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Diversity studies on insect pests of high altitudinal transitional zones of North-western Himalayas

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Abstract. *Kumar P, Thakur TS, Deepika, Sharma N. 2022. Diversity studies on insect pests of high altitudinal transitional zones of North-western Himalayas. Nusantara Bioscience 14: 203-210.* Class Insecta constitute a major fauna and comprise many species of economic importance. Due to climate change and increase in temperature, many insect species are changing their habitat considerably and shifting their hosts, which leads to changes in the diversity of insect pests at different altitudinal gradients. High altitude forest cover is not large and massive as plains forest cover, but it supports some of the very important economical tree species like- *Quercus* sp., Himalayan Poplar, *Betula* sp., *Abies pindrow* (Royle ex D.Don) Royle, *Juniper* spp., Birdcherry, Maple, etc. The present study analyzed any change in insect pest incidences and diversity of pest species due to the change in host preferences or climatic patterns. The study was conducted at four selected sites viz. Rohtang area (Kullu Forest Division), Chanshal area (Rohru Forest Division), Sach area (Churah Forest Division), and Indrahar area (Dharamshala Forest Division) of high altitudinal transitional zones of Himachal Pradesh, India, to study insect pest diversity. A total of 32 insect species were recorded during the study period comprised of the insect orders viz., Coleoptera, Hymenoptera, Hemiptera, Orthoptera, Dermaptera, and Lepidoptera. The present investigation led to the finding that species of Coleoptera (beetles) were the most dominant insects attacking trees of the high altitudinal transitional zone, followed by Lepidoptera (Butterflies and moths) and Hemiptera (aphids).

Keywords: Altitude, dominant, habitat, insect pests, transitional zones

INTRODUCTION

Like many other plants, forests and trees are attacked by insect pests and diseases that inflict extensive damage, resulting in poor tree growth, poor timber quality, and, in rare cases, full forest destruction and decline (Sharma 2016). In addition, various forest pests threaten forests and their services worldwide, causing significant ecological and economic losses (Wingfield et al. 2015; Diagne et al. 2021). The most common insect pests can be grouped into three categories: regeneration, defoliators, and bark beetles (Björkman et al. 2015). The fundamental concepts underlying forest insect population dynamics involve top-down (natural enemies) and bottom-up (host plant) forces operating on insect reproductive success and survival. Furthermore, at large population densities, lateral forces (competition) substantially impact population dynamics (Martin et al. 2013).

Insect pests are major limitations on agricultural and forestry output (Pureswaran et al. 2018; Trisnawati et al. 2022). Despite the lack of comparable global estimates for forestry systems (Niquidet et al. 2016), forest pests such as the gypsy moth (*Lymantria dispar* Linnaeus, 1758) in Appalachian Plateau and mountain pine beetle (*Dendroctonus ponderosae* Hopkins, 1902) in western North America are known to have major ecological consequences. These include eradicating indigenous tree species and widespread defoliation and mortality, which disturb ecosystem processes and decrease biodiversity (Fajvan and Wood 1996; Janes et al. 2014).

The current and anticipated challenges posed by phytophagous insect pests are likely to be exacerbated by projected global warming, which may promote pest population growth, increase outbreak frequencies, and facilitate the geographic expansion of many pest species, resulting in greater economic losses and food security threats (Andrew et al. 2013; Thackeray et al. 2016).

Several criteria govern the level of impact of a novel insect or illness, including the pathogen's virulence and the sort of harm caused by the bug (e.g., phloem- or wood-boring, sap-feeding, or defoliation. In addition, other pest characteristics, such as host specificity and reproductive and dispersal potential, as well as characteristics of the host tree, such as dominance in the forest, role in productivity and nutrient cycle, and provisioning of wildlife food and habitat impacts, can all influence the severity and extent of the damage (Lovett et al. 2006).

Except in the tropics, where season length does not change with elevation, decreasing temperature, shortening of the growing season, increasing climatic variability, increasing exposure to sunlight and wind, and, occasionally, decreasing water availability and soil fertility are all common effects of increasing elevation (Pellissier et al. 2014; Rasmann et al. 2014; De Long et al. 2016). Generally, it has been observed that as elevation rises, the diversity and number of plants, insect herbivores, and predators decrease (Pellissier et al. 2012). A mountain range's geological age influences communities along elevational gradients since older mountains allow for greater species colonization and diversification (Schemske and Mittelbach 2017). Additionally, the regional species pool and the species inhabiting a particular mountain range influence local diversity at various elevations (Ricklefs and He 2016). Numerous species of insect herbivores regularly attack plant species across the entirety of their distribution range. These herbivores may differ in their vulnerability to varying environmental conditions, which could lead to variations in their abundance and the amount of harm they cause to focal host plants along environmental gradients (Pratt et al. 2017). A recent study suggested that in addition to critically reevaluating the evidence supporting spatial gradients in plant-insect herbivore interactions, a new mechanistic framework for forecasting the existing patterns should also be developed (Moreira et al. 2018).

The present study has been conducted at four selected sites in the forests of High Altitudinal Zones of the NW Himalayas to investigate insect pest diversity.

MATERIALS AND METHODS

Study area

The study was conducted from April 2016 to March 2021. The survey was carried out in areas of different high altitudinal transitional zones of Himachal Pradesh, India, to study the pest status of insects and collect the insect pests specimens.

The study was conducted at four selected sites viz. Rohtang area (Kullu Forest Division), Chanshal area (Rohru Forest Division), Sach area (Churah Forest Division), and Indrahar area (Dharamshala Forest Division) (Table 1). Insect fauna and pest status were recorded from selected sites covering different altitudes and forest types viz., Himalayan moist temperate forests: 1,500-3,000 m (Both coniferous and broad-leaved species), Sub-alpine forests: 3,000-3,400 m (Birch and Fir), Moist alpine scrubs: 3,000-3,500 m (Rhododendron), Dry alpine scrubs: 3,400m-3,600m (*Junipers* species) and Alpine meadows:>3,600 m (alpine pasture).

Methodology for insect collection

All four sites were regularly visited, and five transects were established at each study site. Insect samples were collected with the help of different insect collection methods such as using a sweep net (diameter 30 cm and 1.5 mm mesh) light trap only for four hours (if required) of all specimens encountered, hand-picking, pitfall trap, beating tray samples, search method (Figure 1, Figure 2) and by line transect method. Five transects have been established in each forest division, and the collection has been made from selected sites. The start points for each transect were chosen using a random number, and there are 10 collection sites on each transect separated by 20-30 m. These collection sites are placed at right angles to the transect. Each forest category has 25 collection sites (15 pitfalls and 10 leaf litter).

Data collection: Four techniques were used to collect data in the collection sites

Leaf litter: In each of the 10 sites, 1 m^2 quadrate was established, and leaf litter was collected into plastic bags and put in Berlese funnels to dry. The beetles and other insects moved to collected tubes and sorted them out for identification and preservation.

Pitfall traps: In each of the 15 collection sites, 5 pitfall traps (8 cm diameter and 10 cm deep) were dug into the soil surface, a total of 75 traps per habitat. The traps were left for 2 days, then another two days were emptied into sample bottles every 48 hours (Samways et al. 1996) and then taken to the laboratory for sorting and identification.

Beating tray samples: Three transects were randomly selected along with 15 collection sites placed at an interval of 10 meters; beetles were obtained by beating plants' leaves and branches, up to 2.0 meters in height, onto the tray. Insects will be collected for sorting and identification.

Light traps: As insects attract toward the light sources, the collection was done near the lamp posts/street lights in the various sites in the eco-development area. Apart from this, several attempts were made to use the light traps.

Hand-picking: Small Coleopteran beetle like Coccinellidae, Chrysomelidae, Curculionidae, Scolytidae, etc., were collected by hand with the help of fine forceps. (Kumar and Thakur 2014; Kumar et al. 2016).

Pitfall traps primarily capture ground-dwelling insects (Lundgren and McCravy 2011). Sweep netting only traps insects residing on plants at vertical levels that the collector can access (McCravy 2018). Therefore, many alternative sampling techniques should be used in a comprehensive investigation (Spafford and Lortie 2013; González et al. 2020).

Table 1. Geographical positions of different localities

Area	Site	Latitude	Longitude
Dharamsala	Triund	32^{0}15’34.50’’	76^{0}21’23.37’’
Dharamsala	Indrahar Pass	32^{0}17’42.21’’	76^{0}23’01.67’’
Dharamsala	Galu Forest	32^{0}14’55.07’’	76^{0}19’18.72’’
Rohru	Larot	31^{0}14’10.97’’	77^{0}56’49.69’’
Rohru	Chanshal Pass	31^{0}11’48.93’’	77^{0}59’20.11’’
Rohru	Dodra	31^{0}11’45.67’’	78^{0}03’13.18’’
Manali	Jagatsukh	32^{0}12’06.50’’	77^{0}12’16.51’’
Manali	Gulaba	32^{0}19’30.03’’	77^{0}11’50.48’’
Manali	Kothi	32^{0}18’52.77’’	77^{0}11’24.76’’
Manali	Marhi	32^{0}20’55.98’’	77^{0}13’05.67’’
Manali	Rohtang Pass	32^{0}22’17.91’’	77^{0}14’47.84’’
Chamba	Sach Pass	33^{0}00’20.89’’	76^{0}14’23.26’’
Chamba	Satrundi	32^{0}59’31.34’’	76^{0}12’36.95’’
Chamba	Tissa	32^{0}49’49.21’’	76^{0}09’03.02’’
Chamba	Devi Kothi	32^{0}54’31.92’’	76^{0}14’05.55’’
Chamba	Bairagarh	32^{0}54’05.48’’	76^{0}09’47.37’’

Figure 1. Assessment of insect-infested trees at high altitude transition zone in Sach Pass area, Himachal Pradesh, India

Figure 2. Monitoring heavy infestation of tent caterpillar-affected Moru oak trees in Sach Pass, Himachal Pradesh, India

Preservation

During field surveys, the freshly collected specimens of butterflies were kept in a triangular paper envelope, whereas specimens like beetles, bugs, and moths were kept in small specimen containers. Insects were pinned by entomological pins of 38 mm in length. In the laboratory, insect specimens were put in a relaxing chamber, followed by pining perpendicularly through the middle of the thorax at a point equidistant between the bases of forewings. Next, the wings were spread using paper stripes (for butterflies and moths. After that, the insect specimens were allowed to dry in desiccators for 2-3 weeks, depending on climatic conditions. Finally, the dried specimens were transferred to airtight insect boxes containing powdered naphthalene balls. A label written with black Indian ink was fixed on each specimen (Arora 1990). This methodology was also followed by Kumar et al. (2015), Thakur and Kumar (2015), and Kumar (2016).

Identification of insects

Insects collected during the survey using various methods were identified and studied taxonomically by comparing the specimens with the authentic identified collections available at Forest Research Institute, Dehradun, India.

Data analysis

Interpretive data analysis was done using Simpson's index and Shannon-Wiener Diversity Index (H) (Shannon-Wiener 1963) to determine the abundance and diversity of insect species. Next, the concentration of dominance (D) was measured by Simpson's Index (Simpson 1949). Finally, the Evenness (E) Index was calculated by Hill (1973).

RESULTS AND DISCUSSION

During the present study, a total of 32 species of insects belonging to 28 genera, 18 families, and 6 orders were collected and identified (Table 2). Of the six orders, Coleoptera was the most represented, with 15 species corresponding to seven families and seven genera, followed by Lepidoptera with 11 species, nine genera, and six families. On the other hand, Orthoptera and Dermaptera were represented by one species. In terms of population abundance, Lepidoptera was the dominating order with 65.15 relative abundance, followed by Coleoptera (30.17), Hemiptera (2.22), Orthoptera (1.15), Hymenoptera (0.84) and Dermaptera (0.45) (Figure 3). A similar pattern was reported by Singh (2013).

High altitudinal plant species like *Betula utilis* D.Don, *Abies pindrow* (Royle ex D.Don) Royle, *Rhododendron* spp., *Prunus cornuta* (Wall. ex Royle) Steud., *Acer* spp., *Quercus* spp., and *Poplar* spp. are mostly affected by the insect pests.

Distribution of insect pests

The amount and distribution of vegetation in forests depend on the nature of the plant community, the regional climate, past management practices, and the invasion of non-native species. These variations are believed to have significant effects on animal diversity, distribution, and migration patterns, and different canopy components are anticipated to have various impacts on functional and trophic guilds (Heidrich et al. 2020; Tinya et al. 2021). That is especially true for insects, which not only have a significant variety of species but also in terms of life strategies and resource consumption. For instance, variations in tree composition may favor some insect groups' diversity while diminishing or having no effect on others (Leidinger et al. 2021). The complexity of the canopy, as measured by the number of plant layers, the distribution of the vegetation, or other comparable classifications, appears to generally favor increased insect abundance (Knuff et al. 2020) and higher species richness as well (Müller et al. 2018).

High-mountain regions are undergoing tremendous change globally (Pörtner et al. 2019). The rapid increase in air temperature in these places, which are often above tree line between 2,000 and 4,000 meters, is the primary indicator of change and has significant effects on glacier cover (McKernan et al. 2018), streamflow (Hotaling et al. 2017), and dissolved oxygen levels (Jacobsen 2020), among other things. Insects (Moret et al. 2016; Wu et al. 2019) and the creatures they interact with are moving upslope due to warming in mountain environments (Guo et al. 2018; Anderson and Wadgymar 2020). High-mountain environments are experiencing a fast change in their insect communities (Shah et al. 2020). A study on the spatial distribution of insect pests was carried out in four sites, i.e., Chanshal (Shimla), Triund (Dharamshala), Rohtang (Kullu), and Sach (Chamba) areas of Himachal Pradesh, during different seasons of the year. In Figure 5, it was observed that there is clear segregation in species as well as population diversity along with altitude gradient, and climatic factors like temperature and relative humidity also play a pivotal role in the spatial distribution of insects in different habitats. Figure 6 shows that the insects specimens collected from different sites of high altitudinal transitional zones, North-western Himalayas

Table 2. List of identified insect

Order	Family	Species	Triund	Chanshal pass	Rohtang pass	Sach pass
Lepidoptera	Nymphalidae	*Junonia iphita* (Cramer, 1779)		√		√
Lepidoptera	Pieridae	*Pieris canidia* (Sparrman, 1768)	√	√	√	√
Lepidoptera	Pieridae	*Pieris brassicae* (Linnaeus, 1758)	√		√	
Lepidoptera	Pieridae	*Pieris napi* (Linnaeus, 1758)	√	√	√	√
Lepidoptera	Noctuidae	*Asota caricae* (Fabricius, 1775)	√	√	√	√
Lepidoptera	Noctuidae	*Thysanoplusia* spp.	√	√	√	√
Lepidoptera	Noctuidae	*Agrotis ipsilon* (Hufnagel, 1766)	√	√	√	√
Lepidoptera	Lasiocampidae	*Malacosoma* sp.	√	√	√	√
Lepidoptera	Erebidae	*Lymantria Concolor* (Walker,1855)	√	√	√	√
Lepidoptera	Notodontidae	*Thaumetopoea processionea* (Linnaeus, 1758)	√	√	√	√
Lepidoptera	Lasiocampidae	*Lasiocampa trifolii* (Denis & Schiffermüller, 1775)			√	
Coleoptera	Scarabaeidae	*Melolontha furcicauda* (Ancey, 1881)	√	√	√	√
Coleoptera	Scarabaeidae	*Clinteria* sp.	√	√	√	√
Coleoptera	Scarabaeidae	*Brahmina comata* (Blanchard, 1851)	√	√	√	√
Coleoptera	Scarabaeidae	*Mimela amphichroma* (Prokofiev & Zorn, 2016)	√		√	√
Coleoptera	Chrysomelidae	*Phratora vulgatissima* (Linnaeus, 1758)	√		√	√
Coleoptera	Scarabaeidae	*Xylotrupes* sp.	√		√	
Coleoptera	Chrysomelidae	*Plagiodera versicolora* (Laicharting, 1781)	√	√	√	√
Coleoptera	Cerambycidae	*Arhopalus rusticus* (Linnaeus, 1758)	√	√	√	√
Coleoptera	Curculionidae	*Curculio glandium* (Marsham, 1802)		√		√
Coleoptera	Coccinellidae	*Coccinella magnifica* (Redtenbacher, 1843)	√	√	√	√
Coleoptera	Dytiscidae	*Cybister tripunctatus* (Olivier, 1795)		√		√
Coleoptera	Carabidae	*Carabus coriaceus* (Linnaeus, 1758)		√		√
Coleoptera	Scarabaeidae	*Xylotrupes beckeri* (Schauffus, 1885)		√		√
Coleoptera	Scarabaeidae	*Hylocereus* sp.			√	
Coleoptera	Curculionidae	Scolytinae				√
Hemiptera	Pentatomidae	*Halyomorpha* sp.	√	√	√	√
Hemiptera	Pentatomidae	*Podisus* sp.		√		
Dermaptera	Labiduridae	*Labidura* sp.				√
Hymenoptera	Tenthredininae	*Tenthredo cretata* (Konow, 1898)			√	
Hymenoptera	Tenthredininae	*Tenthredo* sp.			√	
Orthoptera	Acrididae	*Gesonula punctifrons* (Stål, 1861)	√	√		√

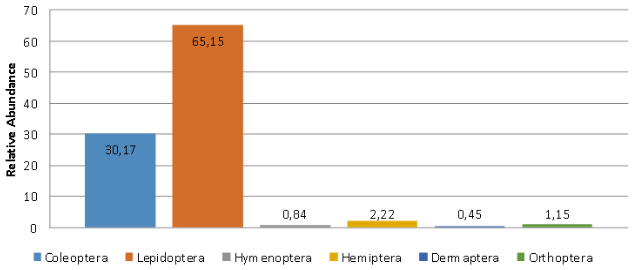

Figure 3. Relative abundance of insect pests in all sites

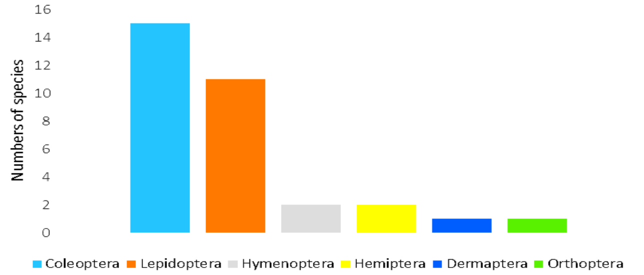

Figure 4. Species richness of different orders of insect pests at different sites

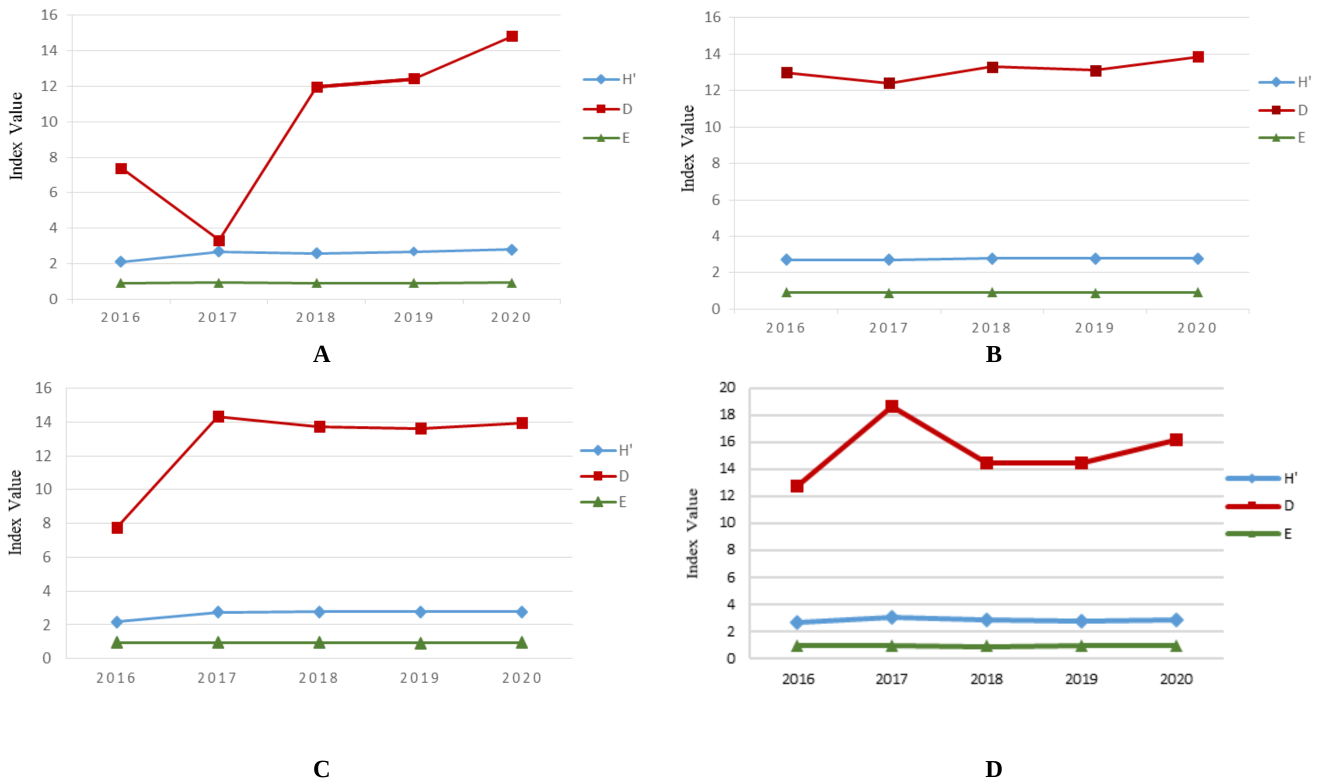

Figure 5. Diversity values of insect pests in the North-western Himalayas: A. Triund area, B. Chanshal area, C. Rohtang area, D. Sach area

Depending on the spatial and temporal variation, insects vary in diversity and abundance (Bashir et al. 2019; Khan et al. 2021). In the present study, the most dominating order Coleoptera (Figure 4) which represented by 15 species belonging to 7 families, the maximum beetles were represented by the family Scarabaeidae followed by Chrysomelidae (2 spp.), Curculionidae (2 spp.), Cerambycidae (1 spp.), Coccinellidae (1 spp.), Dytiscidae (1 spp.) and Carabidae (1 spp.). Coleoptera is one of the most diverse orders of class Insecta as only from India about 15,500 species belonging to 104 families under three sub-orders have been reported (Sengupta and Pal 1998). A study on the species diversity of insects in the southern forest-steppe zone of the Chelyabinsk region also revealed that the largest number of species observed were the representatives of the order Coleoptera (Makarova et al. 2022).

Concerning population abundance Lepidoptera was the dominating order with a relative abundance of 65.15, represented by 11 species belonging to 6 families, the maximum butterflies were represented by the family Pieridae (3 spp.) followed by Nymphalidae (1 spp.), and the maximum moth represented by Noctuidae (3 spp.) followed by Lasiocampidae (2 spp.), Notodontidae (1 spp.), Erebidae (1 spp.). Lepidopterans were also found to be most abundant in the diversity study of Sg. Tiagau Forest Reserve, Malaysia (Razy et al. 2022). More dense vegetation has been observed to boost the number of moths (Müller et al. 2012).

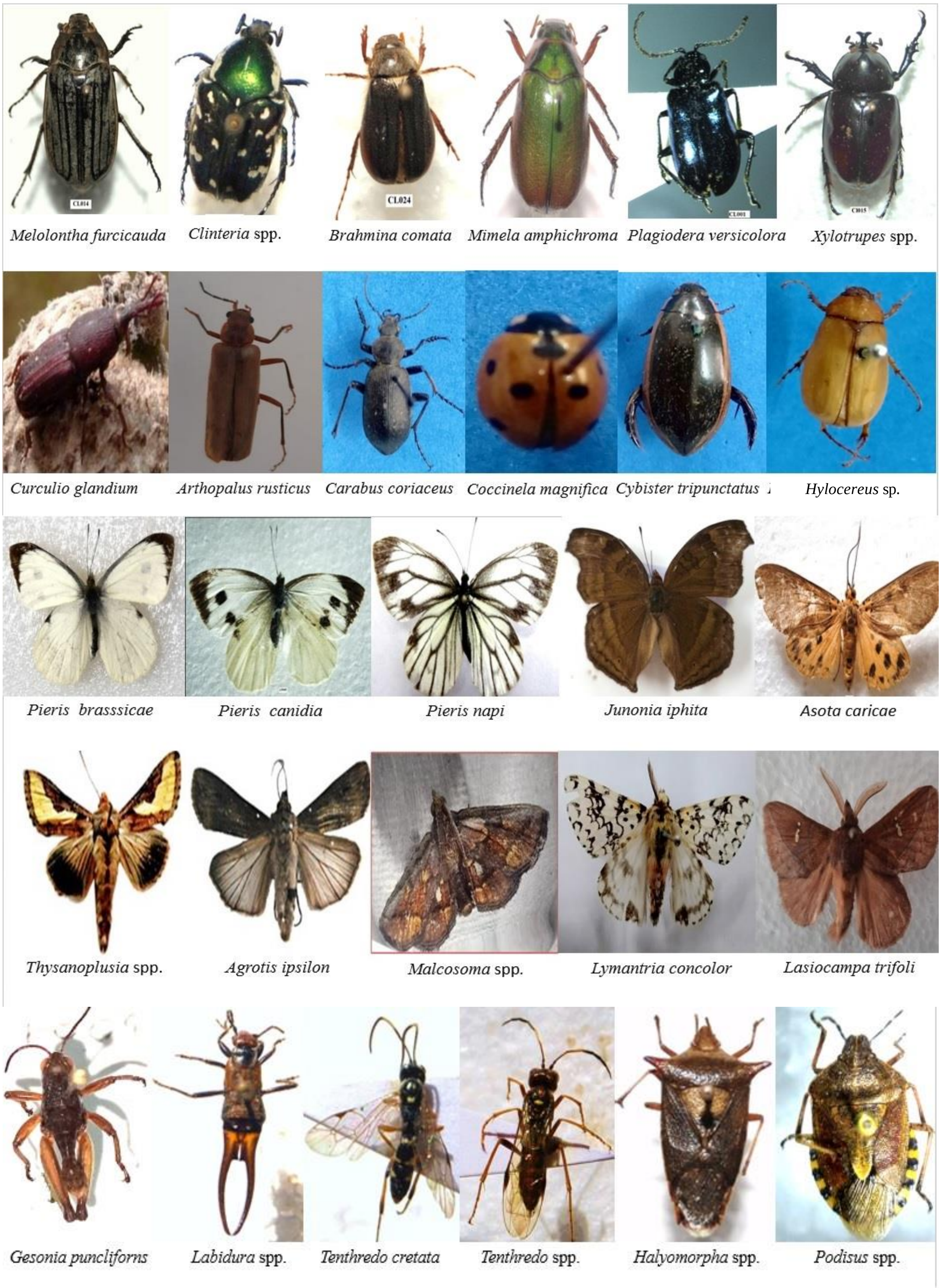

Figure 6. Insects specimens collected from different sites of high altitudinal transitional zones, North-western Himalayas

Order Hymenoptera (Bees and Wasps) is probably the most economically important and beneficial class of Insecta. It contains many insects that are of value as parasites or predators of various insect pests, pollinators, and many commercially important insects, like honey bees. 2 species of Hymenoptera were recorded in the present study, which is represented by 1 family Tenthredininae (2 spp.). Hemipteran fauna of Himachal Pradesh is poorly known except for the family Aphididae, which is rather well explored in comparison to the other families. Some 368 species belonging to 186 genera under 25 families of Hemiptera are so far known from Himachal Pradesh (Varshney 1992). The majority of Hemipteran insects are phytophagous and widely distributed all over the world. Many of them, including aphids, scale insects, leafhoppers, and planthoppers, are significant pests in agriculture and forestry and have a variety of host plants (Guo and Yuan 2016). In the present study, 2 genera of Hemiptera were recorded, which belong to the family Pentatomidae. Just like the Hemiptera order, the order Dermaptera is also very poorly investigated in Himachal, and only one genus of this order was recorded as belonging to the family Labiduridae.

Shishodia and Gupta (2009) have reported Acrididae as the largest family of Orthoptera in Himachal Pradesh. One genus of order Orthoptera was reported to belong to the family Acrididae. The study will help develop the conservation plan to restore the diversity in the region. The biodiversity data revealed that the insects are shifting or expanding their habitat from lower altitude to higher altitude areas as the temperature, relative humidity, and seasonal pattern change. Some insects were also collected from the navel zones of sites, which is an indicator that the area under study and other such areas should be continuously surveyed and monitored to assess the changing spatial distribution of insects to add new taxa to the existing biodiversity. Due to habitat destruction, many species are already extinct, but with the help of this study, we can identify and conserve the threatened taxa. The variation caused by environmental changes can also cause drastic changes in the spatial distribution of high-altitude insect fauna, and only periodic surveys of these areas can help assess the pest incidences and check them by applying effective control measures. Insect pests must be monitored regularly, as well as studies on their ecology, biology, host and distribution patterns, effects on forest ecosystems, and interactions with natural enemies. However, precise knowledge of pests, diseases, and forest ecosystems is required to develop successful pest management strategies (Bista and Thapa 2012; Mohammed et al. 2012).

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REFERENCES

Anderson JT, Wadgymar SM. 2020. Climate change disrupts local adaptation and favours upslope migration. Ecol Lett 23 (1): 181-192. DOI: 10.1111/ele.13427.

Andrew NR, Hill SJ, Binns M, Bahar, MH, Ridley EV, Jung MP, Khusro M. 2013. Assessing insect responses to climate change: What are we testing for? Where should we be heading? PeerJ 1: e11. DOI: 10.7717/peerJ.11.

Arora GS. 1990. Collection and Preservation of Animals (Lepidoptera). Zoological Survey of India, Calcutta.

Bashir MA, Alvi AM, Rehmani MIA, Qasirani TB, Mahpara S, Tariq M. 2019. 46. Pollinators diversity for tomatoes crop under agro-forest ecosystem of Dera Ghazi Khan Punjab Pakistan. Pure Appl Biol 8 (2): 1487-1493. DOI: 10.19045/bspab.2019.80088.

Bista S, Thapa HB. 2012. Retrospective on forest insect pests of Nepal with reference to climate change. In Proceeding of International Conference on The Impacts of Climate Change to Forest Pests and Diseases in The Tropics.

Björkman C, Bylund H, Nilsson U, Nordlander G, Schroeder M. 2015. Forest management to mitigate insect damage in a changing climate: Possibilities and uncertainties. In: Björkman C, Niemelä J (Eds). Climate Change and Insect Pests. CABI, Wallingford. DOI: 10.1079/9781780643786.0000.

De Long JR, Sundqvist MK, Gundale MJ, Giesler R, Wardle DA. 2016. Effects of elevation and nitrogen and phosphorus fertilization on plant defence compounds in subarctic tundra heath vegetation. Funct Ecol 30 (2): 314-325. DOI: 10.1111/1365-2435.12493.

Diagne C, Leroy B, Vaissière AC, Gozlan RE, Roiz D, Jarić I, Courchamp F. 2021. High and rising economic costs of biological invasions worldwide. Nature 592 (7855): 571-576. DOI: 10.1038/s41586-021-03405-6.

Fajvan MA, Wood JM. 1996. Stand structure and development after gypsy moth defoliation in the Appalachian Plateau. For Ecol Manag 89 (1-3): 79-88. DOI: 10.1016/S0378-1127(96)03865-0.

González E, Salvo A, Valladares G. 2020. Insects moving through forest-crop edges: a comparison among sampling methods. J Insect Conserv 24 (2): 249-258. DOI: 10.1007/s10841-019-00201-6.

Guo F, Lenoir J, Bonebrake TC. 2018. Land-use change interacts with climate to determine elevational species redistribution. Nat Commun 9 (1): 1-7. DOI: 10.1038/s41467-018-03786-9.

Guo ZL, yuan ML. 2016. Research progress of mitochondrial genomes of Hemiptera insects. Scientia Sinica Vitae 46 (2): 151-166. DOI: 10.1360/N052015-00229.

Heidrich L, Bae S, Levick S, Seibold S, Weisser W, Krzystek P, Müller J. 2020. Heterogeneity–diversity relationships differ between and within trophic levels in temperate forests. Nat Ecol Evol 4 (9): 1204-1212. DOI: 10.1038/s41559-020-1245-z.

Hill MO. 1973. Diversity and evenness: A unifying notation and its consequences. Ecology 54 (2): 427-432. DOI: 10.2307/1934352.

Hotaling S, Finn DS, Joseph GJ, Weisrock DW, Jacobsen D. 2017. Climate change and alpine stream biology: Progress, challenges, and opportunities for the future. Biol Rev 92 (4): 2024-2045. DOI: 10.1111/brv.12319.

Jacobsen D. 2020. The dilemma of altitudinal shifts: Caught between high temperature and low oxygen. Front Ecol Environ 18 (4): 211-218. DOI: 10.1002/fee.2161.

Janes JK, Li Y, Keeling CI, Yuen MM, Boone CK, Cooke JE, Sperling FA. 2014. How the mountain pine beetle (*Dendroctonus ponderosae*) breached the Canadian Rocky Mountains. Mol Biol Evol 31 (7): 1803-1815. DOI: 10.1093/molbev/msu135.

Khan KA, Bashir MA, Mahmood R, Qadir ZA, Rafiq K, Khan MH, Ghramh HA. 2021. Foraging behavior of western honey bee (*Apis mellifera*) in different time intervals on *Brassica campestris* L. Fresenius Environ Bull 30 (3): 2607-2612.

Knuff AK, Staab M, Frey J, Dormann CF, Asbeck T, Klein AM. 2020. Insect abundance in managed forests benefits from multi-layered vegetation. Basic Appl Ecol 48: 124-135. DOI: 10.1016/.baae.2020.09.002.

Kumar P, Devi R, Mattu VK. 2016. Diversity and abundance of butterfly fauna (Insecta: Lepidoptera) of Subalpine area of Chanshal valley of District Shimla (Himachal Pradesh. J Entomol Zool Stud 4 (4): 243-247.

Kumar P, Kumar M, Thakur MS. 2015. Biodiversity and habitat association of Noctuid moths (Lepidoptera: Noctuidae) in various Chirpine forests of Himachal Pradesh. J Basic Appl Sci Aspects (JBASA).

Kumar P, Thakur S. 2014. Study on faunal diversity of butterflies in Triveni Mahadev (Himachal Pradesh). J Entomol Zool Stud 2 (5): 58-62.

Kumar P. 2016. Studies on seed borer, Plodia interpunctella Hubner (Lepidoptera: Pyralidae) infesting seeds of Chilgoza pine (*Pinus gerardiana* Wall.. Indian For 142 (4): 394-399.

Leidinger J, Blaschke M, Ehrhardt M, Fischer A, Gossner MM, Jung K, Weisser WW. 2021. Shifting tree species composition affects biodiversity of multiple taxa in Central European forests. For Ecol Manag 498: 119552. DOI: 10.1016/j.foreco.2021.119552.

Lovett GM, Canham CD, Arthur MA, Weathers KC, Fitzhugh RD. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. BioScience 56 (5): 395-405. DOI: 10.1641/0006-3568(2006)056[0395:fertep]2.0.co;2.

Lundgren J, McCravy K. 2011. Carabid beetles (Coleoptera: Carabidae) of the Midwestern United States: A review and synthesis of recent research. Terr Arthropod Rev 4 (2): 63-94. DOI: 10.1163/187498311X565606.

Makarova TN, Chernyshova LV, Bazhenova IA, Ulitina OS. 2022. The influence of natural climatic conditions on the species diversity of insects in the conditions of the southern forest-steppe zone of Chelyabinsk region. IOP Conf Ser: Earth Environ Sci 949: 012128. DOI: 10.1088/1755-1315/949/1/012128.

Martin EA, Reineking B, Seo B, Steffan-Dewenter I. 2013. Natural enemy interactions constrain pest control in complex agricultural landscapes. Proc Natl Acad Sci 110 (14): 5534-5539. DOI: 10.1073/pnas.1215725110.

McCravy KW. 2018. A review of sampling and monitoring methods for beneficial arthropods in agroecosystems. Insects 9 (4): 170. DOI: 10.3390/insects9040170.

McKernan C, Cooper DJ, Schweiger EW. 2018. Glacial loss and its effect on riparian vegetation of alpine streams. Freshw Biol 63 (6): 518-529. DOI: 10.1111/fwb.13088.

Mohammed C, Beadle C, Roux J, Rahayu S. 2012. Proceeding of International Conference on The Impacts of Climate Change to Forest Pests and Diseases in The Tropics. Universitas Gadjah Mada, Yogyakarta, Indonesia, 8th-10th October 2012,

Moreira X, Petry WK, Mooney KA, Rasmann S, Abdala-Roberts L. 2018. Elevational gradients in plant defences and insect herbivory: Recent advances in the field and prospects for future research. Ecography 41 (9): 1485-1496. DOI: 10.1111/ecog.03184.

Moret P, Aráuz MDLÁ, Gobbi M, Barragán Á. 2016. Climate warming effects in the tropical Andes: First evidence for upslope shifts of Carabidae (Coleoptera) in Ecuador. Insect Conserv Divers 9 (4): 342-350. DOI: 10.1111/icad.12173.

Müller J, Brandl R, Brändle M, Förster B, de Araujo BC, Gossner MM, Seibold S. 2018. LiDAR-derived canopy structure supports the more-individuals hypothesis for arthropod diversity in temperate forests. Oikos 127 (6): 814-824. DOI: 10.1111/oik.04972.

Müller J, Mehr M, Bässler C, Fenton MB, Hothorn T, Pretzsch H, Brandl R. 2012. Aggregative response in bats: Prey abundance versus habitat. Oecologia 169 (3): 673-684. DOI: 10.1007/s00442-011-2247-y.

Niquidet K, Tang J, Peter B. 2016. Economic analysis of forest insect pests in Canada. Canad Entomol 148 (S1): S357-S366. DOI: 10.4039/tce.2015.27.

Pellissier L, Fiedler K, Ndribe C, Dubuis A, Pradervand JN, Guisan A, Rasmann S. 2012. Shifts in species richness, herbivore specialization, and plant resistance along elevation gradients. Ecol Evol 2 (8): 1818-1825. DOI: 10.1002/ece3.296.

Pellissier L, Roger A, Bilat J, Rasmann S. 2014. High elevation *Plantago lanceolata* plants are less resistant to herbivory than their low elevation conspecifics: Is it just temperature? Ecography 37 (10): 950-959. DOI: 10.1111/ecog.00833.

Pörtner HO, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Weyer N. 2019. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. IPCC Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Pratt JD, Datu A, Tran T, Sheng DC, Mooney KA. 2017. Genetically based latitudinal clines in Artemisia californica drive parallel clines in arthropod communities. Ecology 98 (1): 79-91. DOI: 10.1002/ecy.1620.

Pureswaran DS, Roques A, Battisti A. 2018. Forest insects and climate change. Curr For Rep 4 (2): 35-50. DOI: 10.1007/s40725-018-0075-6.

Rasmann S, Alvarez N, Pellissier L. 2014. The altitudinal niche-breadth hypothesis in insect-plant interactions. Ann Plant Rev 47: 339-359. DOI: 10.1002/9781118472507.ch10.

Razy J, Momin B, John LY, Chung AYC. 2022. Rapid assessment of insect diversity (Ext.), Kalabakan, Sabah. IOP Conf Ser: Earth Environ Sci 1053 (1): 012008. DOI: 10.1088/1755-1315/1053/1/012008.

Ricklefs RE, He F. 2016. Region effects influence local tree species diversity. Proc Natl Acad Sci 113 (3): 674-679. DOI: 10.1073/pnas.1523683113.

Samways MJ, Osborn R, Carliel F. 1996. Effect of a highway on ant (Hymenoptera: Formicidae) species composition and abundance, with a recommendation for roadside verge width. Biodivers Conserv 6: 903-913. DOI: 10.1023/A:1018355328197.

Schemske DW, Mittelbach GG. 2017. Latitudinal gradients in species diversity: Reflections on Pianka's 1966 article and a look forward. Am Nat 189 (6): 599-603. DOI: 10.1086/691719.

Sengupta T, Pal TK. 1998. Faunal Diversity in India: Coleoptera Zoological Survey of India, Calcutta.

Shah AA, Dillon ME, Hotaling S, Woods HA. 2020. High elevation insect communities face shifting ecological and evolutionary landscapes. Curr Opin Insect Sci 41: 1-6. DOI: 10.1016/j.cois.2020.04.002.

Shannon CE, Wiener W. 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana, USA.

Sharma M 2016. Forest pests of forestry plants and their management. Intl J Adv Res 4 (8): 2099-2116. DOI: 10.21474/IJAR01/1427.

Shishodia MS, Gupta S. 2009. Checklist of Orthoptera (Insecta) of Himachal Pradesh, India. J Threat Taxa 1 (11): 569-572. DOI: 10.11609/JoTT.o1923.569-72.

Simpson EH. 1949. Measurement of diversity. Nature 163 (4148): 688-688. DOI: 10.1038/163688a0.

Singh V. 2013. Insect fauna of Khajjiar Lake of Chamba District, Himachal Pradesh, India. Pak J Zool 45 (4): 1053-1061.

Spafford RD, Lortie CJ. 2013. Sweeping beauty: Is grassland arthropod community composition effectively estimated by sweep netting? Ecol Evol 3 (10): 3347-3358. DOI: 10.1002/ece3.688.

Thackeray SJ, Henrys PA, Hemming D, Bell JR, Botham MS, Burthe S, Wanless S. 2016. Phenological sensitivity to climate across taxa and trophic levels. Nature 535 (7611): 241-245. DOI: 10.1038/nature18608.

Thakur V, Kumar P. 2015. Biodiversity of geometrid moths (Lepidoptera) of conifer forests of Saraj Valley of Himachal Pradesh, India. Intl J Curr Res 7 (1): 11426-11429.

Tinya F, Kovács B, Bidló A, Dima B, Király I, Kutszegi G, Ódor P. 2021. Environmental drivers of forest biodiversity in temperate mixed forests–A multi-taxon approach. Sci. Total Environ 795: 148720. DOI: 10.1016/j.scitotenv.2021.148720.

Trisnawati DW, Nurkomar I, Ananda LK, Buchori D. 2022. Agroecosystem complexity of Surjanand Lembaran as local farming systems effects on biodiversity of pest insects. Biodiversitas 23: 3619-3629. DOI: 10.13057/biodiv/d230738.

Varshney RK. 1992. A check list of scale insects and mealy bugs of Southe Asia. Part-I. Rec Zool Surv India 139: 1-152.

Wingfield MJ, Brockerhoff EG, Wingfield BD, Slippers B. 2015. Planted forest health: The need for a global strategy. Science 349 (6250): 832-836. DOI: 10.1126/science.aac6674.

Wu CH, Holloway JD, Hill JK, Thomas CD, Chen I Ho CK. 2019. Reduced body sizes in climate-impacted Borneo moth assemblages are primarily explained by range shifts. Nat Commun 10 (1): 1-7. DOI: 10.1038/s41467-019-12655-y.