Sanyal, A. K. (2013). *An assessment of entomofauna for management and conservation of biodiversity in the Gangotri Landscape*. Annual Progress Report, Wildlife Institute of India, Dehradun, India. 237 pp.
- Verma, A. and Arya, M. K. (2018). Abundance and seasonal diversity of Papilionoidea at Pancheshwar, Proposed Multipurpose Project in Western Himalaya. Biodiversity and Ecosystem Services (Faunal Diversity and Associations). Proceedings of International Biodiversity Congress, Volume IV. pp. 1–8.
- Wagner, D. L., Nelson, M. W. and Schweitzer, D. F. (2003). Shrubland Lepidoptera of southern New England and southeastern New York: ecology, conservation, and management. *Forest Ecology and Management*, 185: 95–112.
[https://doi.org/10.1016/S0378-1127\(03\)00249-4](https://doi.org/10.1016/S0378-1127(03)00249-4)
- Yela, J. L. and Herrera, C. M. (1993). Seasonality and life cycles of woody plant-feeding noctuid moths (Lepidoptera: Noctuidae) in Mediterranean habitats. *Ecological Entomology*, 18: 259–269.
<https://doi.org/10.1111/j.1365-2311.1993.tb01099.x>
- Zecharia, A. P., Tom, J., Thomas, C. and Livingstone, A. R. (2018). Study on the richness of Insect population in a scrub jungle ecosystem at Chennai, Tamil Nadu. *International Journal of Research and Analytical Reviews*, 5 (4): i891–i899.