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Spatial insect diversity paradigms and related ecosystem services in the protected Nandhour Landscape of India

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ABSTRACT. The Nandhour Landscape located in an eco-fragile biodiversity rich Terai Arc Landscape of India is protected in the form of a wildlife sanctuary and is least explored in terms of insect diversity and functions. Therefore, this study aimed to provide baseline information on the biodiversity of insects and their ecological functions in tropical to sub-tropical forest ecosystems which is important for the successful long-term provisioning of ecosystem functions and services in the protected landscape. Using standardized sampling techniques, the present study examined the structure and composition of insect assemblages in terms of their comparative diversity and richness across a range of habitat types in the Nandhour Landscape. Besides, the present study also evaluated the ecological significance of insect fauna. A total of 230 insect species belonging to 47 families and nine orders were recorded from various habitats and Lepidoptera was the most dominant insect order in terms of both richness and abundance, followed by Coleoptera, Hymenoptera, Odonata and others. Species diversity and richness were the highest in dense moist and open dry riverine forests, while the least in plantation forest and agricultural land. The heterogeneous structure and composition substantiated the importance of overall spatial heterogeneity and natural forests in sustaining and maintaining the rich insect diversity. Conservation of insect diversity is highly important as several species provide crucial ecosystem services and aid in the functioning of various ecologically fragile habitats of the landscape.

Key words. Agricultural intensification, Ecosystem services, Heterogeneity, Insect diversity, Protected landscape, Species richness

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INTRODUCTION

Insect biodiversity is a crucial natural resource that sustains humanity by providing several benefits and goods which are known as ecological or ecosystem services (Losey & Vaughan, 2008; Dangles & Casas, 2019). They play a key role in dispense of major four types of ecosystem services viz., provisioning (concerned with the material or energy outputs from the ecosystem), regulating (concerned with the

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regulation of magnitude and dynamics of ecological functions), supporting (concerned with the maintenance of other ecosystem services) and cultural services in form of education, research and recreational benefits (Noreiga et al., 2018). However, due to global climate change and human induced landscape fragmentation and modification, insects are declining at an unprecedented level (Sánchez-Bayo & Wyckhuys, 2019; Seibold et al., 2019), leading to the further loss of a range of irreplaceable services essential for humankind (Sarmiento-Garcés & Hernández, 2021).

Insecta is the most dominant, ubiquitous and diverse taxonomic group, comprising about 58% of the known global biodiversity and about 66% of all animals on the earth (Zhang, 2011). Such a huge diversity of insect species in a variety of life-forms renders them as a critical biotic component for the functioning and integrity of ecosystems. The largest insect orders namely, Coleoptera, Lepidoptera, Hymenoptera, Diptera and Odonata are the major functional groups, contributing towards ecosystem services in significant ways. They play important ecological roles as herbivores, pollinators, decomposers, parasitoids and predators, and provide a comprehensive overview of provisioning, cultural, supporting and regulating services (Schowalter et al., 2018). Besides the provisioning of important ecosystem services, insects have direct or indirect impacts on agriculture, human health and the global economy. It has been estimated that insects provide such services of worth about $57 billion per year in the United States alone (Losey & Vaughan, 2006). Among the insect groups, beetles (Coleoptera) contribute significantly towards decomposition, bioturbation, pest and parasite control, seed dispersal, nutrient cycling and pollination (Nichols et al., 2008; Kirmse & Chaboo, 2020). Bees (Hymenoptera) have several nutritional and therapeutic uses, and provide economic benefits through products like honey, beeswax, royal jelly, propoils and venom (Ameixa et al., 2018). They are also well-known pollinators of many cultivated and wild plants, and help in seed and fruit production (Melin et al., 2014). Dragonflies and damselflies (Odonata) due to their predaceous nature are extremely important in the biocontrol of disease vectors and crop pests (May, 2019). Termites (Isoptera) and ants (Hymenoptera) aid in decomposition, soil formation and compaction, control of erosion rates, increasing soil fertility and seed dispersal (Ameixa et al., 2018; Pant et al., 2020). Many insect species are used as direct food and feed by humans, thus providing critical provisioning services (Rumbos & Athanassiou, 2021).

About 15% of the global terrestrial surface is covered with protected areas, of which the protected areas in the Indo-Malayan Realm are experiencing the highest rates of human induced pressures (Geldmann et al., 2019). There are also evidences of loss of insect diversity and abundance even in protected areas (Hallmann et al., 2017; Wagner, 2020), thus, it is imperative to evaluate and understand insect assemblages for the development of conservation strategies and policies in regions of prime biological importance (Habel et al., 2019). Such quantifications of insect diversity and composition are essential and pre-requisite for the successful long-term provisioning of ecological functions and services, especially in the areas associated with high biodiversity (Harvey et al., 2020). Insect diversity and richness is crucial for the integrity and functioning of terrestrial and freshwater ecosystems. Insects serve as ecosystem engineers through their role as the major modifiers and controllers of the physical state of abiotic and biotic materials (Samways, 2005). Insects have short development period and show quick response towards minor ecological changes and disturbances in their habitats (Bergman et al., 2018). Many insect taxa due to their conspicuousness and susceptibility to environmental changes are used as the bio-indicators of ecosystem health and integrity (May, 2019; Sharma et al., 2020; An & Choi, 2021). The structure and composition of insect diversity are majorly determined by environmental conditions, vegetation and edaphic variables, and anthropogenic ecological modifications (Gómez-Cifuentes et al., 2020; Kirmse & Chaboo, 2020). Land-use types and habitat heterogeneity at the landscape level are the major determinants of insect diversity and richness patterns at different spatial scales (Bergman et al., 2018; Habel et al., 2021), and thus have implications in their conservation planning and management (Barton et al., 2009; Albert et al., 2021).

The Nandhour Landscape (NL), a local biodiversity hotspot, is a representative sub-landscape of the *Shiwalik-bhabar* tract in a vast conservation geographic division called the Terai Arc Landscape

(TAL) which is an eco-sensitive *terai-bhabar* region in the outer slopes of the Shiwalik Himalaya to the foothill areas and Gangetic flood plains (Chanchani et al., 2014). Despite the crucial ecological significance of insects, their assemblages are almost entirely unknown, and there is a critical information gap on the diversity of insects in one of the most environmentally sensitive and biologically diverse eco-regions of the NL. There are several modern studies on insect biodiversity across the globe (Joshi et al., 2008; Chung et al., 2013, 2020, Balakrishnan et al., 2014; Najar & Bashir, 2016; Phauk et al., 2019; Verma & Arya, 2020; Singh et al., 2021). However, the NL has not been comprehensively surveyed and documented for regional insect diversity since the British Colonial Era. In this regard, biodiversity studies on insects are crucial from the standpoint of their diversity, conservation, and contributions in ecological functions as well as to assess the impact of environmental and land-use changes on them (Beiroz et al., 2017, 2018; Salomão et al., 2019). Such studies are extremely important in establishing a baseline scientific foundation required for the formulation of effective conservation and management policies, as well as for identifying local biodiversity hot spot centers within the protected areas (Bhargav et al., 2009; Sharma et al., 2020). Since there is no extensive study to understand the, composition of insects, the present study aimed to (***a***) document the species composition and relative abundance of different groups of insects, (***b***) analyze the alpha and beta diversity patterns in different habitats, and (***c***) investigate and explore their crucial role in the sustainability and integrity of the NL.

MATERIAL AND METHODS

Study area. The study area encompassed various eco-regions of the NL, stretched between 28°56′29.35″ to 29°16′39.79″ N Latitudes and 79°33′03.82″ to 80°10′00.03″ E Longitudes in the state Uttarakhand of India (Fig. 1). The NL is conserved in the form of Nandhour Wildlife Sanctuary forming a core zone in an area of 269.95 km^2 and surrounded by a buffer zone of 540.26 km^2 area. The protected landscape is well known for its spatial heterogeneity and rich biodiversity, also serving as a crucial corridor for wildlife migration across the forests of Nepal and India (Verma, 2011). The landscape is featured by a diverse range of land-use and habitat types, housing floral and faunal elements of the both Himalaya and peninsular India (Irengbam et al., 2017). The landscape is criss-crossed by a number of rivers, bounded by the Himalaya in the north and the *terai* region in the south, and the topography is represented by steep mountains, high denudational hills, broad and narrow valleys, flat and rugged slopes, and flood plains. It harbors diverse and complex ecosystems of tropical moist and dry deciduous forest, sub-tropical forest, mixed forest, riverine forest, scrublands, grasslands, wetlands, barren lands, plantation forests, cultivation lands, human settlements etc. (Verma, 2011; Mehra, 2015). The NL experiences a sub-tropical to temperate type of climate.

The region receives heavy annual rainfall of more than 1400 mm mainly from the south-west monsoons during mid-June to September-October and the maximum mean temperatures range from 28°C in January to 37°C in May (Mehra, 2015). For the purpose of the present study, samplings were performed in a variety of habitat types to reflect the importance of overall spatial heterogeneity in sustaining insect diversity. A total of eight study sites based on different habitat types were selected in the NL within an elevational range of 245–1050 m above sea level (Fig. 1, Table 1). Disturbances and management practices in different study sites were noted during the study period. Dominant vegetation is represented by trees such as *Shorea robusta*, *Tectona grandis*, *Dalbergia sisso*, *Syzygium cumini*, *Ehretia laevis*, *Terminalia arjuna*, *Cassia fistula*, *Haldina cordifolia*, *Mallotus philippensis*, *Mallotus repandus*, *Aegle marmelos*, *Toona ciliata*, *Melia azedarach*, *Ficus benghalensis*, *Ficus religiosa*, *Ficus racemosa*, *Schleichera oleosa*, *Bombax ceiba*, *Diploknema butyracea*, *Ailanthus excelsa*, *Pinus roxburghii* etc. The common shrubs are *Calotropis procera*, *Murraya koenigii*, *Clerodendrum infortunatum*, *Justicia adhatoda*, *Ziziphus xylopyrus*, *Ageratina adenophora*, *Lantana camara*, *Colebrookea oppositifolia*, *Glycosmis pentaphylla* and *Woodfordia fruticosa*.

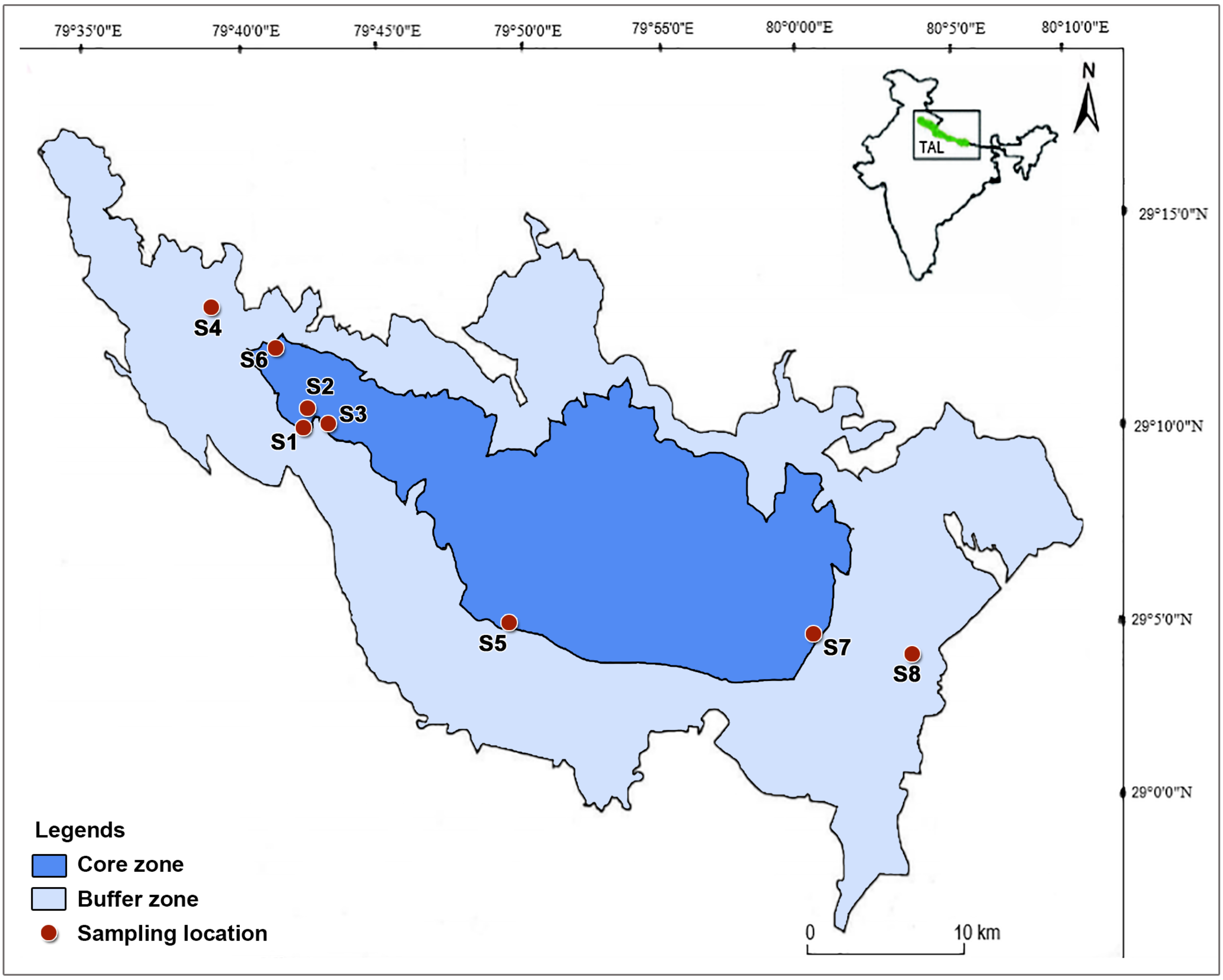

Figure 1. Maps showing the location of sites selected for insect samplings in the protected Nandhour Landscape, Terai Arc Landscape (TAL) in India (Modified from Verma, 2011).

Data collection. Insect samplings were performed during eight consecutive sampling days of a month from March 2018 to February 2020 along three permanent linear transects (each measuring 300 m × 10 m), spaced about 300–500 m apart from each other, laid in a random and stratified manner in each of the eight study sites. Insects exhibit a huge diversity of habits (Beeson, 1941), and therefore several sampling methods that are widely and commonly used for the estimation of different taxonomic groups were adopted along the median axis of each permanent transect. This included modified Pollard walk method designed for the estimation of butterfly abundance (Pollard, 1977; Pollard and Yates, 1993), net sweeping method using a standard entomological net, beating trays method using white entomological sheet (measuring 1.8 m × 1.2 m), hand sorting method using forceps, light traps method and baited pitfall traps method for insect samplings other than butterflies (Bhargav et al., 2009).

The adult populations of diurnal insects within each sampling transect were visually estimated by employing methods such as net sweeping, beating trays and hand sorting during the period of maximum activity, i.e. from 08:00 to 13:00 h of a day (Bhargav et al., 2009; Balakrishnan et al., 2014). Light traps method was employed for the sampling of nocturnal insects using an incandescent bulb of 18 W placed over a white entomological sheet from 19:30 to 21:30 h of a day.

Table 1. Descriptions of the study sites selected for insect samplings in the Nandhour Landscape.

Site code	Geographical Coordinates		Elevation (m.a s.l.)	Habitat	Major Vegetation	Practices & Disturbances
	Latitudes (N)	Longitudes (E)				
S1	29°07.22'	79°42.05'	315	Agricultural land	*Azadirachta indica*, *Mangifera indica*, *Syzygium cumini*, *Tectona grandis*, and many cultivated crops and vegetables	Cultivation Pesticides and fertilizers
S2	29°07.58'	79°42.15'	332	Plantation forest	*Ageratum conyzoides*, *Asclepias curassavica*, *Bidens pilosa*, *Shorea robusta*, *Solanum nigrum*, *Tectona grandis*	Butterfly conservation zone for ecotourism
S3	29°08.00'	79°42.19'	353	Dense moist riverine forest	*Albizia procera*, *Bauhinia variegata*, *Dalbergia sissoo*, *Ficus semicordata*, *Ficus virens*, *Kydia calycina*, *Mallotus repandus*, *Syzygium cumini*	Forest patrolling, camping
S4	29°13.54'	79°38.20'	419	Moist bhabar sal forest	*Aegle marmelos*, *Careya arborea*, *Mallotus philippensis*, *Shorea robusta*, *Tectona grandis*, *Terminalia alata*	Grazing, collection of fuelwood and fodder
S5	29°04.09'	79°49.16'	245	Open dry riverine forest	*Acacia catechu*, *Cordia dichotma*, *Dalbergia sissoo*, *Ficus racemosa*, *Haldina cordifolia*, *Holoptelea integrifolia*, *Persea gamblei*	Forest patrolling, illicit felling, grazing
S6	29°13.09'	79°41.32'	1044	Subtropical chir pine forest	*Anogeissus latifolia*, *Boehmeria rugulosa*, *Grewia optiva*, *Myrica esculenta*, *Ougeinia oojeinensis*, *Pinus roxburghii*, *Quercus leucotrichophora*	Forest fires, fuelwood and forest products
S7	29°04.15'	80°01.05'	350	Moist Shiwalik sal forest	*Adina cordifolia*, *Anogeissus latifolia*, *Diploknema butyracea*, *Lagerstroemia parviflora*, *Mallotus philippensis*, *Shorea robusta*, *Tectona grandis*, *Terminalia alata*	Silvicultural activities
S8	29°04.49'	80°05.32'	280	Moist mixed deciduous forest	*Adina cordifolia*, *Dalbergia sisso*, *Mallotus philippensis*, *Mitragyna parviflora*, *Shorea robusta*, *Tectona grandis*, *Terminalia arjuna*, *Toona ciliata*	Logging, transportation

In order to sample ground dwelling insects, five pitfall traps made of plastic jars of 9 cm in diameter and 10 cm in depth, each baited with about 30 g of fresh mammalian dung, were set up 30 m right away from the light traps placed in each transect (Barton et al., 2009). The baited traps were kept open and observed after every eighth day. Additional collections from crevices, decaying logs, leaf litter, and beneath rocks and stones were also made by employing the opportunistic sampling method in each permanent transects (Bhargav et al., 2009).

Identification of species and ecosystem services provided by insect fauna: The collected specimens of insects were transferred into jars containing 10% ethyl acetate soaked cotton. The specimens were preserved following the methodology by Upton and Mantle (2010). The species were compared with the authoritative reference collections present in the Insect Biodiversity Laboratory of Department of Zoology, D.S.B. Campus, Kumaun University, Nainital, and identified on the basis of key morphological descriptions in the available literature. Voucher specimens of the species which were not identified in the laboratory, were sent to the Northern Regional Station of Zoological Survey of India, Dehradun and the Entomological Section of Forest Research Institute, Dehradun for further identifications. Species which still could not be got identified were sorted to the morphospecies level and identified at the genus level. Most of the butterfly species were identified visually in the field with the help of published literature (Kumar, 2008; Kehimkar, 2016; Singh, 2017; Sondhi & Kunte, 2018). Plant species were identified using published information (Verma, 2011; Mehra, 2015), and by the help of experts and taxonomists at G.B.P. National Institute of Himalayan Environment and Sustainable Development, Almora. The identified insects were arranged in different taxonomic groups to prepare an inventory for the study area.

The functions and services provided by insects are categorized into four major ecosystem services viz., provisioning services in the form of nutrition source, food chain supplementation, economic benefits, regulating services in the form of carbon sequestration, climate regulation, control of pests and pathogens, soil formation and nutrient regulation, supporting services in the form of pollination, decomposition, mineralization, seed dispersal and cultural services in the form of bioindicators, conservation tool, education, tourism, cultural heritage, religion and spiritual values (Noreiga et al., 2018; Dangles & Casas, 2019). Assuming the relationships between insects and their ecological roles, information on each ecosystem services provided by each reported species was retrieved by using direct (field based) and indirect (literature based) observations (Beeson, 1941; Nichols et al., 2008; Bhargav et al., 2009; Melin et al., 2014; Golfieri et al., 2016; Ameixa et al., 2018; Beiroz et al., 2018; May, 2019; Kirmse & Chaboo, 2020; Pant et al., 2020; Sharma et al., 2020; An & Choi, 2021).

Data analyses. The monthly data collected from all transects during the two years of study period was pooled to obtain total richness and various diversity estimates of insect assemblages in different selected sites of the study area. Based on distribution and abundance data, the status of recorded insect species was evaluated into six categories: very rare (VR) when recorded with 1-5 individuals in a study site, rare (R) when recorded with 6–10 individuals in one or two study sites, locally common (LC) when found with more than 10 individuals at a particular study site, uncommon (UC) when recorded with 11-50 individuals in two to four study sites, common (C) when found in average numbers in multiple study sites and very common (VC) when found in high numbers across six to eight study sites (Verma, 2021). In order to represent the distribution pattern rank-abundance curves were made after log transforming the abundance data of insect assemblages in different study sites (Magurran, 2004). For representation of the sampling efforts individual-based rarefaction curves (Gotelli & Colwell, 2001), were made using the software PAST 3.04 (Hammer et al., 2001). Using monthly census data collected during the two years of survey period as the replicates, comparisons of total species richness and abundance across study sites were done by one-way analysis of variance (ANOVA), followed by pair-wise multiple comparisons through Tukey's HSD post-hoc tests at the 5% level of significance in the software SPSS (Version 24).

Alpha diversity measures such as Shannon's Index (H_S) for species diversity (Shannon & Weaver, 1949) given as $H_S = -\sum pi\ ln\ pi$, where pi is the proportional abundance of the species *i*, Margalef's Index (H_M) for species richness (Margalef, 1972) given as $H_M = S - 1/ln\ N$, where *S* is number of species and *N* is number of individuals and Simpson's Index (D_S) for species dominance (Simpson, 1949) given as $D_S = \sum (Ni/N)^2$, where *Ni* is the number of individuals species *i* and *N* is the total abundance of all species were calculated for determining the assemblage structure and diversity of insects in the study area. Beta diversity measure namely, Whittaker's Index given as $\beta_W = a/b - 1$, where a is the total number of species and *b* is the mean number of species was calculated across selected sites for determining the heterogeneity of insect assemblages in the study area (Whittaker, 1960; Magurran, 2004). The alpha and beta diversity measures were calculated in the software PAST 3.04 (Hammer et al., 2001). A Non-metric Multi-dimensional Scaling (NMDS) plot based on Bray-Curtis similarity was constructed to determine the interdependence of insect assemblages in different study sites using the software PAST 3.04 (Hammer et al., 2001). Identified ecosystem services provided by recorded species under different insect orders were tabulated into four major ecosystem services viz. provisioning, regulating, supporting and cultural.

RESULTS

A total of 16,939 individuals of 230 insect species belonging to 47 families and nine taxonomic orders viz., Lepidoptera (48.69% species), Coleoptera (18.26%), Hymenoptera (10%), Odonata (9.56%), Orthoptera (8.26%), Hemiptera (2.17%), Diptera (1.73%), Isoptera (0.86%) and Neuroptera (0.43%) were recorded during the study period (Appendix 1). Lepidoptera was the most dominant and abundant order (72.15% individuals), followed by Coleoptera (11.34%), Hymenoptera (5.98%), Odonata (5.13%), Orthoptera (4.30%), Hemiptera (0.41%), Diptera (0.41%), Isoptera (0.21%), and Neuroptera (0.03%). Thus, based on the relative number of species and individuals, Lepidoptera, Coleoptera, Hymenoptera, Odonata and Orthoptera were the major insect orders in the study area. About 23 species were recorded as very common, 96 species were common, 71 species were uncommon and 14 species were locally common, while 13 species each were rare and very rare in the study area (Appendix 1). The individual based rarefaction curves were steeper and upper asymptote for insect assemblages in each study sites (Fig. 2). The early asymptotic curves were attained by S1, S2, S6 and S7, while the curves for S3, S5, S4 and S8 attained an asymptote later. As per one-way ANOVA, species richness and abundance in selected study sites differed significantly (Richness: $F = 8.062$; $df = 7, 184$ and $P < 0.005$, Abundance: $F = 7.605$; $df = 7, 184$ and $P < 0.005$). Post-hoc tests resulted in the highest insect richness and abundance for S3 and S5 while lowest for S1, S2, S6 and S7 (Fig. 3). No significant differences were found within S3, S5, S4 and S8.

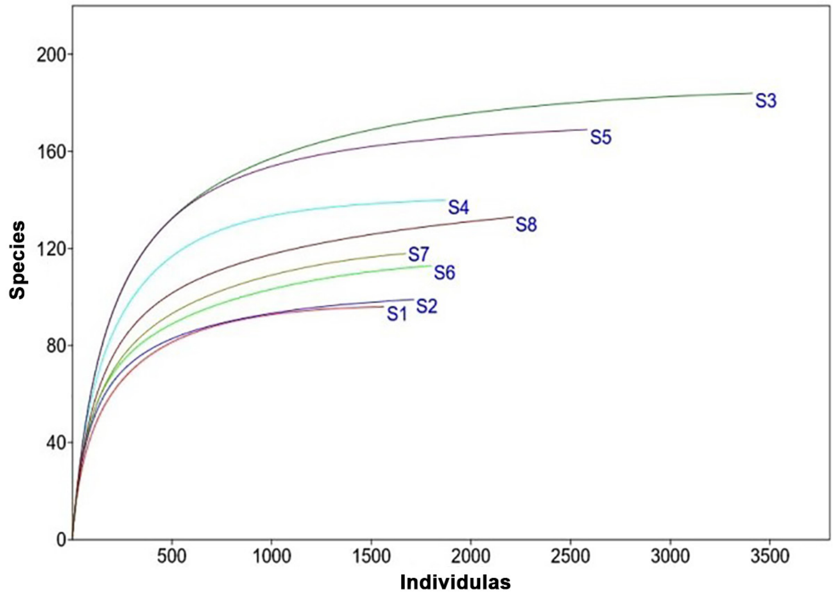

Figure 2. Sample based individual rarefaction curves for insect assemblages recorded in various study sites.

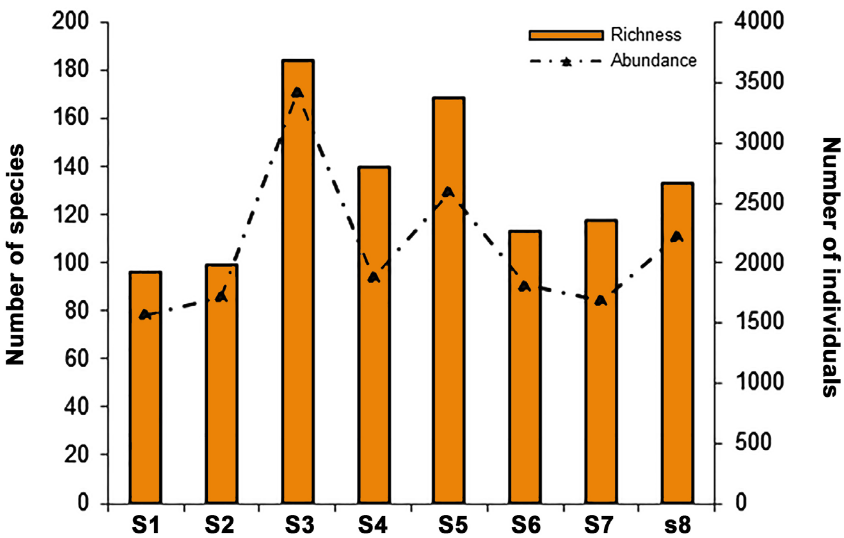

Figure 3. Species richness and abundance of insect fauna recorded in various study sites during 2018–2020.

Rank-abundance plots resulted in gentle curves indicating a more or less even distribution pattern of insect assemblages in different study sites (Fig. 4). The relatively less steeper curves indicated high diversity and richness in S3 and S5, while least diversity resulted in more steeper curves for S1 and S2. The highest Shannon's species diversity (H_S) was recorded in S3, followed by S5, S4, S8, S6, S7, S2 and S1 (Table 2). The highest Margalef's species richness (H_M) was recorded in S3, followed by S5, S4, S8, S7, S6, S2 and S1. Species dominance was the highest in S5 (D_S = 0.987), while the lowest in S1 (D_S = 0.969).

High beta diversity was recorded within S6 and S7 (β_W = 0.428), S6 and S3 (β_W = 0.414), S6 and S5 (β_W = 0.397), S6 and S2 (β_W = 0.396) (Table 3). On the other hand, beta diversity was low when S3 compared with S5 (β_W = 0.150), S7 compared with S8 (β_W = 0.171), S3 compared with S4 (β_W = 0.209), and S4 compared with S5 (β_W = 0.216). The NMDS analysis demonstrated the impact of varied ecological conditions in structuring the patterns of insect assemblages across different study sites (Fig. 5). The plot depicted that the insect assemblage in S6 was much distinct than in other study sites. S3 and S5 showed much similarity and unique species composition. Similarly, the insect assemblages in S7 and S8 resembled each other.

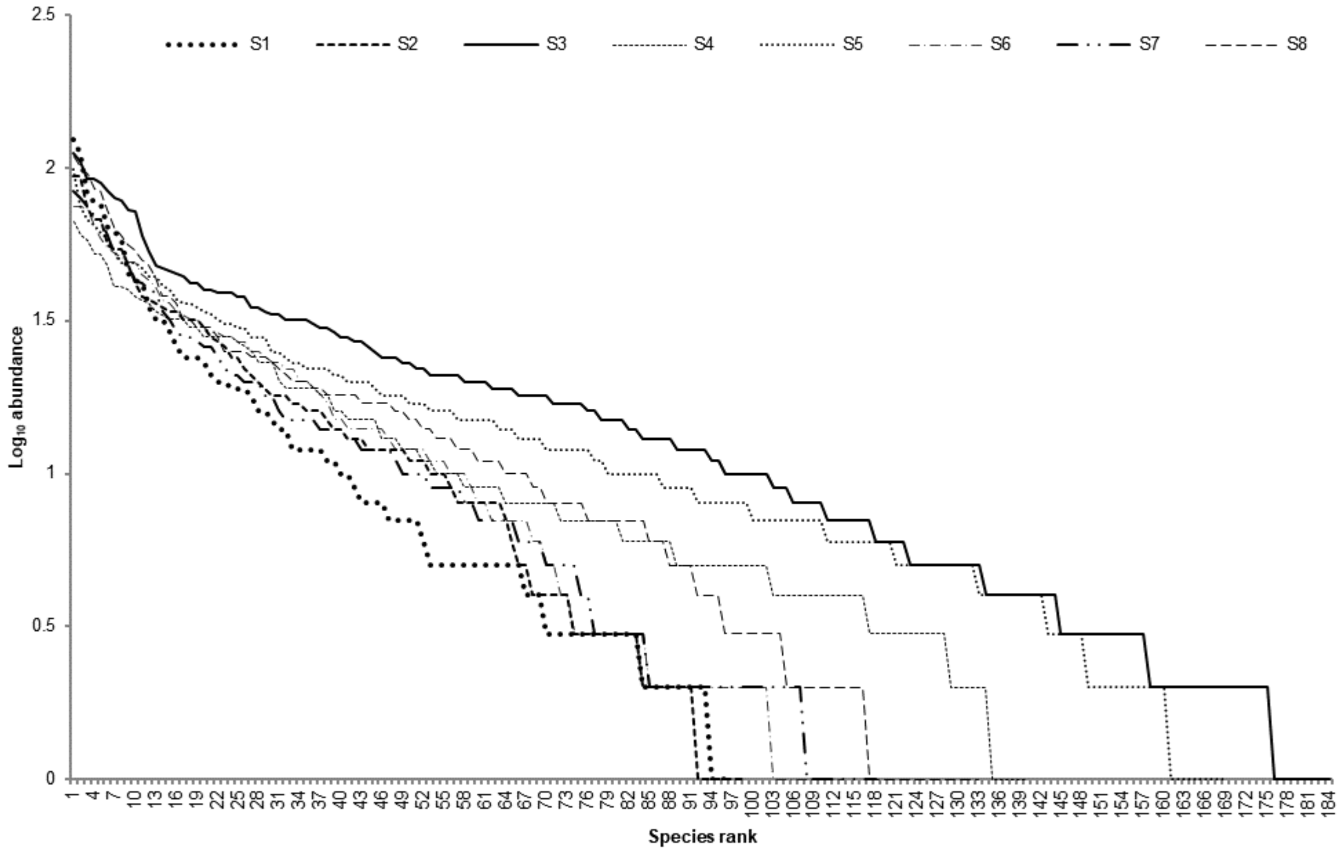

Figure 4. Rank abundance curves of insect fauna recorded in various study sites during 2018–2020.

Table 2. Values of alpha diversity indices for insect fauna recorded in various study sites during 2018–2020.

Diversity measures	Study sites							
	S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*
Shannon's diversity (H_S)	3.912	4.087	4.710	4.521	4.701	4.197	4.180	4.310
Margalef's richness (H_M)	12.90	13.15	22.49	18.43	21.37	14.92	15.74	17.12
Simpson's dominance (D_S)	0.969	0.977	0.987	0.985	0.987	0.980	0.978	0.980

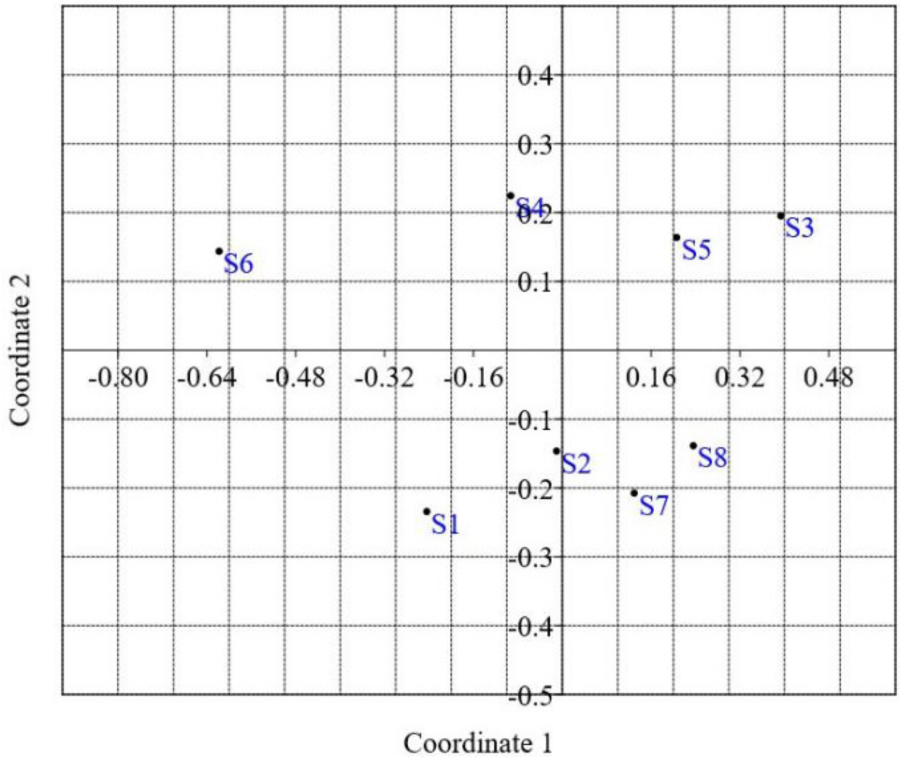

Figure 5. Non-metric Multi-dimensional Scaling (NMDS) plot based on Bray-Curtis similarity for insect fauna recorded in various study sites during 2018–2020.

Table 3. Matrix of Whittaker's index (β_W) for insect assemblages recorded in various study sites during 2018–2020.

	S1	***S2***	***S3***	***S4***	***S5***	***S6***	***S7***	***S8***
S1	0							
S2	0.3025	0						
S3	0.3785	0.3427	0					
S4	0.2881	0.3221	0.2098	0				
S5	0.3434	0.3432	0.1501	0.2168	0			
S6	0.2918	0.3962	0.4141	0.3122	0.3971	0		
S7	0.3457	0.2903	0.2715	0.2480	0.2682	0.4285	0	
S8	0.3799	0.3189	0.2365	0.2893	0.2516	0.3983	0.1713	0

β_W ranges between 0 to 1, with higher numbers indicating greater beta diversity

About 69.13% of the total recorded species were identified for their provisioning services in form of wildlife nutrition, and goods and products, about 23.91% species were identified for their regulating services in form of pest and fungus control, soil formation and compaction, and about 61.30% species were identified for their supporting services in form of pollination, decomposition and seed dispersal (Table 4). About 62.17% species were identified for their cultural services in form of tourism attraction, bio-indication, symbolism and legal protection for biodiversity conservation. Butterflies (Lepidoptera), and dragonflies and damselflies (Odonata) due to their attractive and charismatic appearance hold the immense potential for entomo-tourism in the study area. Species belonging to orders Lepidoptera, Odonata and Coleoptera are useful for their bio-indicative roles in assessing ecological parameters such as habitat structure and modifications, human disturbance and contamination, biodiversity levels and patterns.

Table 4. Number of species under total insect orders identified for mediating various ecosystem services in the Nandhour Landscape.

Ecosystem services	Lepidoptera	Coleoptera	Hymenoptera	Odonata	Orthoptera	Hemiptera	Diptera	Isoptera	Neuroptera	Total
Provisioning	106	23	5	0	19	4	0	2	0	159
Wildlife nutrition	106	23	2	0	19	4	0	2	0	156
Goods and products	0	0	3	0	0	0	0	0	0	3
Regulating	0	23	5	22	0	1	1	2	1	55
Pest control	0	15	5	22	0	1	1	0	1	45
Fungus control	0	5	0	0	0	0	0	0	0	5
Soil formation and compaction	0	7	0	0	0	0	0	2	0	9
Supporting	92	20	23	1	0	0	3	2	0	141
Pollination	92	7	22	1	0	0	3	0	0	125
Decomposition	0	13	2	0	0	0	0	2	0	17
Seed dispersal	0	7	2	0	0	0	0	0	0	9
Cultural	112	9	0	22	0	0	0	0	0	143
Tourism services	89	0	0	22	0	0	0	0	0	111
Bio-indication	112	9	0	22	0	0	0	0	0	143
Symbolic and legally protected	10	0	0	0	0	0	0	0	0	10

The Common Peacock Butterfly (*Papilio bianor*) recently designated as the State Butterfly of Uttarakhand has symbolic importance and can be used as flagship taxa in conservation programs. As per the Indian Wildlife (Protection) Act 1972, nine species were found legally protected under different schedules. Butterflies namely, *Papilio clytia* (Papilionidae), *Castalius rosimon* (Lycaenidae), *Neptis sankara* (Nymphalidae) are listed under Schedule I, *Cepora nerrisa*, *Eurema andersonii* (Pieridae), *Lampides boeticus* (Lycaenidae), *Libythea lepita* (Nymphalidae) are listed under Schedule II, and *Euploea core*, *Euploea mulciber* (Nymphalidae) are listed under Schedule IV. These legally protected species play crucial role in biodiversity conservation (Anonymous, 2006).

DISCUSSION

Information on distribution and diversity of vertebrates is generally available, but such information on insect fauna was sorely lacking from the NL located in an eco-sensitive zone of the TAL. Therefore, the present study highlighted the presence of rich insect diversity of 230 species under nine orders which play a key role in dynamics and regulation of many ecosystem services and must be preserved for maintaining the genetic diversity in different ecosystems of the protected landscape. The reported species richness constituted 5.57% of the total species known from Uttarakhand (Chandra, 2011). Order Lepidoptera was the most species rich, followed by Coleoptera which is in accordance with previous studies conducted in different forest ecosystems (Joshi et al., 2008; Park et al., 2013; Verma & Arya, 2020). In contrast, few studies have also reported the pre-dominance of Coleoptera among insect communities (Balakrishnan et al., 2014; Singh et al., 2021).

The overall values of alpha diversity indices were moderately high for insect assemblages recorded in various habitats of the study area. The Shannon's species diversity (H_S) ranged between 3.91–4.71, Margalef's richness (H_M) between 12.90–22.49 and Simpson's dominance (D_S) between 0.969–0.987, indicating the success-fullness of conservation of eco-fragile habitats in supporting high insect diversity and richness. In comparison to studies on insect biodiversity across the globe, Joshi et al. (2008)

recorded 122 species under eight insect orders and H_S between 3.61–5.42 from different elevations of the Pindari Forest in Western Himalaya, India. Chung et al. (2013) recorded 113 insect species and H_S between 3.73–4.61 from the Bukit Hampuan Forest Reserve in Sabah, Malaysia. Balakrishnan et al. (2014) reported 929 insect species under six orders and H_S between 3.69–4.95 in different coastal habitats of Tamil Nadu, southeast coast of India. Najar and Bashir (2016) reported H_S between 2.04–2.39, H_M between 1.81–2.39 and D_S between 0.865–0.900 of 15 species under seven orders from meadows and agriculture fields of Doodhpathri in Budgam, Jammu and Kashmir. Phauk et al. (2019) documented Shannon's diversity (H_S = 4.20) of 147 morpho-species under 12 insect orders from different biodiverse habitats of Kulen Promtep Wildlife Sanctuary in Cambodia. Chung et al. (2020) recorded 73 insect species and H_S between 3.98–4.37 from the Tenompok Forest Reserve in Sabah, Malaysia. Verma and Arya (2020) recorded H_S = 4.55 and H_M = 16.01 of 140 species under seven orders from the Proposed Multipurpose Project at Pancheshwar in the Western Himalaya. Singh et al. (2021) reported 156 species of insects under five orders, and H_S = 1.52 and H_M = 0.79 from the Parvati Aranga Bird Sanctuary in Gonda District, Uttar Pradesh, India. Such differences in species diversity and richness are due to ecological distinctiveness of geographical sites, varied sampling size and efforts of surveyors.

The insect species richness and abundance were the highest in dense moist riverine forest (S3) and open dry riverine forest (S5), while the least in plantation forest (S2) and agricultural land (S1). The moist bhabar sal forest (S4), moist mixed deciduous forest (S8), subtropical chir pine forest (S6) and moist Shiwalik sal forest (S7) were associated with moderate levels of diversity and richness patterns. These findings clearly indicated that insect assemblages in terrestrial ecosystems are strongly influenced by the landscape variables such as land-use pattern and habitat structure which generate spatial differences in the availability of resources in discrete habitats (Sharma et al., 2020). The results also concurred with the studies reporting maximum diversity and richness of different groups of insects in riverine forests or natural habitats, while the minimum in plantation forest and habitats disturbed or managed by humans (Davis et al., 2001; Bhargav et al., 2009; Arya et al., 2020). Forest habitats provide diverse food resources and congenial living environment, while habitat simplification caused by forest disturbance poses adverse impacts on insect assemblages (Davis et al., 2001; Albert et al., 2021). Moreover, the riverine ecosystems usually have greater environmental heterogeneity and complexity, and provide unique vegetation and large quantities of diverse resources in form of adequate food supply, better mating and ovipositioning sites, safety from predation and low disturbance, hence are important priority sites for insect conservation (Bhargav et al., 2009; Medina et al., 2020; An & Choi, 2021). Natural forests are also known to preserve forest specialist or dispersal limited species of insects (Sharma et al., 2020; Albert et al., 2021; Stanbrook et al., 2021). On the other hand, landscape homogenization due to agricultural intensification and declines in soil properties due to traditional agricultural pest-management practices result in reduced diversity and local extinctions of insect assemblages (Archaux et al., 2018), and organic farming is known to support relatively higher levels of biodiversity (Bengtsson et al., 2005; Mone et al., 2014). Therefore, it is here suggested that the organic farming methods to mitigate the ecological damages caused by agricultural pesticides and contamination must be encouraged in the NL.

The beta diversity patterns indicated the presence of heterogeneous insect species compositions in different study sites, which is due to pristine ecological conditions and overall spatial heterogeneity of the NL covered by tropical moist deciduous to subtropical broad leaved forests. Species compositions were fairly homogeneous within riverine forests (S3 and S5), and within moist Shiwalik and mixed deciduous sal forest (S7 and S8). NMDS also showed a distinct structure and composition in the highly anthropized natural environments (S1 and S2). The subtropical chir pine forest (S6) located at the relatively higher elevation also supported unique insect assemblages in comparison to other study sites experiencing tropical environments at lower elevations. Thus, the results of beta diversity and NMDS clearly indicated the important role of spatial heterogeneity in structuring the rich insect diversity pattern in different study sites of the protected NL. The assemblage heterogeneity of insects associated with spatial heterogeneity and habitat complexity of the landscape corroborates findings from different regions of the world (Barton et al., 2009; Bhargav et al., 2009; Bergman et al., 2018). In particular, heterogeneous landscape structures increase the diversity of ecological niches, which results in high species diversity, including specialist species (Pedley & Dolman, 2020; Habel et al., 2021).

Though biodiversity conservation has gained considerable momentum, immediate actions and assiduous efforts are still required for proper management and propagation of insects inhabiting ecologically fragile habitats of the NL. Disturbances from human activities in the form of increased cultivation and expansion, forest fires, free ranging cattle grazing, illicit felling and logging, collections of fuelwood, fodder and forest products in the study area could pose adverse impacts on insect diversity by directly limiting their food resources and shelter. Fragmentation of natural vegetation and non-scientific management of forests could be detrimental for several species of insects in the study area. Disturbance and land-use change strongly affect insect communities in a forest ecosystem (Davis et al., 2001; Beiroz et al., 2018; Sharma et al., 2020), and lead to their significant reductions with assemblages dominated by few generalist species (Habel et al., 2021). Such changes severely interrupt species ecological interactions and may further lead to reductions in overall biodiversity patterns (Brühl & Zaller, 2019; Seibold et al., 2019) as well as declines in a range of socioeconomic benefits (Sarmiento-Garcés & Hernández, 2021) and ecosystem services (Rodríguez-Echeverry et al., 2018). Therefore, anthropogenic disturbances such as over-exploitation, illegal utilizations, excessive grazing, unauthorized access and non-forestry related developments should be checked and monitored regularly in and around the sanctuary for effective insect conservation.

The present study found a high diversity of 230 species belonging to nine insect orders in various habitat types and eco-fraile habitats which are critically important for conservation of insect diversity and related ecosystem services. The heterogeneous structure, diversity and composition of insects including several unique, legally protected and diverse assemblages indicated the high conservation value and status of the spatial heterogeneity of the NL. Riverine and tropical to sub-tropical forest ecosystems are critical for high species diversity and richness, and should be prioritized for insect conservation and resilient provisioning of ecosystem services. Each group of insects because of their significant contributions to ecosystem functions and services are important in biodiversity conservation and sustainability of the protected eco-fragile landscape of Nandhour. Further detailed studies on ecological interactions and resource preferences of insects should be planned to ensure their long term conservation in the landscape.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution in the paper as follows: M.K.A: Conceptualization and study design, Confirmation of identifications, Supervision; H.C: Investigation, Sorting and collection of data, Identification, Analysis and interpretation of results, Review and editing original draft; A.V: Data collection, Formal analysis, Writing of original draft, Correction of draft after review process. All authors read and approved the final version of the manuscript.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Appendix 1. Distribution of insect species across study sites with their recorded status in the **Nandhour Landscape.**

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
1	**Lepidoptera**	**Hesperiidae**	*Aeromachus stigmata* (Moore)	-	-	-	-	-	+	-	-	LC
2			*Borbo bevani* (Moore)	+	+	+	+	+	+	+	+	C
3			*Parnara guttatus* (Moore)	+	+	+	+	+	+	+	+	C
4			*Potanthus dara* (Kollar)	-	-	+	+	+	-	-	-	UC
5			*Pseudocoladenia fatih* (Kollar)	-	-	+	-	+	-	-	-	UC
6			*Tagiades litigiosa* Moschler	-	-	+	+	-	+	-	+	UC
7			*Telicota bambusae* (Moore)	-	-	+	+	+	-	-	+	UC
8			*Udaspes folus* (Cramer)	+	-	-	-	+	+	-	-	R
9		**Riodinidae**	*Abisara bifasciata* Moore	-	-	+	-	-	-	+	-	R
10			*Dodona durga* (Kollar)	-	-	+	+	+	+	+	+	C
11			*Zemeros flegyas* (Cramer)	-	+	+	-	+	+	+	+	C
12		**Pieridae**	*Catopsilia pomona* (Fabricius)	+	+	+	+	+	+	+	+	VC
13			*Catopsilia pyranthe* (Linnaeus)	+	+	+	+	+	+	+	+	VC
14			*Cepora nerissa* (Fabricius)	-	-	+	-	+	-	-	+	C
15			*Colias erate* (Esper)	-	+	+	-	+	+	-	+	C
16			*Colias fieldii* Menetries	+	+	+	+	+	+	+	+	C
17			*Delias eucharis* (Drury)	+	+	-	-	-	-	-	+	C
18			*Eurema hecabe* (Linnaeus)	+	+	+	+	+	+	+	+	VC
19			*Eurema andersonii* (Moore)	-	-	+	+	+	-	-	-	UC
20			*Eurema blanda* (Boisduval)	-	+	+	+	+	-	-	-	C
21			*Eurema brigitta* (Stoll)	+	+	+	-	+	-	-	-	C
22			*Eurema laeta* (Boisduval)	+	+	+	+	+	+	+	+	VC
23			*Gonepteryx rhamni* (Linnaeus)	+	+	+	+	+	+	+	+	C
24			*Pareronia hippia* (Fabricius)	-	+	+	-	+	-	+	+	C
25			*Pieris brassicae* (Linnaeus)	+	+	+	+	+	+	+	+	VC
26			*Pieris canidia* (Linnaeus)	+	+	+	+	+	+	+	+	VC
27		**Papilionidae**	*Graphium nomius* (Esper)	-	-	+	+	-	-	-	+	UC
28			*Graphium sarpedon* (Linnaeus)	-	-	+	-	+	-	+	+	UC
29			*Papilio bianor* Cramer	-	-	+	+	+	+	-	+	C
30			*Papilio clytia* (Linnaeus)	-	-	+	-	-	-	-	+	UC
31			*Papilio demoleus* (Linnaeus)	+	+	+	+	+	+	+	+	C
32			*Papilio polytes* (Linnaeus)	+	+	+	+	+	+	+	+	VC
33			*Papilio protenor* Cramer	-	-	+	+	-	+	-	+	UC

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
34		**Lycaenidae**	*Arhopala amantes* (Hewitson)	-	-	-	-	-	-	+	-	LC
35			*Castalius rosimon* (Fabricius)	-	-	+	-	+	-	-	+	UC
36			*Flos asoka* (de Niceville)	-	-	-	-	-	-	+	-	R
37			*Heliophorus sena* (Kollar)	+	+	+	-	+	+	+	+	VC
38			*Jamides celeno* (Cramer)	+	+	+	-	+	+	+	-	C
39			*Lampides boeticus* (Linnaeus)	+	+	+	+	+	+	+	+	C
40			*Loxura atymnus* (Stoll)	-	-	-	-	+	-	+	+	UC
41			*Pseudozizeeria maha* (Kollar)	+	+	+	+	+	+	+	+	VC
42			*Talicada nyseus* (Guerin-Meneville)	-	-	+	+	-	+	-	-	C
43			*Tarucus nara* (Kollar)	-	-	+	-	+	-	-	-	R
44			*Zizeeria karsandra* (Moore)	+	+	+	+	+	+	+	+	C
45			*Zizina otis* (Fabricius)	+	+	+	+	-	-	-	-	UC
46			*Zizula hylax* (Fabricius)	-	+	-	-	-	-	-	-	LC
47		**Nymphalidae**	*Acraea issoria* (Hubner)	-	-	+	-	+	+	-	+	UC
48			*Aglais caschmirensis* (Kollar)	+	+	+	+	+	+	+	+	C
49			*Ariadne merione* (Cramer)	+	+	+	+	+	+	+	+	C
50			*Athyma cama* Moore	-	-	+	-	+	-	-	+	UC
51			*Athyma perius* (Linnaeus)	-	-	+	-	-	-	+	+	UC
52			*Athyma zeroca* Moore	-	-	+	-	-	-	-	-	VR
53			*Charaxes agrarius* Swinhoe	-	-	-	-	+	-	-	-	R
54			*Charaxes bharata* Felder & Felder	-	-	+	-	+	-	-	-	UC
55			*Cyrestis thyodamas* Boisduval	-	+	-	-	+	+	-	+	UC
56			*Danaus chrysippus* (Linnaeus)	+	+	+	+	+	+	+	+	C
57			*Danaus genutia* (Cramer)	+	+	+	+	+	+	+	+	C
58			*Euploea core* (Cramer)	+	+	+	+	+	+	+	+	VC
59			*Euploea mulciber* (Cramer)	-	+	+	-	+	-	+	+	C
60			*Euthalia aconthea* (Cramer)	+	+	-	-	+	-	-	+	UC
61			*Hestinalis nama* (Doubleday)	-	-	+	-	+	-	-	-	UC
62			*Hypolimnas bolina* (Linnaeus)	-	+	+	+	+	-	+	+	C
63			*Junonia almana* (Linnaeus)	-	+	+	+	+	-	-	+	C
64			*Junonia atlites* (Linnaeus)	-	+	+	-	+	-	-	+	C
65			*Junonia iphita* (Cramer)	+	+	+	+	+	+	+	+	VC
66			*Junonia lemonias* (Linnaeus)	+	+	+	+	+	+	+	+	VC

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
67			*Junonia orithya* (Linnaeus)	+	+	+	+	+	+	+	+	C
68			*Kallima inachus* (Doyere)	-	-	+	-	+	-	-	-	UC
69			*Kaniska canace* (Linnaeus)	-	-	-	+	-	+	-	-	UC
70			*Lethe confusa* Aurivillius	-	-	-	-	+	-	-	-	VR
71			*Lethe rohria* (Fabricius)	-	-	-	+	-	+	-	-	UC
72			*Libythea lepita* Moore	-	-	-	-	-	+	-	+	UC
73			*Melanitis leda* (Linnaeus)	+	+	+	-	+	+	+	+	C
74			*Mycalesis perseus* (Fabricius)	-	+	-	+	-	+	-	-	UC
75			*Neptis hylas* (Linnaeus)	-	+	+	+	+	+	+	+	C
76			*Neptis sankara* (Kollar)	+	-	+	+	+	-	-	-	UC
77			*Neptis sappho* (Pallas)	-	-	+	+	-	+	-	+	C
78			*Pantoporia hordonia* (Stoll)	-	-	+	-	+	-	+	+	UC
79			*Parantica aglea* (Stoll)	+	+	+	+	+	+	+	+	C
80			*Phalanta phalantha*(Drury)	+	+	+	+	+	-	+	+	C
81			*Symbrenthia lilaea* Moore	-	-	+	+	+	+	-	+	C
82			*Tirumala limniace* (Cramer)	+	+	+	+	+	-	+	+	C
83			*Vagrans egista* (Cramer)	-	-	+	-	+	-	-	-	UC
84			*Vanessa cardui* (Linnaeus)	-	+	+	+	+	+	-	-	C
85			*Vanessa indica* (Herbst)	+	+	+	+	+	+	+	+	LC
86			*Ypthima asterope* (Klug)	-	-	-	-	+	-	-	-	VC
87			*Ypthima huebneri* Kirby	+	+	+	+	+	+	+	+	LC
88			*Ypthima nareda* (Kollar)	-	-	-	-	-	+	-	-	UC
89			*Ypthima nikaea* Moore	-	-	-	+	-	+	-	-	UC
90		**Erebidae**	*Creatonotos transiens* Walker	-	-	+	-	-	-	-	+	UC
91			*Cyana bellissima* (Kollar)	-	+	+	+	+	-	+	+	C
92			*Cyana detrita* Walker	+	+	+	-	+	+	+	+	VC
93			*Eressa confinis* (Walker)	+	+	+	+	+	-	-	-	C
94			*Machrobrochis prasena* (Moore)	-	-	+	-	+	-	-	-	UC
95			*Nyctemeres adversata* Schaller	-	-	+	+	+	-	-	-	UC
96			*Syntomoides imaon* Cramer	+	+	+	-	+	+	+	+	C
97			*Vamuna remelana* (Moore)	-	-	-	-	+	-	-	-	LC
98			*Erebus caprimulgus* (Fabricius)	-	-	+	-	+	-	-	-	UC
99			*Fodina pallula* Guenee	-	-	-	-	-	+	-	+	UC
100			*Spirama retorta* Clerck	-	-	+	-	-	-	-	-	VR

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
101			*Trigonodes hyppasia* Cramer	-	-	+	-	-	-	-	-	VR
102			*Episteme adulatrix* (Kollar)	-	-	+	-	+	-	-	-	UC
103		**Crambidae**	*Bradina diagonalis* (Guenee)	+	-	+	-	+	-	-	-	UC
104			*Cnaphalocrocis medinalis* (Guenee)	+	+	+	+	+	-	+	+	VC
105			*Spoladea recurvalis* (Fabricius)	+	+	+	+	+	-	+	+	VC
106			*Tyspanodes linealis* (Moore)	-	-	+	-	+	-	-	-	UC
107		**Sphingidae**	*Daphnis nerii* (Linnaeus)	-	-	+	-	-	-	-	-	VR
108			*Macroglossum nycteris* (Kollar)	-	-	+	-	-	+	-	-	UC
109			*Theretra nessus* (Drury)	-	-	-	-	-	+	-	-	LC
110		**Eupterotidae**	*Eupterote* sp.	-	-	-	-	-	-	+	+	UC
111		**Geometridae**	*Ourapteryx clara* (Butler)	-	-	-	-	+	-	-	+	UC
112		**Saturnidae**	*Actias selene* Hubner	-	-	+	-	+	-	-	-	UC
113	**Coleoptera**	**Scarabaeidae**	*Anomala antiqua* (Gyllenhal)	+	+	+	+	+	+	+	+	C
114			*Anomala decipiens* (Arrow)	+	+	+	+	-	-	+	+	C
115			*Catharsius capucinus* (Fabricius)	-	-	+	-	+	-	+	+	UC
116			*Copris sacontala* Redtenbacher	-	-	-	-	+	-	-	-	VR
117			*Gymnopleurus miliaris* (Fabricius)	-	-	+	+	+	-	+	+	UC
118			*Heliocopris bucephalus* (Fabricius)	-	-	-	-	+	-	-	-	R
119			*Lepidiota albistigma* Burmeister	-	-	+	-	+	-	-	+	UC
120			*Melolontha cuprescens* Blanchard	-	-	+	-	-	-	-	-	VR
121			*Onitis falcatus* Wulfen	-	-	+	-	+	-	-	-	R
122			*Onthophagus dama* (Fabricius)	+	-	+	+	+	-	+	+	C
123			*Oryctes nasicornis* (Linnaeus)	-	+	+	-	+	-	-	+	UC
124			*Popillia* sp.	-	-	-	-	+	-	-	-	LC
125			*Protaetia pretiosa* (Nonfried)	-	+	+	-	+	-	+	+	C
126		**Coccinellidae**	*Adalia* sp.	-	-	-	-	-	+	-	-	VR
127			*Chilocorus infernalis* (Mulsant)	-	-	-	-	-	+	-	-	VR
128			*Coccinella septempunctata* Linnaeus	+	+	+	+	+	+	+	+	VC
129			*Coccinella transversalis* (Fabricius)	-	+	+	-	-	-	+	+	C
130			*Leis dimidiata* (Fabricius)	-	-	+	-	-	-	-	+	UC
131			*Menochilus sexmaculatus* (Fabricius)	-	-	+	-	-	-	-	-	R
132			*Psyllobora vigintiduopunctata* (Linnaeus)	-	-	+	-	-	-	-	-	R
133		**Carabidae**	*Calomera chloris* Hope	-	-	+	-	-	-	-	-	LC
134			*Chlaenius* sp.	-	+	+	+	-	-	+	-	UC

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
135			*Cicindela flexuosa* (Fabricius)	+	-	+	-	-	-	-	+	UC
136			*Cosmodela intermedia* (Chaudoir)	-	-	+	-	-	-	-	-	LC
137			*Ophonus rufibarbis* (Fabricius)	-	-	+	+	+	-	+	+	C
138			*Scarites sulcatus* Olivier	-	-	-	-	-	+	-	-	VR
139		**Chrysomelidae**	*Colasposoma metallicum* (Clark)	-	-	-	-	-	+	-	-	LC
140			*Charidotella* sp.	-	-	-	-	-	+	-	-	LC
142			*Corynodes peregrinus* (Fuessly)	-	-	+	-	-	+	-	+	UC
142			*Meristata trifasciata* Hope	-	-	-	-	-	+	-	-	LC
143			*Zygogramma bicolorata* Pallister	+	+	+	+	-	-	+	+	VC
144		**Meloidae**	*Epicauta mannerheimi* (Maklin)	-	-	+	-	-	-	-	-	R
145			*Epicauta* sp.	-	-	-	-	-	+	-	-	VR
146			*Hycleus* sp.	-	-	-	-	-	+	-	-	R
147			*Mylabris cichorii* (Linnaeus)	+	-	+	+	-	-	+	+	C
148			*Mylabris pustulata* (Thunberg)	-	+	+	+	-	+	+	+	C
149		**Elateridae**	*Adelocera* sp.	-	-	+	-	-	-	-	-	VR
150			*Heteroderes macroderes* Candeze	-	-	-	-	-	-	-	+	VR
151		**Cerambycidae**	*Dorysthenes huegelii* (Redtenbacher)	-	-	-	-	-	-	+	-	R
152		**Lucanidae**	*Metopodontus biplagiatus* (Westwood)	-	-	-	-	-	-	+	+	UC
153		**Tenebrionidae**	*Gonocephalum* sp.	-	-	+	-	-	-	-	-	R
154		**Hydrophilidae**	*Hydrophilus triangularis* Say	-	-	+	-	-	-	-	-	LC
155	**Hymenoptera**	**Andrenidae**	*Andrena cineraria* (Linnaeus)	+	+	+	+	+	+	-	-	UC
156		**Apidae**	*Amegilla cingulata* (Fabricius)	+	+	+	+	+	-	+	+	C
157			*Apis cerana* Fabricius	-	-	+	+	+	+	+	+	C
158			*Apis dorsata* Fabricius	+	+	+	+	+	+	+	+	VC
159			*Apis florea* Fabricius	+	-	+	+	+	+	+	+	C
160			*Bombus haemorrhoidalis* Smith	+	+	+	+	+	+	+	-	C
161			*Xylocopa auripennis* Lepeletier	+	-	+	+	+	+	+	+	C
162		**Formicidae**	*Camponotus compressus* (Fabricius)	+	+	+	+	+	-	+	+	C
163			*Polyrhachis simplex* Mayr	+	-	+	+	+	+	+	+	C
164		**Halictidae**	*Nomia curvipes* (Fabricius)	+	-	-	+	-	+	-	-	UC
165			*Halictus* sp.	+	+	+	+	-	+	-	-	UC
166		**Pompilidae**	*Pepsis* sp.	+	-	+	+	+	+	-	-	UC
167		**Scoliidae**	*Phalerimeris* sp.	+	+	+	+	+	+	+	+	UC
168			*Scolia affinis* Guerin	+	+	+	+	+	+	+	+	C

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
169			*Scolia* sp.	-	-	+	+	+	-	+	+	C
170		**Sphecidae**	*Ammophila atripes* Smith	-	+	+	+	+	-	+	+	C
171			*Sceliphron* sp.	+	+	+	+	+	+	+	+	C
172			*Sphex* sp.	+	-	+	+	+	+	+	+	C
173		**Vespidae**	*Labus* sp.	-	+	+	+	-	+	-	-	UC
174			*Polistes dorsalis* (Fabricius)	+	+	+	+	+	+	+	+	C
175			*Polistes stigma* (Fabricius)	+	-	+	+	+	+	+	+	C
176			*Vespa velutina* (Lepeletier)	+	-	+	+	+	+	+	-	C
177			*Vespula flaviceps* (Smith)	+	+	+	+	+	+	-	-	C
178	**Odonata**	**Libellulidae**	*Acisoma panorpoides* Rambur	+	-	+	+	+	+	-	-	C
179			*Aethriamanta brevipennis* (Rambur)	+	+	+	+	+	+	+	+	C
180			*Brachythemis contaminata* (Fabricius)	+	+	+	+	+	+	+	+	C
181			*Crocothemis servilia* Drury	+	+	+	+	+	+	+	+	VC
182			*Orthetrum glaucaum* (Brauer)	+	+	+	+	+	+	+	+	C
183			*Orthetrum pruinosum* (Burmeister)	+	+	+	+	+	+	+	+	VC
184			*Orthetrum sabina* (Drury)	+	-	+	+	+	-	+	-	C
185			*Orthetrum taeniolatum* (Schneider)	+	+	+	+	+	+	+	+	C
186			*Orthetrum triangulare* (Selys)	+	-	+	+	+	+	+	+	C
187			*Palpopleura sexmaculata* (Fabricius)	+	-	-	+	-	+	-	-	UC
188			*Pantala flavescens* (Fabricius)	+	-	+	+	+	+	+	+	C
189			*Rhodothemis rufa* (Rambur)	+	-	+	+	+	+	-	-	C
190			*Trithemis festiva* (Rambur)	-	+	+	+	+	-	+	-	C
191			*Trithemis pallidinervis* (Kirby)	-	-	+	+	+	-	+	-	UC
192		**Coenagrionidae**	*Ceriagrion coromandelianum* (Fabricius)	+	+	-	+	+	+	-	-	C
193			*Ischnura rubilio* Selys	+	+	+	+	+	-	-	-	C
194			*Pseudagrion australasiae* Selys	+	-	+	+	+	-	-	-	UC
195			*Pseudagrion rubriceps* Selys	-	+	+	+	+	-	-	-	UC
196		**Calopterygidae**	*Neurobasis chinensis* (Linnaeus)	+	+	+	+	+	+	+	+	C
197		**Chlorocyphidae**	*Aristocypha fenestrella* Rambur	-	-	+	+	+	+	+	+	C
198			*Aristocypha quadrimaculata* (Selys)	+	-	+	+	+	+	+	+	C
199			*Paracypha unimaculata* (Selys)	-	-	+	+	+	-	-	-	UC
200	**Orthoptera**	**Acrididae**	*Acrida exaltata* (Walker)	+	+	+	+	+	+	+	+	UC

Appendix 1. Continue

S. No.	Order	Family	Species name	Distribution across study sites								Status
				S1	S2	S3	S4	S5	S6	S7	S8	
201			*Ceracris fasciata* (Brunner von Wattenwyl)	+	+	+	+	+	+	+	+	C
202			*Choroedocus illustris* (Walker)	-	+	+	+	+	-	+	-	C
203			*Cyrtacanthacris tatarica* (Linnaeus)	-	-	+	+	+	-	-	-	UC
204			*Diabolocatantops innotabilis* (Walker)	-	+	+	+	+	-	+	+	C
205			*Gastrimargus africanus* (Saussure)	-	-	+	+	+	-	+	+	VC
206			*Oxya* sp.	-	-	+	+	+	-	-	-	UC
207			*Paraconophyma scabra* (Walker)	+	-	+	+	+	-	+	+	C
208			*Phlaeoba antennata* (Brunner von wattenwyl)	+	-	-	-	+	+	-	-	UC
209			*Phlaeoba panteli* Bolivar	-	-	+	+	+	-	+	-	UC
210			*Sphingonotus longipennis* Saussure	-	-	+	+	+	-	+	+	C
211			*Tylotropidius varicornis* (Walker)	-	-	-	+	+	+	-	-	C
212			*Xenocatantops humilis humilis* (Serville)	-	+	+	+	+	-	+	+	VC
213		**Gryllidae**	*Gryllus*sp.	+	+	+	+	+	+	+	+	C
214			*Teleogryllus testaceus* (Walker)	-	-	+	+	+	-	+	-	C
215		**Pyrgomorphidae**	*Chrotogonus trachypterus* (Blanchard)	-	-	+	+	+	-	+	+	UC
216			*Aularches miliaris* (Linnaeus)	-	+	+	+	+	+	+	+	C
217		**Tettigoniidae**	*Himertula kinneari* (Uvarov)	-	+	+	+	+	-	+	+	C
218			*Phaneroptera sp.*	+	-	-	+	+	+	-	-	UC
219	**Hemiptera**	**Cicadellidae**	*Bothrogonia* sp.	+	+	+	+	+	+	-	-	C
220		**Ceropidae**	*Callitettix versicolor* (Fabricius)	+	-	+	+	+	+	-	-	UC
221			*Cosmoscarta* sp.	-	+	+	+	+	+	+	-	C
222		**Reduvidae**	*Harpactor* sp.	-	+	+	+	+	-	+	+	C
223		**Coreidae**	*Serinetha augur* (Fabricius)	-	-	+	+	+	-	+	+	C
224	**Diptera**	**Bombyllidae**	*Bombylius* sp.	-	-	+	+	+	-	+	-	C
225		**Syrphidae**	*Episyrphus balteatus* (De Geer)	-	+	+	+	+	-	+	+	C
226			*Eristalis tenax* (Linnaeus)	+	-	+	+	+	+	-	+	C
227		**Asilidae**	*Neoitamus* sp.	-	-	+	+	+	-	+	+	C
228	**Isoptera**	**Termitidae**	*Microcerotermes championii* Snyder	-	-	-	+	+	-	+	+	UC
229			*Odontotermes obesus* (Rambur)	-	-	-	+	+	-	+	+	UC
230	**Neuroptera**	**Chrysopidae**	*Chrysoperia carnea* (Stephens)	+	-	-	+	+	+	-	-	UC

Abbreviations: VC = very common, C = common, UC = uncommon, LC = locally common, R = rare, VR = very rare

الگوهای تنوع مکانی حشرات و برونداد زیست‌بوم‌های مرتبط در منطقه محافظت شده ناندور، هند

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چکیـــده: زیستگاه مرتعی ناندور در منطقه ترایی هند با تنوع زیستی غنی و حساس قرار گرفته و تحت عنوان پناهگاه حیات وحش محافظت‌شده، به عملکرد و تنوع زیستی حشرات کمتر مورد مکاشفه قرار گرفته است. این مطالعه با هدف گردآوری اطلاعات تنوع زیستی حشرات و عملکرد آنها در اکوسیستم‌های جنگلی نیمه‌گرمسیری و گرمسیری که به نوبه خود از لحاظ فعالیت بلندمدت برونداد و عملکرد اکوسیستمی اهمیت دارند، انجام شد. در این تحقیق، بر اساس روش‌های نمونه‌برداری استاندارد، ساختار و ترکیب گروه‌های مختلف حشرات به لحاظ تنوع و غنای گونه‌ای در زیرمجموعه‌های مختلف زیستگاه ناندور تعیین شد. به‌علاوه در این تحقیق اهمیت اکولوژیک فون حشرات نیز مورد ارزیابی قرار گرفت. به طور کلی، ۲۳۰ گونه از حشرات متعلق به ۴۷ خانواده از ۹ راسته در زیستگاهای مختلف ثبت شد که از بین آنها بال‌پولکیان به عنوان فراوان‌ترین راسته حشرات هم از لحاظ فراوانی و غنای گونه‌ای شناخته شدند. پس از آنها، حشرات راسته‌های سخت‌بال‌پوشان، بال‌غشاییان، طیاره‌مانندها و دیگر گروه‌ها قرار داشتند. بیشترین مقادیر شاخص‌های غنا و تنوع گونه‌ای در جنگل‌های متراکم و مرطوب و جنگ‌ها باز بستر رودخانه‌ها مشاهده شد، در حالیکه در مناطق کشاورزی و جنگل‌کاری شده، این مقادیر به حداقل رسیده بود. ساختار و ترکیب غیرهمگن نشان‌دهنده اهمیت جنگل‌های طبیعی و ناهمگونی مکانی عمومی در پایداری و نگهداری سطح بالای تنوع حشرات است. حفاظت از تنوع حشرات به لحاظ این‌که گونه‌های متعددی از آنها نقش عملکردی کلیدی در اکوسیستم داشته، بسیار مهم بوده و به فعالیت زیرواحدهای زیستی حساس این منطقه کمک می‌کند.

واژگـان کلیدی: تشدید کشاورزی، خدمت اکوسیستم‌ها، ناهمگونی، تنوع حشرات، چشم‌انداز محافظت شده، غنای گونه‌ای