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Original Research

Spatio-Temporal Distribution and Diversity of Butterflies (Lepidoptera: Papilionoidea) Across Biotopes in the Kumaun Division of Western Himalaya: Implications for Habitat Modification and Environmental Monitoring

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Abstract: The abundance and richness of butterflies in any ecosystem help in developing effective conservation measures. This study surveyed butterfly assemblages across three distinct biotopes in the Kumaun region of Uttarakhand, India. Random surveys from March 2023 to February 2024 were conducted in agricultural crop fields, riverine land, and urban human-settlement areas. A total of 94 butterfly species belonging to six families were recorded. Family Nymphalidae comprised maximum 42 species, followed by Pieridae (19), Lycaenidae (17), Papilionidae (08), Hesperiidae (05), and Riodinidae (03). Beta diversity revealed clear variations among the biotopes. The riverine biotope showed the highest alpha diversity and species richness, followed by urban and agriculture lands. Agricultural land and river catchment shared the highest number of common species, with the lowest similarity observed between urban and agricultural biotopes. Butterfly diversity peaked during summer and post-monsoon seasons across all biotopes. Seven species were listed under Schedule-II of the Indian Wildlife (Protection) Act (1972), and one species under Schedule-IV. The decline in butterfly diversity within the agricultural landscapes suggests the negative impact of habitat loss, due to expanding agricultural frontline in the Nainital district. Overall, the study highlights the potential of butterfly communities as sensitive ecological indicators for monitoring habitat modification and environmental health in the Western Himalaya.

1. INTRODUCTION

Habitat heterogeneity strongly influences biodiversity by increasing niche availability and resource diversity (Bazzaz 1975, Tews et al. 2004, Braga & Diniz 2015). Among terrestrial insects, butterflies, belonging from Order Lepidoptera, are widely used as ecological indicators due to their ease of monitoring and responsiveness to environmental and climatic changes (Kocher & Williams 2000). However, human-modified ecosystems and agro-ecosystems usually appear inefficient for the sustenance of insect diversity, especially butterflies (Sagwe et al. 2015, Chettri et al. 2018, Samraj & Agnihotri 2021). The effects of landscape degradation driven by accelerated climate change, urbanization, agricultural development, poses major threat to biodiversity (Sagwe et al. 2015, Gallou et al. 2017). Addressing the ecological effects of habitat loss and fragmentation requires evaluating the susceptibility of any biotope to landscape change (Weißhuhn 2019). Since most butterflies have distinct environment needs (Leon-Cortes et al. 2004), monitoring their abundance and distribution across spatially distinct biotopes can inform their timely conservation decisions (Blair & Launer 1997, Munyuli 2013, Fontaine et al. 2016, An & Choi 2021).

The Indian Himalayan Region (IHR) harbours rich butterfly diversity. Several studies have documented butterfly diversity and habitat associations across both protected and unprotected landscapes of the IHR (Singh & Bhandari 2003, 2006, Uniyal 2007, Bhardwaj & Uniyal 2011, Sarma et al. 2012, Qureshi et al. 2014, Kumar et al. 2016, Chettri et al. 2018, Paunikar & Sharma 2022). Despite numerous studies in the Western Himalaya (Joshi & Arya 2007, Bhardwaj et al. 2012, Kumar et al. 2017, Verma & Arya 2018, Arya et al. 2020a, Samraj & Agnihotri 2021, Verma & Arya 2022), spatial variation of butterfly assemblages within the Kumun region of Uttarakhand remains insufficiently unexplored. Similarly, existing records from district Nainital in Kumaun division so far (Smetacek 2002, 2010, 2011a, 2011b, 2012a, 2012b, Tyagi et al. 2011, Meena & Dayakrishna 2017, Sondhi 2017, Arya et al. 2018, Arya et al. 2020b, Chandra et al. 2023), lack comparative or habitat/biotope based analysis. Consequently, systematic documentation of butterfly diversity across heterogeneous biotopes of the Kumaun Himalaya remains inadequate. Given the paucity of comparative studies evaluating how heterogeneous biotopes influence butterfly assemblages across seasons, a focused assessment is required to understand habitat-specific responses. Therefore, the present study examines the impact of habitat simplification on butterfly community composition, by analyzing (a) structure and composition of species assemblages in urban, riverine, and agricultural biotopes, (b) seasonal diversity variations, and (c) biodiversity conservation values of these biotopes. The study assesses the potential of butterflies as bioindicators of biotope integrity under the influence of agriculture expansion and urbanization.

Unlike previous studies from the Kumaun Himalaya that largely focus on checklist-based inventories or site-specific records, this study adopts a comparative biotope-based evaluation of butterfly assemblages across contrasting land-use systems. It addresses this gap by providing a spatio-temporal assessment of butterfly diversity across agricultural, riverine and urban landscapes in the Kumaun division, thereby offering insights into habitat modification and its implications for environmental monitoring.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is situated in the Kumaun Himalayan region of Uttarakhand, northern India. The district Nainital, covering 4251 m^2, is located at an altitude of 151m to 2581m msl and is the sixth largest district in the state. The district comprises diverse topographic regions with contrasting landscapes that create micro-climatic variations influencing soil and vegetation patterns. Changes in vegetation, relief, and slope also affect the faunal assemblages (Acharya & Vijayan 2015). The present study emphases on three structurally distinct biotopes based on elevation, degree of biotic stress, vegetation types and disturbance intensity. These include the Agriculture Biotope, the Riverine Biotope, and the Urban Biotope, located at elevations of 350m, 950-1150m, and 2100-2300m, respectively (Fig. 1). Owing to the differences in the terrain in all three, the average rainfall patterns, relative humidity, monthly temperature differed in each biotope. The climatic data was recorded by using digital min/max thermo-hygrometer.

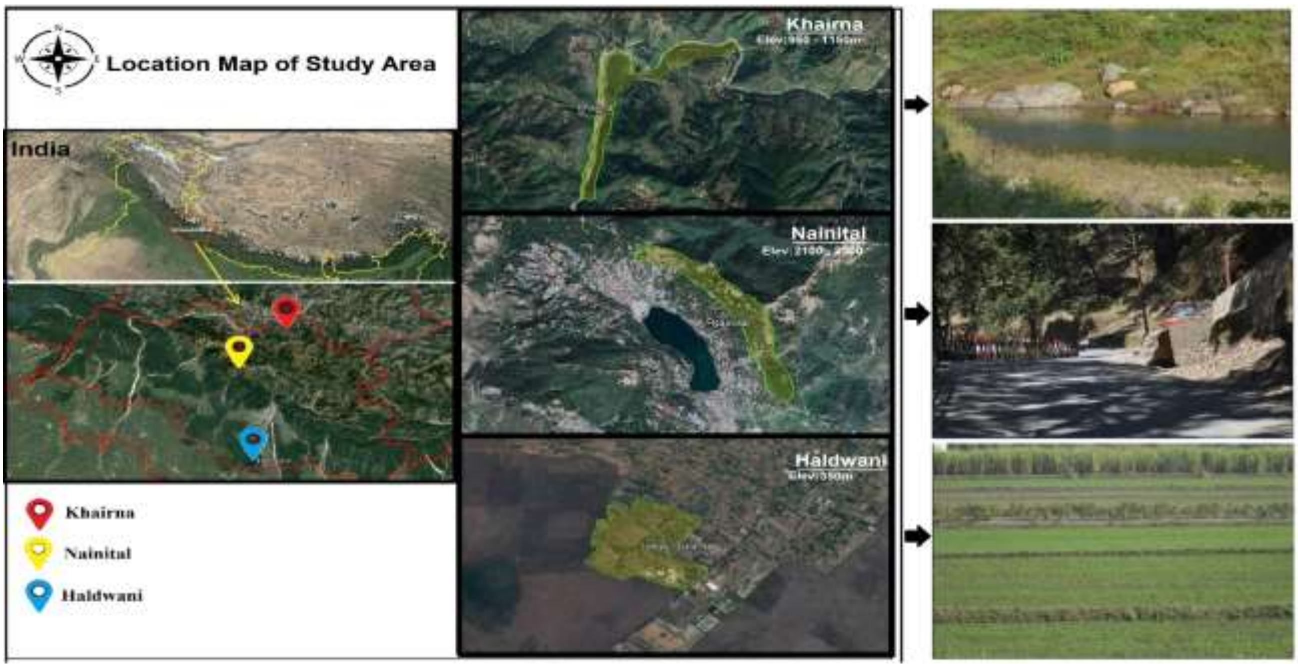


Fig. 1. Map showing selected sampling biotopes ranging in elevational zone from 350-2300m.

Agriculture Biotope *(aB)*

It is located in the Haripur Jamansingh village, Haldwani, that consists of arable lands representing a rural habitat. The area experiences warmer summers with relatively higher rainfall than winters. Annual kharif crops include paddy, maize, while rabi crops comprise wheat, sugarcane, pulses, mustard and *Trifolium alexandrinum*. On the other hand, fruit bearing and ornamental plants on the field margins or hedgerows include *Catharanthus roseus, Hibiscus, Pyrostegia venusta, Tagetes* sp., *Artocarpus heterophyllus*, *Mangifera indica*, *Carica papaya*, *Punica granatum*, *Phyllanthus emblica*. Anthropogenic disturbances such as surface burning, litter removal, fodder collection, small-scale construction are common. Butterflies were observed along two transects: one along the field margins and another within the crop fields.

Riverine Biotope *(rB)*

It is located along the bank of Kosi River near Jyari village, Khairna. The river bed averages approximately 80m in width, flowing towards the North-west direction. The area is characterized by broad-leaved and needle-leaved trees with dense shrub and ground vegetation. Common planted tree species along the banks include *Cinnamomum tamala, Syzygium cumini, Prunus persica,* while adjoining natural plant vegetation include *Pinus roxburghii*, *Ricinus communis*, *Ficus* spp. etc. Shrub and ground layers are dominated by *Berberis asiatica, Callicarpa macrophylla*, *Lantana camara, Hypericum oblongifolium, Zanthoxylum armatum, Debrigessia longifolia, Ageratina adenophora, Conyza japonica.* The river separates a relatively undisturbed mountainous area on the right bank from a semi-modified landscape with small market places and highway crossings on the left bank. Wood cutting for fuelwood, grazing, fodder collection, and construction along the river bank have altered the surrounding forest cover. Butterfly communities were sampled in two transects fixed on both the banks of the river Kosi.

Urban Biotope *(uB)*

The urban biotope belonged to the town of Nainital, and represents a highly disturbed landscape characterized by dense human settlements and exponential tourists influx. The area experiences a monsoon-dominated climate with peak rainfall during mid-June to September. The tree layer comprises mixed evergreen and deciduous species dominated by *Acer oblongum, Aesculus indica, Buddleja asiatica, Cupressus torulosa, Quercus leucotricophora, Q. floribunda, Rhododendron arboreum.* Common shrubs and herbs include *Berberis* sp.*, Debrigessia longifolia, Pyracantha crenulata, Rubus ellipticus, Ageratina adenophora, Bidens pilosa, Cirsium* sp., *Erigeron* sp.*, Rumex nepalensis, Salvia* sp.*, Urtica dioica.* Surrounding forests are subjected to grazing, fuel wood and fodder collection. Expansion of settlements and occasional forest fire have increased anthropogenic pressure. Transects were chosen with varied degree of anthropogenic pressures: one experienced recurrent human disturbances and the other was located in a moderately disturbed area adjacent to forest cover (Table 1).

Table 1: Characteristic features of biotopes selected for butterfly sampling.

Biotope	Location	Elevation (m)	Geographical coordinates	Landscape Element & Vegetation Type	Level of Disturbance
Agriculture (*aB*)	Haldwani	350	29°09’16.1”N Latitude 79°28’40.6”E Longitude	Cultivation fields of cereal and vegetable crops for agricultural practices	Moderate

Riverine (***rB***)	Khairna	950-1150	29°29’56.7”N Latitude 79°30’19.2”E Longitude	Low-lying area Needle and broad leaved and plantation forests with good cover of grasses	Low
Urban (***uB***)	Nainital city	2100-2300	29°23’29.643” N Latitude 79°28’8.436” E Longitude	Hilly terrain Mixed deciduous forest near human habitation	High

2.2 Sampling and identification of butterflies

Monthly sampling of butterfly species was carried out twice a month in each biotope during March 2023-February 2024. Each visit lasted three consecutive days, along each transect between 08:00-15:00. Two 500m line transects were established per biotope, wherein butterfly count based on wing morphology was performed using the point count method and the modified Pollard Walk Method (Pollard 1977). Due to varying physiography of the biotopes, transects were placed within a landscape span of approximately 3km in each biotope to ensure representative habitat coverage. Along each transect, ten fixed point-count stations were established at regular intervals. Butterfly abundance was recorded for 5-minutes at each point, maintaining a consistent pace within the observer's radius. Although detectability may vary among the biotopes, sampling effort, time of day, transects length, duration of observation was standardized to enable comparative assessment butterflies. Some of the cryptic species such as *Celastrina* spp., *Lethe confusa, L. verma, Neptis* spp. etc., whose identification on the field was not possible from photography, were collected using butterfly nets, identified and released unharmed. No individual was harmed during the study. Butterfly identification was conducted following field guides like Kehimkar (2014) and Sondhi and Kunte (2018). The presence of preferred host plants 2.5m on either sides of each transect was documented using Clark et al. (2007).

2.3 Analysis of data

Five major groups of butterflies were classified based on the frequency of occurrence of individuals in all biotopes: Very Rare (1-3 individuals), Rare (4-10 individuals), Uncommon (11-20 individuals), Common (21-40 individuals), and Very Common (>41 individuals). These rarity categories are descriptive and intended to indicate field observations rather than indicate inferential population status of butterflies. To interpret the collected data, the distribution of months was categorized into four seasons: (i) summer- March, April, May, (ii) monsoon- June, July, August, (iii) post-monsoon- September, October, November, and (iv) winter- December, January, February.

Functionality of butterflies based on information on their larval host plants was examined built on published sources worldwide such as Wynter-Blyth (1957), Veenakumari et al. (1997), Robinson et al. (2023), Smetacek

(2011c), Smetacek & Smetacek (2011), Ghorai & Sengupta (2014), Sengupta et al. (2014), Naik & Mustak (2015), Joshi et al. (2016), Nitin et al. (2018), Sondhi & Kunte (2018). Based on the range of host plant utilization, butterfly species were assigned into three polyphagy categories for host specificity, Monophagous: species feeding on plant species belonging to one genus, Oligophagous: species feeding on plant genera belonging to one family, and Polyphagous: species feeding on a variety of larval food plants belonging to more than one plant family (Smetacek 2012a).

Based on this classification, the oligophagous and polyphagous butterfly species were considered as the host generalists, while the monophagous butterflies were considered as the host specialists.

The abundance and species richness patterns for each biotope across seasons were also enumerated separately. Heat map illustrating seasonal equitability or evenness of species across different seasons was plotted against normalized abundance. Normalized abundance was calculated using formula proposed by Naik et al. (2022).

$$xi - min\,(x)/max\,(x) - min\,(x)$$

(Where *x*= absolute frequency and *N*= total)

Heat map was designed to visualize the occurrence of butterflies across seasons, wherein Hierarchical Cluster analysis (HCA) was performed to understand relationship between seasons and species assemblage. The analysis was based on normalized abundance data, which is suitable for presence-abundance matrices exhibiting strong seasonal variation. The Heat map was prepared online using the Heatmapper website: http://www.heatmapper.ca/ (Babicki et al. 2016). Rank-abundance curve for species distributional patterns in different biotopes were created after log converting the abundance data. To analyse sampling efforts, individual-based rarefaction curves were computed for each biotope (Magurran 2004) using the software PAST version 3.4 (Hammer et al. 2001). Likewise, butterfly diversity among families and biotopes were calculated using alpha diversity metrics such as Shannon's Index (*Hs*) for species diversity (Shannon & Weaver 1949), Simpson's Index (*D*) for species dominance (Simpson 1949) and Margalef's Index (*Hm*) for species richness (Margalef 1972) using PAST 3.4. For analysis of comparisons in butterfly richness and abundance among biotopes, one-way ANOVA was performed using the SPSS version 22, followed by pair-wise multiple comparisons through Tukey's HSD post-hoc testing at the 5% significance level. Further, Jaccard similarity index (J) was used to assess similarity in species composition among biotopes based on shared species, following the equation by Niwattanakul et al. (2013):

$$\text{J} = a \cup b/a \cap b$$

Where a= number of species of butterflies present at Site A and b= number of species of butterflies present at Site B.

Bray-Curtis cluster analysis based on single linkage similarity was performed using Bio-diversity Pro (Lambshead et al. 1997, McAleece 1998).

3. RESULTS

3.1. Species richness, Family composition and Status of butterfly fauna

A total of 94 species representing 66 genera and six families were recognized across the three study sites during the study period. Family Nymphalidae was the most abundant, comprising 44.7% of the total species, followed by Pieridae (20.2%), Lycaenidae (18.1%), Papilionidae (8.5%), Hesperiidae (5.3%), and Riodinidae (3.2%). Table 2 provides an inventory of identified butterfly species, seasonal abundance, and their polyphagy category in different biotopes. Fig. 2 displays some of the notable butterfly species found during the study.

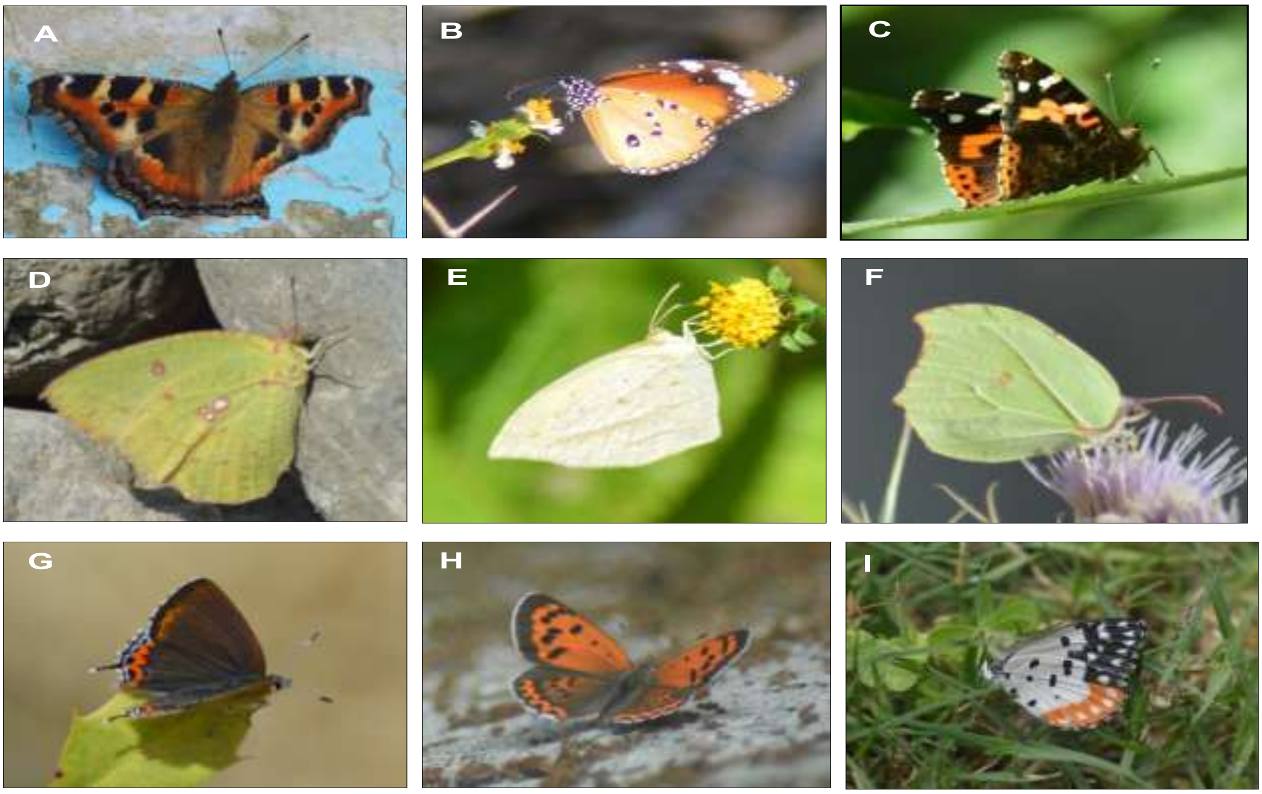


Fig. 2: Photo plates of butterflies identified from the study area. (A) *Aglais caschmirensis.* (B) *Danaus chrysippus*, (C) *Vanessa indica*, (D) *Catopsilia pyranthe*, (E) *Eurema laeta*, (F) *Gonepteryx nepalensis*, (G) *Heliophorus sena*, (H) *Lycaena panava*, (I) *Talicada nyseus*, (J) *Papilio polytes*, (K) *Borbo bevani*, (L) *Dodona durga.*

Table 2: Distribution, species composition and seasonal abundance of butterfly population in different biotopes (*aB*, *rB*, *uB*) during the study period.

Family	Scientific Name	(*aB*)				(*rB*)				(*uB*)			
		S	M	PM	W	S	M	PM	W	S	M	PM	W
Nymphalidae	*Acraea issoria* (Hübner)[P]	0	0	0	0	1	2	2	0	1	4	2	1
	Aglais caschmirensis (Kollar)[P]	0	0	0	0	6	8	12	4	34	16	18	8
	Ariadne ariadne (Linnaeus)[M]	2	4	5	3	0	2	5	2	0	0	0	0
	Ariadne merione (Cramer)[O]	2	2	35	31	4	6	20	0	0	0	0	0
	Argynnis hyperbius (Linnaeus)[P]	0	0	1	0	1	0	2	0	1	0	1	0

	Aulocera swaha (Kollar) [M]	0	0	0	0	0	0	0	0	3	2	6	1
	Callerebia annada (Moore) [O]	0	0	0	0	0	0	0	0	8	6	8	0
	Cyrestis thyodamas Doyere [P]	2	1	1	2	2	2	1	1	0	0	0	0
	Danaus chrysippus (Linnaeus) [P]	18	5	14	1	4	5	25	1	9	10	11	0
	Danaus genutia (Cramer) [O]	10	11	11	2	9	2	16	3	6	9	13	0
	Euploea core (Cramer)[P]	3	1	3	1	3	3	0	0	7	2	4	0
	Euthalia aconthea (Cramer) [P]	6	4	3	0	2	2	3	0	0	0	0	0
	Euthalia patala (Kollar) [M]	0	0	0	0	0	0	0	0	2	7	1	0
	Hypolimnas bolina (Linnaeus) [P]	3	6	2	0	1	2	4	0	0	0	0	0
	Issoria issaea (Gray) [P]	0	0	0	0	0	0	0	0	4	1	0	0
	Junonia almana (Linnaeus) [P]	12	5	1	10	16	1	1	1	9	3	3	0
	Junonia iphita (Cramer) [O]	4	0	2	0	5	1	2	0	15	4	1	0
	Junonia lemonias (Linnaeus) [P]	2	4	5	1	4	1	3	0	3	0	2	0
	Junonia orithya (Linnaeus) [P]	9	6	5	2	5	3	2	0	0	0	0	0
	Kallima inachus (Doyere) [P]	0	0	0	0	4	1	0	0	0	0	0	0
	Kaniska canace (Linnaeus) [P]	0	0	0	0	0	1	0	0	1	0	1	0
	Lasiommata schakra (Kollar) [M]	0	0	0	0	0	0	0	0	5	8	4	0
	Lethe confusa Aurivillus [O]	0	0	0	0	0	1	0	0	1	4	2	0
	Lethe verma (Kollar) [O]	0	0	0	0	0	0	0	0	0	4	2	0
	Melanitis leda (Linnaeus) [O]	0	0	0	0	0	2	0	0	0	4	3	0
	*Mycalesis visala*Moore [O]	1	5	3	1	0	2	1	0	0	0	0	0
	Neptis hylas (Linnaeus) [P]	11	5	8	0	4	0	4	0	9	2	8	1
	Neptis sappho (Pallas) [M]	6	5	8	1	10	1	6	0	0	0	0	0
	Orinoma damaris Gray [M]	0	0	0	0	0	0	0	0	0	0	1	0
	Parantica aglea (Stoll)[O]	2	1	3	0	3	3	5	0	4	6	2	0
	Parantica sita (Kollar)[O]	0	3	3	0	2	2	0	0	2	6	2	0
	Phalanta phalantha (Drury) [P]	0	0	0	0	1	1	27	1	6	0	19	3
	Pseudergolis wedah (Kollar)[O]	0	0	0	0	11	9	8	1	0	0	0	0
	Sephisa dichroa (Kollar) [P]	0	0	0	0	0	0	0	0	1	2	0	0
	Symbrenthia lilaea (Hewitson)[O]	7	2	0	4	1	1	5	0	3	0	9	0
	Tirumala limniace (Cramer)[O]	0	2	0	0	1	1	0	0	0	0	0	0
	Vanessa cardui (Linnaeus) [P]	0	0	0	0	4	0	3	0	14	1	7	0
	Vanessa indica (Herbst) [P]	0	0	0	0	3	0	9	0	26	2	16	4
	Ypthima baldus (Fabricius) [O]	4	14	8	2	2	3	2	2	0	0	0	0
	Ypthima huebneri Kirby[M]	11	14	7	3	4	2	1	0	0	0	0	0
	Ypthima nareda (Kollar) [M]	0	0	0	0	2	1	0	0	0	2	1	0
	Ypthima nikaea Moore[M]	0	0	0	0	0	0	1	0	4	4	3	0
Pieridae	*Aporia agathon* [P]	0	0	0	0	0	0	0	0	16	10	0	0
	Belenois aurota (Fabricius) [P]	8	2	4	1	4	3	1	0	4	0	0	0

	Catopsilia pomona (Fabricius) [O]	14	18	12	6	11	3	11	2	10	6	8	1
	Catopsilia pyranthe (Linnaeus)[O]	9	14	10	16	7	3	9	3	11	6	7	0
	Cepora nerissa (Fabricius) [O]	13	6	3	1	7	1	2	0	0	0	0	0
	Colias erate (Esper)[O]	5	0	1	0	3	1	1	0	5	1	0	0
	Colias fieldii Menetries [P]	27	1	0	0	10	0	0	0	24	4	2	0
	Delias belladonna (Fabricius)[O]	0	0	0	0	3	1	2	0	11	4	2	0
	Eurema andersonii (Moore)[M]	11	1	10	3	3	0	7	0	4	3	2	0
	Eurema blanda (Boisduval) [P]	4	4	6	10	4	2	8	1	0	0	0	0
	Eurema brigitta (Stoll)[P]	8	4	14	4	4	5	11	0	9	5	15	0
	Eurema hecabe (Linnaeus)[O]	24	20	12	24	8	4	12	0	22	7	11	0
	Eurema laeta (Boisduval)[O]	13	6	8	3	6	0	14	2	12	9	14	0
	Gonepteryx nepalensis Doubleday [P]	0	0	0	0	3	0	6	0	7	10	10	2
	Leptosia nina (Fabricius)[P]	1	4	3	3	0	2	1	1	0	0	0	0
	Pareronia hippia (Fabricius)[O]	1	1	4	0	0	2	4	0	0	0	0	0
	Pieris brassicae (Linnaeus) [P]	29	19	20	10	28	10	14	8	29	24	15	2
	Pieris canidia (Linnaeus)[P]	35	17	16	17	32	13	17	8	28	27	20	3
	Pontia daplidice (Linnaeus)[P]	13	4	2	1	3	0	1	0	1	3	0	0
Lycaenidae	*Catochrysops strabo* (Fabricius)[P]	0	1	4	1	1	0	2	0	0	0	0	0
	Celastrina argiolus (Linnaeus)[P]	0	0	0	0	0	0	0	0	10	6	13	1
	Celastrina huegelii (Moore) [P]	0	0	0	0	0	0	0	0	2	3	9	7
	Celatoxia marginata (de Niceville) [M]	0	0	0	0	0	0	0	0	1	3	6	0
	Euchrysops cnejus (Fabricius) [O]	0	0	7	12	2	0	5	0	0	0	0	0
	Heliophorus moorei (Hewitson) [M]	0	0	0	0	0	0	0	0	0	0	1	0
	Heliophorus sena (Kollar) [P]	0	0	0	0	11	1	8	0	52	24	17	7
	Jamides celeno (Cramer) [P]	2	0	1	0	0	1	2	0	0	0	0	0
	Lampides boeticus (Linnaeus) [O]	11	2	1	0	2	2	2	0	14	3	0	0
	Lycaena panava (Westwood) [M]	0	0	0	0	0	0	0	0	12	38	6	0
	Lycaena phlaeas (Linnaeus) [P]	0	0	0	0	0	0	0	0	2	3	3	0
	Pseudozizzeria maha (Kollar) [P]	27	21	23	9	7	6	6	1	5	2	4	1
	Talicada nyseus (Guerin-Meneville) [O]	20	7	37	21	10	6	14	5	0	0	0	0
	Udara sp. [O]	0	0	0	0	2	1	0	1	1	1	1	0
	Zizeeria karsandra (Moore) [P]	43	18	16	14	5	3	4	2	0	2	2	0
	Zizina otis (Fabricius) [P]	3	2	3	0	2	1	2	0	0	0	0	0
	Zizula hylax (Fabricius) [P]	4	1	2	0	2	0	1	0	0	0	0	0
Papilionidae	*Atrophaneura varuna* (White) [P]	0	0	0	0	0	1	0	0	3	7	5	0
	Byasa polyeuctes (Fruhstorfer)[P]	0	0	0	0	0	0	0	0	4	14	7	0
	Graphium sarpedon (Linnaeus) [P]	0	0	0	0	2	0	0	0	1	2	1	0
	Papilio bianor Cramer [O]	0	0	0	0	7	0	0	0	8	0	0	0
	Papilio demoleus Linnaeus [P]	10	9	3	3	2	2	1	0	4	2	0	0
	Papilio machaon Linnaeus [P]	0	0	0	0	1	0	0	0	2	0	0	0
	Papilio polytes Linnaeus [O]	10	16	14	5	17	12	17	4	9	13	18	0

	Papilio protenor Cramer[P]	0	0	0	0	0	2	0	0	2	1	0	1
Hesperiidae	*Borbo bevani* (Moore)[O]	3	1	5	6	2	2	6	0	1	4	5	0
	Celaenorrhinus munda (Moore)[O]	0	0	0	0	0	0	0	0	0	3	0	0
	Celaenorrhinus pero de Niceville[O]	0	0	0	0	0	0	0	0	1	1	2	0
	Parnara guttatus (Moore)[P]	2	6	6	0	3	2	5	2	0	0	0	0
	Potanthus dara (Kollar)[O]	0	0	0	0	1	3	1	0	0	0	1	0
Riodinidae	*Abisara fylla* (Westwood)[O]	0	0	0	0	1	0	0	0	1	2	0	0
	Dodona durga (Kollar)[P]	0	0	0	0	0	1	1	0	7	3	2	0
	Zemeros flegyas (Cramer)[M]	1	1	0	0	2	2	0	0	3	0	0	0

Abbreviations: S: Summer, M: Monsoon, PM: Post Monsoon, W: Winter, [M]: Monophagus, [O]: Oligophagus, [P]: Polyphagus (Source: Wynter-Blyth 1957, Sondhi & Kunte 2018, Robinson et al. 2023)

Of the total 94 recorded butterfly species, seven species (*Aporia agathon, Ceporia nerissa, Euchrysops cnejus, Eurema andersonii, Euthalia patala, Lampides boeticus* and *Papilio machaon*) are listed under Schedule-II of Indian Wildlife (Protection) Act (1972) and one species, *Euploea core* under Schedule-IV. Additionally, 11 species are classified as "Least Concerned" under the IUCN Red List of Threatened Species (IUCN 2020), including *Belenois aurota*, *Danaus chrysippus*, *Euploea core*, *Eurema brigitta*, *Graphium sarpedon*, *Junonia almana*, *Junonia orithya*, *Lampides boeticus*, *Phalanta phalantha*, *Pontia daplidice* and *Vanessa cardui*. Table 3 illustrates the site-wise records of legally protected species observed during the study. Of the 3592 individuals recorded, 25.53% were categorized as very common, 28.72% common, 17.02% uncommon, 23.40% rare, and 5.31% very rare, indicating dominance of few abundant species in the Kumaun region.

Table 3: Status of butterfly species under Indian Wildlife (Protection) Act, 1972.

Family	Species Name	Biotope			Protection Status IWPA, 1972
		aB	***rB***	***uB***	
Papilionidae	*Papilio machaon*			✓	Schedule-II
Pieridae	*Aporia agathon*			✓	Schedule-II
	Ceporia nerissa	✓			Schedule-II
	Eurema andersonii	✓	✓	✓	Schedule-II
Lycaenidae	*Euchrysops cnejus*	✓	✓		Schedule-II
	Lampides boeticus	✓	✓	✓	Schedule-II
Nymphalidae	*Euthalia patala*			✓	Schedule-II
	Euploea core	✓	✓	✓	Schedule-IV

Abbreviations: *aB*= Agriculture biotope, *rB*= Riverine biotope, *uB*= Urban biotope, ✓= Presence, IWPA: Indian Wildlife (Protection) Act (Source: Anonymous 2006)

Shannon diversity indices value of different butterfly families showed differences among the different biotopes during the study period (Table 4). Nymphalidae exhibited the highest diversity across all the biotopes, particularly in *rB* (*Hs*=3.16), suggesting that riverine environments support more heterogeneous butterfly community. In contrast, families Riodinidae and Hesperiidae showed less diversity indices values, being attributed to their low population in the present study.

Table 4: Variation in diversity indices of butterfly species observed in different biotopes.

Family	Genus	Species	Individuals	Diversity Indices (*Hs*)		
				aB	***rB***	***uB***
Nymphalidae	29	42	1236	2.77	3.16	2.99
Pieridae	12	19	1319	2.52	2.52	2.46
Lycaenidae	14	17	694	1.67	2.04	1.82
Papilionidae	4	8	242	0.65	0.98	1.67
Hesperiidae	4	5	74	0.69	1.04	1.12
Riodinidae	3	3	27	0	0.95	0.86

3.2. Relationship between butterfly diversity and biotopes

Across the selected biotopes, 76 butterfly species were recorded from the riverine biotope (*rB*), 70 species from the urban biotope (*uB*) and 52 species from the agricultural biotope (*aB*). Species analysis revealed distinct variation in assemblages, with steeper upper asymptotic curves obtained for all biotopes (Fig. 3). *aB* and *uB* attained early asymptote curve than *rB*, indicating comparatively lower richness. Asymptotic rarefaction curves for all biotopes indicate sufficient sampling efforts throughout the study and that observed differences in richness reflect ecological variation rather than sampling bias. The one-way ANOVA analysis showed significant differences in species richness among biotopes (F= 6.130, $P < 0.05$), highlighting the sensitivity of butterfly communities to land-use differences and micro-habitat structure. However, species abundance did not differed significantly (F= 1.722, $P >$ 0.05).

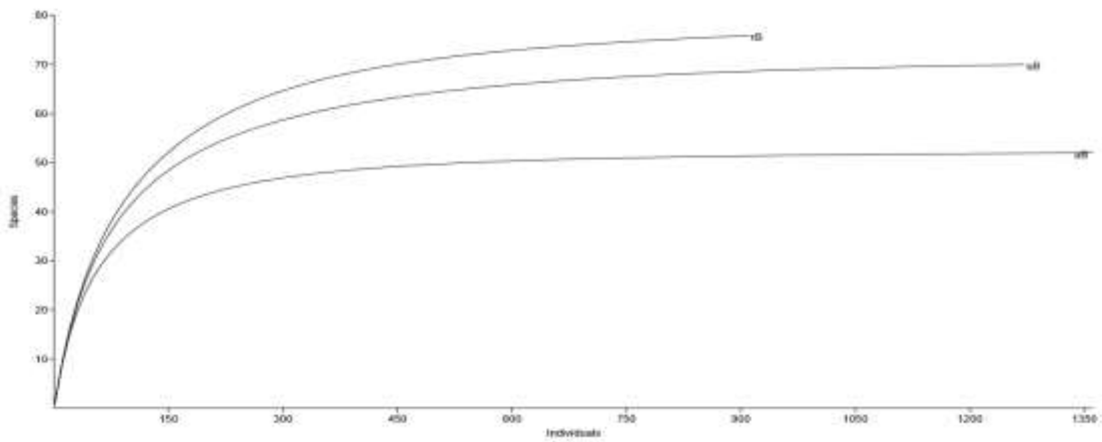


Fig. 3: Individual-based rarefaction curves for butterfly assemblages in different biotope types.

Alpha diversity indices such as Shannon-Wiener alpha diversity (*Hs*) and Margalef richness (*Hm*) showed that the riverine biotope (*rB*) supported the highest species diversity and richness (*Hs*=3.88 and *Hm*=10.97), followed by the (*uB*) with *Hs*=3.79 and *Hm*=9.63. The agriculture biotope (*aB*) had the lowest diversity and richness, with *Hs*=3.57 and *Hm*=7.05. Simpson's dominance index (*D*) was also highest in (*rB*) = 0.97, indicating a more even community structure with strong dominance of a few species (Table 5). The rank abundance plot for *aB* was steeper, indicating an unequal distribution, whereas, the curves for *uB* and *rB* produced smooth patterns inferring an equitable distribution pattern of butterfly assemblages (Fig. 4).

Table 5: Diversity indices of butterfly communities from the study area.

Diversity indices	*aB*	*rB*	*uB*
Butterfly species	52	76	70
Individuals	1377	929	1286
Dominance_D	0.03	0.02	0.03
Simpson_1-D	0.96	0.97	0.96
Shannon_H	3.57	3.88	3.79
Margalef	7.05	10.97	9.63

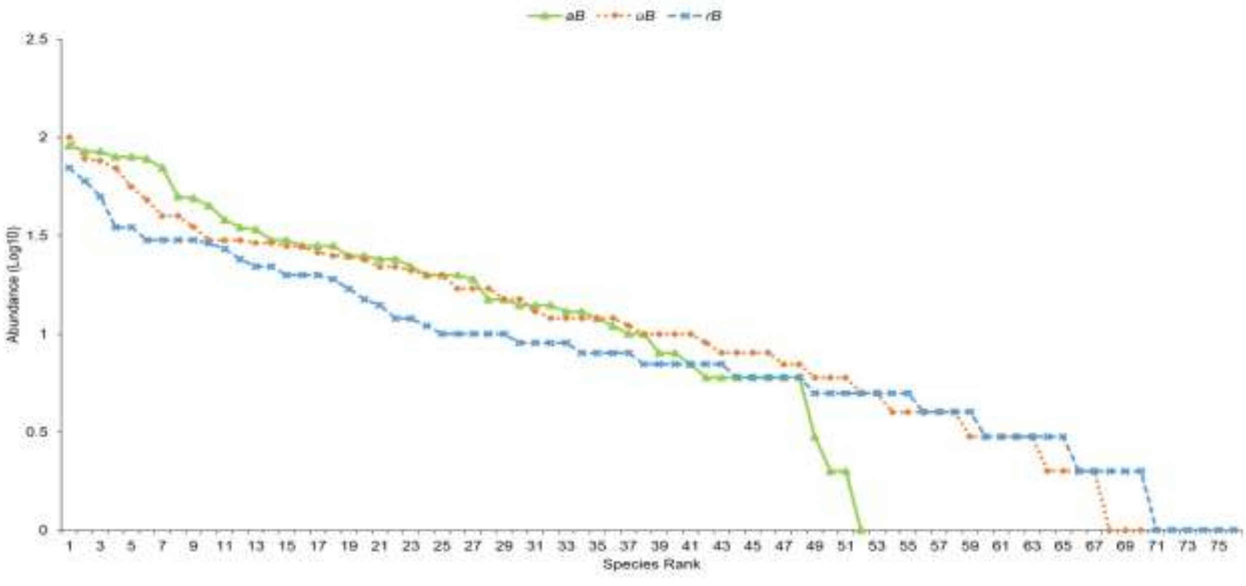


Fig. 4: Rank-abundance curves of butterfly species assemblages in three biotopes.

Vegetation heterogeneity across biotopes influenced butterfly assemblages. Comparative data on larval host plants gathered from studies by eminent workers showed that the butterfly community exhibited broad feeding preferences. Of the 94 species, 47 species (50%) were polyphagous, 33 (35.1%) were oligophagous and 14

(14.89%) were monophagous (Table 2). The agriculture biotope comprised the highest proportion of host generalists (90.3%), followed by the urban biotope 84.28%, with a few specialists (10%), restricted to the forest edges. In contrast, the riverine biotope supported the highest proportion of monophagous species (14.47%) of the other two biotopes, reflecting relatively undisturbed vegetation.

3.3 Species diversity and Biotope association

Single-linkage Bray-Curtis cluster analysis revealed highest similarity between riverine and agriculture biotopes (62.74%), while the urban biotope showed 56.77% similarity (Fig. 5). Fifty-two species were common between riverine and agricultural lands, 51 between riverine and urban, while 28 species were common between urban and agriculture biotopes. Based on the distance matrix and clusters obtained, Jaccard's coefficient index was also highest between *aB* and *rB* (0.68), followed by *rB* and *uB* (0.54). The lowest similarity index (0.32) was observed between *aB* and *uB* (Table 6).

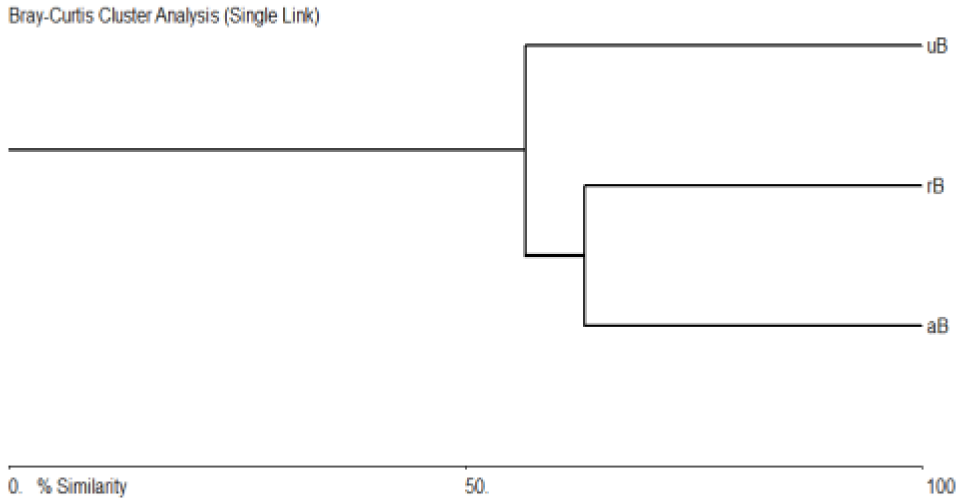


Fig. 5: Bray–Curtis cluster analysis showing similarity of butterfly assemblages across biotopes using single linkage method

Table 6: Jaccard similarity coefficients among different biotopes.

	aB	***rB***	***uB***
aB	*		
rB	0.68	*	
uB	0.32	0.54	*

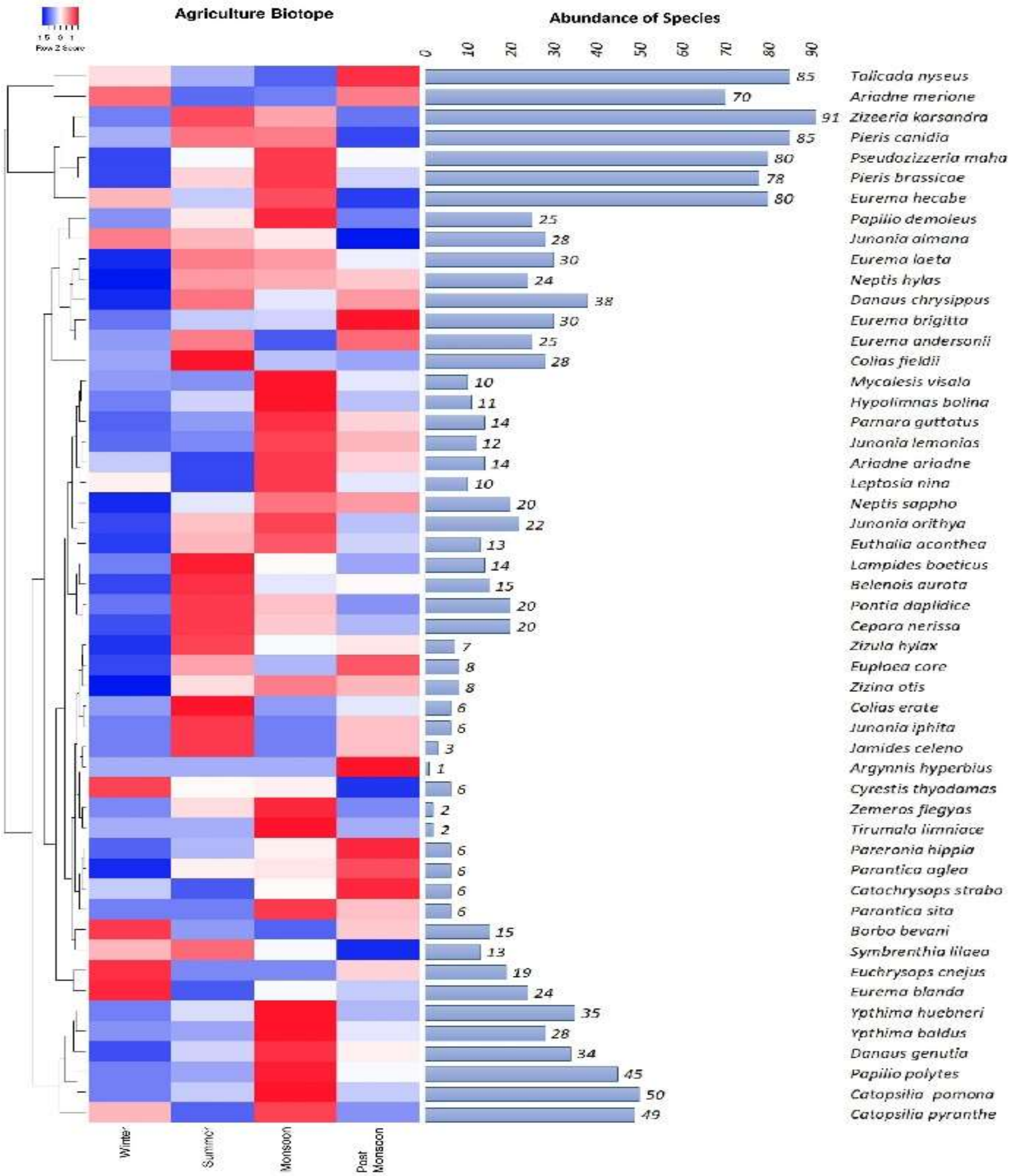
3.4 Season wise distribution of butterfly fauna

The study found that butterflies in all biotopes exhibited a highly seasonal trend, with both total species richness and individual abundance varying significantly across the seasons throughout the year. Bi-annual peaks in richness were observed during summer (March-May) and post-monsoon (September-November) across all study sites, while winter recorded the lowest richness due to reduced temperature and plant availability. On the other hand, species abundance was highest during the summer season in *aB* and *uB*, with 33.7% and 40.04% individuals respectively and during post-monsoon season in *rB* with 39.7% individuals.

The heat map of seasonal abundance indicated irregular species occurrence throughout the year (Fig. 6). In *aB*, dominant species such as *Zizeeria karsandra*, *Pieris canidia, Eurema hecabe* were relatively rare in winters and post monsoon, whereas *Talicada nyseus, Ariadne merione* remained relatively abundant. Twenty sseven pecies including *Mycalesis visala, Hypolimnas bolina, Ypthima yubneri, Y. baldus* etc. peaked during monsoon, and were nearly absent in other seasons.

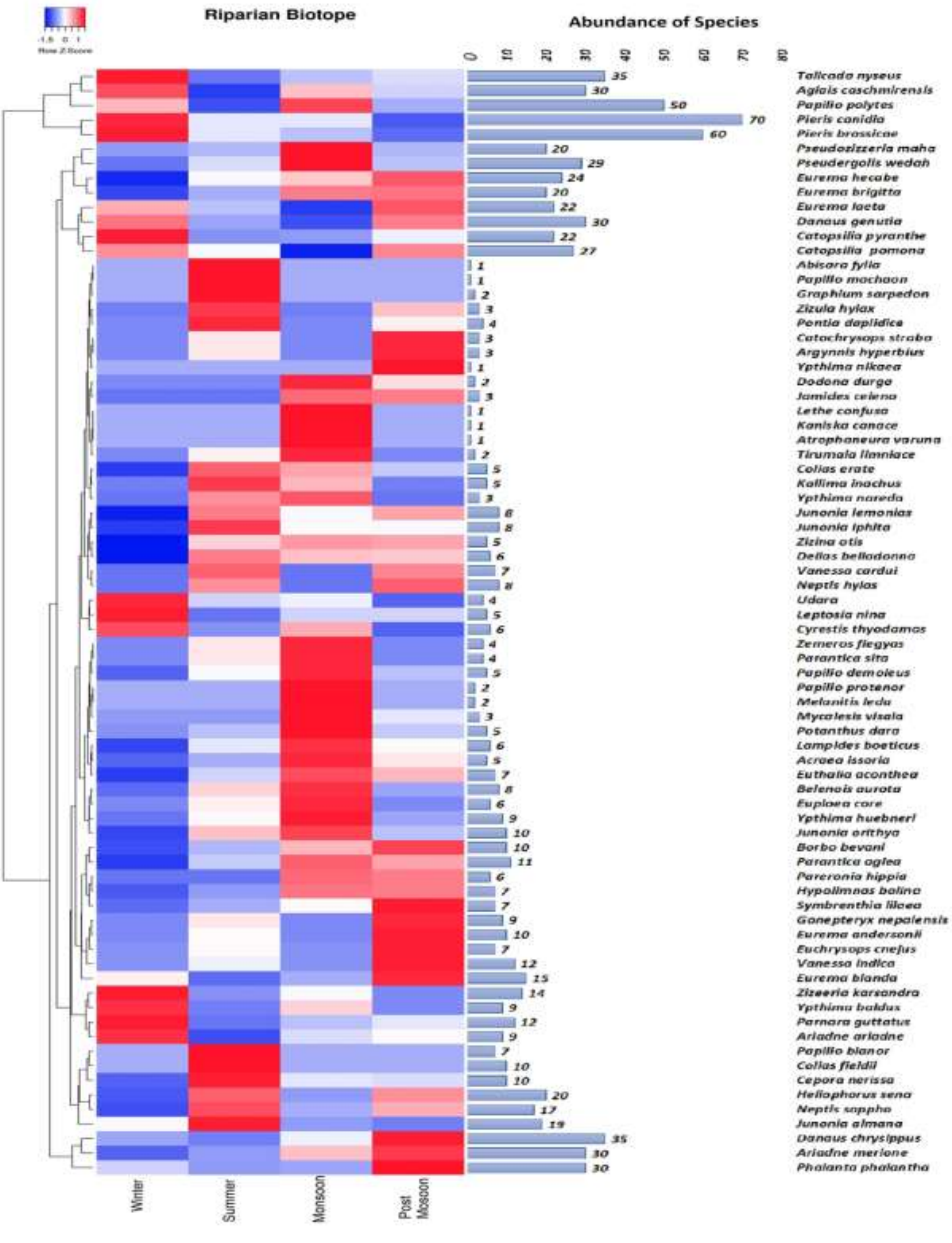
In *rB*, species distribution was influenced by river-mediated microclimate. Most species extended across two to three seasons, rather than showing strict seasonality. Species such as *Junonia lemonias, Zizina otis, Delias belladonna,* occurred in three seasons, while approximtely 24 species (e.g., *Papilio polytes, Eurema brigitta, Cyrestis thyodamas, Ariadne merione* etc.) were recorded in two seasons.

In *uB*, several dominant species including *Heliophorus sena, Aglias caschmirensis, Pieris canidia, Vanessa indica, Colias fieldii* etc. exhibited biannual peaks showing, primarily during summer and post-monsoon. Of the 70 recorded species in *uB*, 53 attained peak abundance during post-monsoon, indicating favourable climatic and vegetational conditions.

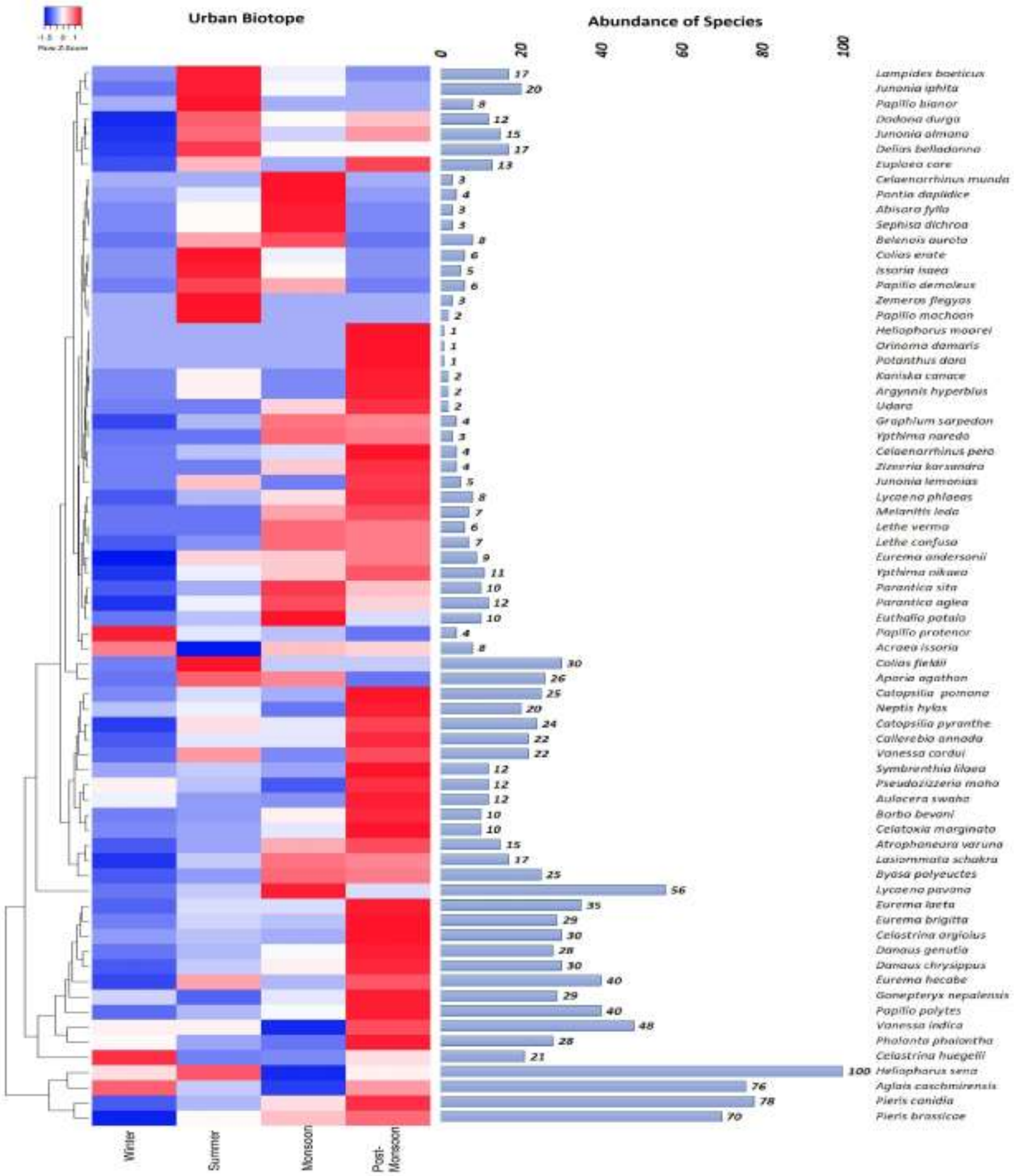


Row Z Score
Agriculture Biotope
Abundance of Species
0 10 20 30 40 50 60 70 80 90
Talicada nyseus 85
Ariadne merione 70
Zizeeria karsandra 91
Pieris canidia 85
Pseudozizzeria maha 80
Pieris brassicae 78
Eurema hecabe 80
Papilio demoleus 25
Junonia almana 28
Eurema laeta 30
Neptis hylas 24
Danaus chrysippus 38
Eurema brigitta 30
Eurema andersonii 25
Colias fieldii 28
Mycalesis visala 10
Hypolimnas bolina 11
Parnara guttatus 14
Junonia lemonias 12
Ariadne ariadne 14
Leptosia nina 10
Neptis sappho 20
Junonia orithya 22
Euthalia aconthea 13
Lampides boeticus 14
Belenois aurota 15
Pontia daplidice 20
Cepora nerissa 20
Zizula hylax 7
Euploea core 8
Zizina otis 8
Colias erate 6
Junonia iphita 6
Jamides celeno 3
Argynnis hyperbius 1
Cyrestis thyodamas 6
Zemeros flegyas 2
Tirumala limniace 2
Pareronia hippia 6
Parantica aglea 6
Catochrysops strabo 6
Parantica sita 6
Borbo bevani 15
Symbrenthia lilaea 13
Euchrysops cnejus 19
Eurema blanda 24
Ypthima huebneri 35
Ypthima baldus 28
Danaus genutia 34
Papilio polytes 45
Catopsilia pomona 50
Catopsilia pyranthe 49
Winter
Summer
Monsoon
Post Monsoon

A


Riparian Biotope
Abundance of Species
0
10
20
30
40
50
60
70
80
Talicada nyseus 35
Aglais caschmirensis 30
Papilio polytes 50
Pieris canidia 70
Pieris brassicae 60
Pseudozizzeria maha 20
Pseudergolis wedah 29
Eurema hecabe 24
Eurema brigitta 20
Eurema laeta 22
Danaus genutia 30
Catopsilia pyranthe 22
Catopsilia pomona 27
Abisara fylia 1
Papilio machaon 1
Graphium sarpedon 2
Zizula hylax 3
Pontia daplidice 4
Catochrysops strabo 3
Argynnis hyperbius 3
Ypthima nikaea 1
Dodona durga 2
Jamides celeno 3
Lethe confusa 1
Kaniska canace 1
Atrophaneura varuna 1
Tirumala limniace 2
Colias erate 5
Kallima inachus 5
Ypthima nareda 3
Junonia lemonias 8
Junonia iphita 8
Zizina otis 5
Delias belladonna 6
Vanessa cardui 7
Neptis hylas 8
Udara 4
Leptosia nina 5
Cyrestis thyodamas 6
Zemeros flegyas 4
Parantica sita 4
Papilio demoleus 5
Papilio protenor 2
Melanitis leda 2
Mycalesis visala 3
Potanthus dara 5
Lampides boeticus 6
Acraea issoria 5
Euthalia aconthea 7
Belenois aurota 8
Euploea core 6
Ypthima huebneri 9
Junonia orithya 10
Borbo bevani 10
Parantica aglea 11
Pareronia hippia 6
Hypolimnas bolina 7
Symbrenthia lilaea 7
Gonepteryx nepalensis 9
Eurema andersonii 10
Euchrysops cnejus 7
Vanessa indica 12
Eurema blanda 15
Zizeeria karsandra 14
Ypthima baldus 9
Parnara guttatus 12
Ariadne ariadne 9
Papilio bianor 7
Colias fieldii 10
Cepora nerissa 10
Heliophorus sena 20
Neptis sappho 17
Junonia almana 19
Danaus chrysippus 35
Ariadne merione 30
Phalanta phalantha 30
Winter
Summer
Monsoon
Post Mosoon

B



C

Fig. 6: Heat map showing patterns of normalized abundance of butterfly species in different seasons at different biotopes during study period. (A) Agriculture, (B) Riverine, (C) Urban.

4. DISCUSSION

Different habitats provide distinct mosaics, that support diverse butterfly assemblages. The biotopes of the Kumaun region, play an important role in maintaining butterfly diversity. Nymphalidae was the most dominant family, consistent with findings from other studies (Bhardwaj et al., 2012; Chettri et al., 2018; Verma & Arya

2018; Samraj & Agnihotri 2021), administering maximum species richness in each season in all study sites. Its dominance may be linked to the polyphagous nature of its members, enabling tolerance to disturbance and microclimatic variation, whereas Riodinidae family was least represented.

The observed butterfly communities spanning elevations from 350-2300m msl within the Nainital district, demonstrate a greater species richness in the riverine biotope (*rB*). Greater habitat heterogeneity, edge interfaces and stable moisture regimes likely supported diverse larval host plants and adult resources, reflected in the higher asymptotic rarefaction curve, rather than any sampling artefacts. In contrast, anthropogenic pressures in other biotopes simplified their community structure. Several specialist species such as *Pieris canidia*, *P. brassicae*, *Papilio polytes*, *Talicada nyseus*, *Danaus chrysippus*, *Aglais caschmirensis*, *Ariadne merione*, *Danaus genutia* and *Phalanta phalantha* were more prominent in *rB* (11.84% of total species richness present), suggesting the influence of moderate canopy cover and vegetation composition.

Likewise, in the (*uB*), dominant species included *Heliophorus sena*, *Pieris canidia*, *Aglais caschmirensis*, *P. brassicae*, *Lycaena panava* and *Vanessa indica*, accounting for 8.57% of total species. Despite the proximity to forest edges, disturbance such as forest clearings, grazing, and roadside traffic and extreme climatic conditions, likely reduced the richness compared to (*rB*). These disturbances favored some disturbance-tolerant generalist species, and resulting in relatively higher abundance, but lower diversity in the urban biotope.

Agricultural land (*aB*) showed reduced richness, likely due to disturbance levels including frequency, and application of pesticides, tillage activities to control insect pests and crop harvest, periodic surface burning which affect larval food plants, could have necessarily caused land used changes which led to a phenomenon of homogenization of species. This may shift communities from less mobile specialists to more mobile generalists, reducing functional diversity (Bhardwaj et al. 2012, Börschig et al. 2013, Singh et al. 2017). Dominant generalist species of the biotope were *Zizeeria karsandra*, *Talicada nyseus*, *Pieris canidia*, *Eurema hecabe*, *Pseudozizzeria maha*, *Pieris brassicae*, *Ariadne merione* and *Catopsilia Pomona*, whose polyphagy and higher survival led to their highest abundance and steeper rarefaction curve for *aB*. The results therefore highlight skewed challenges of agricultural expansion in the selected rural area from the district for the first time as well.

Since the ecology of butterfly communities is influenced by several factors, seasonal conditions are a key determinant, affecting their life cycle and distribution patterns (Kunte 1997). Agricultural and urban biotopes recorded highest abundance during summer season, typical to other studies (Padhye et al. 2006, Parandhaman et al. 2012), possibly due to the occurrence of different vegetation and successive flowering stages providing more food resources. This contradicts the findings of other studies that report higher numbers during the rainy season (Kunte 1997, Pozo et al. 2008, Hussain et al. 2011, Manwar & Wankhade 2014). Conversely, (*rB*) showed higher abundance during late monsoon, similar to Gohel & Rava (2019), Arya et al. (2020b), likely reflecting host plants availability. Winter recorded the lowest species richness and abundance in all biotopes. Overall, these spatial and temporal variations lead the potential of butterfly communities to act as sensitive ecological indicators of land-use changes in the Kumaun Himalaya.

Under the Indian Wildlife (Protection) Act of 1972, several Schedule II species and one Schedule IV species were recorded. Our study revealed that some legally protected species, such as *Euthalia patala* and *Papilio machaon*, were found as rare or very rare, while few others appeared to be common or very common, such as *Aporia agathon*, *Cepora nerissa*, *Euchrysops cneju*s, *Lampides boeticus*, *Euploea cor*e, and *Eurema andersonii*. This suggests that these biotopes are crucial for the survival of these threatened species as well, and therefore, vegetation management and conservation should focus on the most preferred plant families.

5. CONCLUSIONS

This study explores the interaction between butterflies and their environment, making it possible to evaluate them as bio-indicators of ecological health of the Himalayan ecosystems under increasing disturbances. A total of 30 species (31.91% of the total species) co-occurred across all three biotopes, indicating a wider distributional range and population stability. The study highlights the importance of riverine sites for butterfly biodiversity, as they support the largest number of species and are the best-structured habitats. Whereas, in order to mitigate anthropogenic effects on butterfly populations in urban and agro-ecosystems, it is imperative to address human disturbances such as habitat degradation or pesticide usage, and to engage local communities. Furthermore, maintaining host tree species or native larval host plants along riverbanks, preserving hedgerows in agricultural fields and protecting forest-edge microhabitats in urban landscapes should be prioritized to sustain butterfly diversity.

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