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Monitoring Biodiversity and Temperature-Dependent Patterns of Insects in Wet and Moist Sal Forest of Western Himalayas

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Abstract: Sal forest ecosystems are home to a diverse array of insect communities. The Western Himalayan range, particularly the Shivaliks, is characterized by its sal forests, which exhibit significant ecoclimatic habitat variability. Sal forests of the Himalayas support a rich diversity of insect fauna. The study investigated, investigated the turnover of insect communities, species diversity, seasonal fluctuations, and their correlation with temperature across two distinct sal forests with different rainfall regimes. Through random sampling, we monitored the insect fauna in both wet and sal forest. The two forest types have significantly similar species composition and diversity. Order Lepidoptera predominates in both forests, and most insect communities exhibit higher species diversity during the warmer summer months. In total, 7,787 individuals representing 92 species and 13 orders were recorded, with 64 species shared between sites and relatively low turnover (31% dissimilarity). Principal component analysis revealed a strong temperature dependence, with insect communities thriving between 24–34°C, highlighting a distinct thermal niche across both forests. Further studies that emphasize the need for conservation and long-term monitoring of insect fauna in this region is recommended.

Keywords: Biogeography, Diversity, Insects, Sal, *Shorea robusta,* Western Himalayas

The Western Himalayan region, with its complex terrain and diverse microclimates, supports some of the most ecologically significant forest ecosystems in South Asia. Among these, the wet and moist Sal forests, dominated by *Shorea robusta* Gaertn. f., are recognized for their high ecological and economic value. *S.robusta* exhibits a gregarious growth pattern and is distributed widely across the Himalayan foothills in India, Nepal, and Bangladesh (Baral et al., 2022, Majumdar et al., 2014), with further extensions into Bhutan and southern China (Nepal 2023). These forests thrive at altitudes ranging from near sea level up to 1500 meters, and they harbor a wide variety of insect taxa critical for pollination, nutrient cycling, and as indicators of ecosystem health.

Insects are key components of forest ecosystems, yet recent studies have raised concerns over widespread declines in insect populations globally, attributed to anthropogenic pressures, habitat loss, and climate change (Forister et al., 2011; Sánchez-Bayo and Wyckhuys 2021). These declines are particularly alarming in ecologically sensitive regions like the Himalayas, where insects play indispensable roles in sustaining biodiversity. Temperature, a dominant abiotic factor, influences insect physiology, phenology, and distribution patterns, making it a crucial variable in understanding insect responses to environmental change. Monitoring shifts in insect diversity and abundance along temperature gradients is therefore vital for anticipating the impacts of climate change on forest ecosystems (Montgomery et al., 2021).

Despite the ecological importance of sal forests, there remains a significant knowledge gap in the documentation and monitoring of their insect communities, particularly in different rainfall regimes of sal forests in the Western Himalaya. Some records highlight the presence of insect pests such as *Hoplocerambyx spinicornis*, a major defoliator of *S. robusta* in the region (Singh 2021), but there is limited data on the broader insect assemblages and their ecological relationships. Vudem et al. (2010) mentioned that the lack of extensive entomological surveys within Sal forest ecosystems, and no studies have yet examined how insect biodiversity in these forests correlates with local temperature regimes. Additionally, the species turnover of insects between the Sal forests of two distinct rainfall regimes is not documented. This research aims to address these gaps by conducting a systematic survey of insect diversity and assessing temperature-dependent patterns in the Western Himalaya's wet and moist Sal forests. Using established arthropod monitoring protocols,

MATERIAL AND METHODS

Description of sites: The sal forest of Ranibagh (hereafter referred to as RSF) is 600 meters above sea level. The area under survey is located between latitude 29.28882° and longitude 79.55140° and is flanked by the Gaula River. This area is marked by its excellent richness of flora and fauna, and is a moist Sal forest. The transects studied in the Sal forest of Kaladhungi (hereafter referred to as KSF) are located at an elevation of 400 meters and between

29.30476°N, 79.33974°E to 29.30828°N, 79.34312°E, and are flanked by the Boar River and are a wet sal forest. The elevation of transects was carefully selected to minimize the effect of altitudinal habitat heterogeneity, ensuring more uniform ecological and environmental conditions for the study.

Sampling: The study was conducted between May 2022 and June 2023. The forests were visited during the daytime and nighttime on consecutive days to record diurnal and nocturnal insects. Temperature was recorded throughout the day using a digital thermometer. Additionally, various trapping methods and instruments were used, such as light traps and sweep nets, and collecting jars, to collect specimens. 100m.sq. transects were randomly selected, and the line-transect method was followed at each transect to observe the insects.

Collection of insects: Insects were preserved using cotton-soaked fumigants (chloroform or 10% ethyl acetate) at the lab by stretching and pinning the insects following Upton and Mantle (2010). Furthermore, insect diversity and abundance were studied through observational approaches. Identification of insects was done after bringing the collected insects to the lab. The insects were examined for their physical characteristics and compared to the reference collections in the Insect Biodiversity Laboratory at the Department of Zoology, D.S.B. Campus, Kumaun University, Nainital, based on key descriptions. Those that could not be identified at the species level were identified at the genus level. Surveys were performed during the night to observe the nocturnal insects using insect Night traps following Jonason et al. (2014).

Statistical analysis: The data was analyzed statistical software Paleontological Statistics (PAST 4.03), Brodgar v2.7.5, and Microsoft Excel for developing models, graphs, diversity indices, evenness, accumulation, distribution, and visualization. α-Diversity indices were estimated using the PAST v4.03 statistical software. Population parameters, such as evenness and richness, include the Shannon and Gini-Simpson Index, and the Margalef and Menhinick Index, respectively. Whittaker and Wilson-Shmida β diversity index was estimated using PAST software. Indices such as Jaccard's Dissimilarity and Bray-Curtis Dissimilarity index were used to analyze the similarities of insect community distribution between the two sal forests.

Seasonal index and fluctuations: The total period of the survey was divided into 4 seasons: Summer=S, Rainy=R, Winter=W, and Autumn=A (Farooq et al., 2021). March, April, and May are considered Summer; June, July, and August as Rainy; September, October, and November as Autumn; and finally, December, January, and February as winter. Seasonal diversity was checked using the species frequencies in the PAST v4.03 Statistical software. Seasonal fluctuations and seasonal index were calculated using slight modifications to the method Mathew and Anto (2007) used.

Seasonal Index = (Monthly mean/Overall mean) x 100 (1)

Status of species: The status of insect species was based on the number of sightings, following Farooq et al. (2021). The insects were assigned different status with slight modification to Farooq et al. (2021). Very Common (VC) >=70 sightings, Common (C) = 30-69, Occasional = (O) = 10-29, Rare = (R) =<=9

Evaluating impacts of temperature: PCA with variant-covariant was employed for analyzing non-parametric multi-dimensional arrays. The correlation was analyzed between the abundance of orders and their relationship to annual temperature using the Bray-Curtis correlation matrix for each site.

RESULTS AND DISCUSSION

General findings: Total of 7787 individuals of insects belonging to 92 species and 13 orders were recorded across the two aal forest areas, with 80 species of insects from RSF and 77 species from KSF were recorded. Of these, 64 species are common to both Sal forests, whereas 16 and 13 are unique to RSF and KSF, respectively (Table 1). Twelve orders were recorded at KSF and 13 orders at RSF. 3384 individuals were recorded from the Ranibagh Sal forest, belonging to 79 species of insects from 13 different Orders. These findings may be the consequences of high vegetative diversity within the two Sal forests, which was previously reported by Pandey et al. (2023). Such high biodiversity is also supported by slightly disturbed ecosystems aided by their geographic isolation (Hussain et al., 2023) since both forests stand away from anthropogenic disturbances. Order Lepidoptera was the most abundant order (40%) with 11 Families (45.5%) and 36 species, with family Pieridae (seven genera and eight species) having the highest number of individuals (10.12%) among all the orders, followed by order Diptera (13.7%), and Hymenoptera (13.17%). 4403 individuals were recorded from the KSF, belonging to 77 species of insects from 12 different Orders. Annual evenness shows congruence (9.7) in both forests. Out of these, Order Lepidoptera was the most abundant order (32%) with nine families (45.5%) and 31 species, with family Pieridae having the highest number of individuals among all the orders (13.6%). Bashar and Chowdhury (2021) form deciduous sal forests of Bhawal and Madhupur in central Bangladesh observed that dominant was Hymenoptera, accounting for 31% of the identified species. In present study Lepidoptera was the dominant order, accounting for 40% species at the moist Sal forest (RSF) and

Table 1. Insect fauna associated with Sal forests and their habitat preferences

Family	Taxa	RSF	KSF	Habitat
Order Lepidoptera				
Papilionideae	*Papilio polytes* (Linnaeus)	+	+	Wet & Moist
Papilionideae	*Papilio clytia dissimilis* (Linnaeus)	+	+	Wet & Moist
Papilionideae	*Papilio demoleus* (Linnaeus)	+	+	Wet & Moist
Papilionideae	*Papiliopta aristolochiae* (Fabricius)	+	-	Moist
Pieridae	*Zemeros flegyas* (Cramer)	+	+	Wet & Moist
Pieridae	*Eurema hecabe* (Linnaeus)	+	+	Wet & Moist
Pieridae	*Leptosia nina* (Fabricius)	+	+	Wet & Moist
Pieridae	*Catopsilia pomona*(Fabricius)	+	+	Wet & Moist
Pieridae	*Catopsilia pyranthe* (Linnaeus)	+	+	Wet & Moist
Pieridae	*Belenois aurota* (Fabricius)	+	+	Wet & Moist
Pieridae	*Pieris brassicae* (Linnaeus)	+	+	Wet & Moist
Pieridae	*Cepora nerissa* (Fabricius)	+	+	Wet & Moist
Nymphaladeae	*Tirumala limniaceae* (Cramer)	+	+	Wet & Moist
Nymphaladeae	*Junonia lemonias* (Linnaeus)	+	+	Wet & Moist
Nymphaladeae	*Phalanta phalantha* (Drury)	+	-	Moist
Nymphaladeae	*Symbrenthia lilaea* (Hewitson)	+	-	Moist
Nymphaladeae	*Ypthima baldus* (Fabricius)	+	+	Wet & Moist
Nymphaladeae	*Euthalia aconthea (Cramer)*	-	+	Wet
Hesperidae	*Telicota bambusae* (Moore)	+	-	Moist
Riodinidae	*Abisara bifasciata* (Moore)	+	-	Moist
Lychenidae	*Zizeeria karsandra* (Moore)	+	+	Wet & Moist
Lychenidae	*Lampidus boeticus*(Linnaeus)	+	+	Wet & Moist
Arctiidae	*Cyana adita* (Moore)	+	-	Moist
Carambidae	*Luma sericea* (Butler)	-	+	Wet
Carambidae	*Endocrossis flavibasalis* (Moore)	+	+	Wet & Moist
Carambidae	*Conogethis punctiferalis* (Guenée)	+	+	Wet & Moist
Geometridae	*Ornithospila avicularia* (Warren)	+	+	Wet & Moist
Geometridae	*Campaea perlata* (Guenée)	-	+	Wet
Geometridae	*Pelagodes spp.* (Holloway)	+	+	Wet & Moist
Geometridae	*Hypomecis cineracea* (Moore)	+	-	Moist
Geometridae	*Timandra correspondens* (Hampson)	+	+	Wet & Moist
Geometridae	*Pingasa ruginaria* (Guenée)	+	-	Moist
Erebidae	*Perina nuda* (Fabricius)	+	+	Wet & Moist
Erebidae	*Oraesia emarginata* (Fabricius)	+	+	Wet & Moist
Erebidae	*Mocis undata* (Fabricius)	+	+	Wet & Moist
Noctuidae	*Helicoverpa armigera* (Hubner)	+	+	Wet & Moist
Noctuidae	*Athetis transversa* (Walker)	+	+	Wet & Moist
Noctuidae	*Mythimna separata* (Walker)	+	-	Moist
Noctuidae	*Spodoptera litura* (Fabricius)	+	-	Moist
Eupterotini	*Eupterote undata* (Blanchard)	-	+	Wet
Eupterotini	*Eupterote bifasciata* (Kishida)	-	+	Wet

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Table 1. Insect fauna associated with Sal forests and their habitat preferences

Family	Taxa	RSF	KSF	Habitat
Order Orthoptera				
Tettigoniidae	*Tettigoniidae spp.* (Continua)	+	+	Wet & Moist
Tettigoniidae	*Sathrophyllia rugosa* (Stål)	-	+	Wet
Acrididae	*Arphia conspersa* (Cudder)	+	-	Moist
Acrididae	*Acrida exaltata* (Walker)	-	+	Wet
Gryllidae	*Gryllus confirmatus* (Walker)	+	+	Wet & Moist
Gryllidae	*Teleogryllus testaceus* (Walker)	-	+	Wet
Order Coleoptera				
Scarabaeidae	*Mimela fulgidivittata* (Blanchard)	+	-	Moist
Scarabaeidae	*Mimela splendens* (Gyllenhal)	-	+	Wet
Scarabaeidae	*Holotricia serrata* (Fabricius)	+	+	Wet & Moist
Scarabaeidae	*Onthophagus orientalis* (Harold)	+	+	Wet & Moist
Scarabaeidae	*Agamopus unguicularis* (Harold)	+	+	Wet & Moist
Scarabaeidae	*Lepidiota albistigma* (Burmeister)	+	+	Wet & Moist
Scarabaeidae	*Maladera castanea* (Arrow)	+	+	Wet & Moist
Coccinellidae	*Coccinella septempunctata* (Linnaeus)	+	+	Wet & Moist
Carabidae	*Bradycellus spp.* (Erichson)	+	+	Wet & Moist
Elateridae	*Adelocera spp.* (Latreille)	+	+	Wet & Moist
Cerambycidae	*Dorysthenus huegelii* (Redtenbacher)	+	+	Wet & Moist
Meloidae	*Zonitoschema pallidissima* (Reitter)	+	+	Wet & Moist
Brentidae	*Caenorhychodes diagramma* (Boisduval)	-	+	Wet
Order Odonata				
Libellulidae	*Orthetrum taeniolatum* (Schneider)	+	+	Wet & Moist
Libellulidae	*Crocothermis serivilia* (Drury)	+	+	Wet & Moist
Order Blattodea				
Blattidae	*Blatta orientalis* (Linnaeus)	+	+	Wet & Moist
Blattidae	*Periplaneta americana* (Linnaeus)	-	+	Wet & Moist
Order Mantodeae				
Hymenopodidae	*Creobroter gemmatus* (Saussure)	+	+	Wet & Moist
Mantidae	*Mantis religiosa* (Linnaeus)	+	+	Wet & Moist
Gonypetidae	*Gonypetyllis spp.* (Wood-Mason)	+	+	Wet & Moist
Order Neuroptera				
Chrysopidae	*Chrysoperla carnea* (Stephens)	+	-	Moist
Chrysopidae	*Leucochrysa insularis mina* (Walker)	+	+	Wet & Moist
Order Trichoptera				
Rhyacophilidae	*Rhyacophila spp.* (Pictet)	+	-	Moist
	Order Hemiptera			
Largidae	*Physopelta gutta* (Burmeister)	+	+	Wet & Moist
Pyrrhocoriidae	*Dindymus versicolor* (Herrich-Schaeffer)	+	+	Wet & Moist
Pyrrhocoriidae	*Dysdercus sidae* (Montrouzier)	+	+	Wet & Moist
Pentatomidae	*Nezara viridula* (Linnaeus)	+	+	Wet & Moist
Rhyparochromidae	*Diecuches notatus* (Dallas)	+	+	Wet & Moist
Miridae	*Closterotomus spp.* (Fieber)	+	+	Wet & Moist

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Table 1. Insect fauna associated with Sal forests and their habitat preferences

Family	Taxa	RSF	KSF	Habitat
Order Diptera				
Stratiomyidae	*Hermetia illucens* (Linnaeus)	+	+	Wet & Moist
Tabanidae	*Tabanus rubidus* (Wiedemann)	+	-	Moist
Sarcophagidae	*Sarcophaga argyrostoma* (Robineau-Desvoidy)	+	+	Wet & Moist
Muscidae	*Musca domestica* (Linnaeus)	+	+	Wet & Moist
Culicidae	*Anopheles fluviatilis* (James)	+	+	Wet & Moist
Culicidae	*Culex pipiens* (Linnaeus)	+	+	Wet & Moist
Culicidae	*Aedes aegypti* (Linnaeus)	-	+	Wet
Order Hymenoptera				
Vespidae	*Vespa tropica* (Linnaeus)	+	+	Wet & Moist
Vespidae	*Polistes olivaceus* (DeGeer)	+	+	Wet & Moist
Apidae	*Apis cerana* (Fabricius)	+	+	Wet & Moist
Apidae	*Apis dorsata* (Fabricius)	+	+	Wet & Moist
Formicidae	*Oecophylla smaragdina* (Fabricius)	+	+	Wet & Moist
Ichneuonidae	*Enicospilus* sp. (Stephens)	+	+	Wet & Moist
Order Isoptera				
Termitidae	*Microtermes obesi* (Holmgren)	+	+	Wet & Moist
Order Ephimeroptera				
Ephemeridae	*Ephemera* sp1 (Linnaeus)	-	+	Wet
Ephemeridae	*Ephemera* sp2 (Linnaeus)	+	-	Moist
Baetidae	*Labiobaetis spp.* (Novikova and Kluge)	+	+	Wet & Moist
Total individuals		3378	4403	7781

32% at the Wet Sal forest (KSF). The mean annual temperature of RSF is reportedly higher than KSF. Higher mean temperatures at RSF can increase the abundance and diversity of Lepidopterans, especially moths in dry and moist habitats, which aligns with the findings of Choi (2008), Goswami et al. (2023) and Mishra et al. (2016).

Apis cerana (6.32%) was the most sighted species in RSF. A total of eight species were rare at RSF and KSF, *Physopelta gutta* (5.8%) was the most sighted species, followed by *Apis cerana* and *Apis dorsata* (Table 1) Only three species were rare visitors at KSF, which include *Gonypetyllis sp*. (0.18%) and *Labiobaetis sp*. (0.09%). Overall, *Apis cerana* (4.5%) was the most sighted species, followed by *Physopelta gutta* (5.9%) and *Apis dorsata* (5.1%). Five rare species existed overall, which are *Rhyacophila sp*. (0.6%), *Labiobaetis sp*. (0.6%), *Sathrophyllia rugosa* (0.01%), *Arphia conspersa* (0.01%), and *Ephemera sp*. (0.01%).

Seasonal community dynamics: The Shannon index indicates the highest evenness during the summer season at RSF and KSF (3.95 and 3.90, respectively), while the least during the autumn at KSF (3.05) and during winters at RSF (3.46) (Table 2). The Margalef index was highest for the year (9.78) at RSF. Highest species richness was recorded during the autumn season at RSF (10.47) and during the summer season at KSF (9.33). The least richness was during the months of autumn (KSF=5.40) and winter (RSF=6.90). Such seasonal trends align with previous studies of macro-invertebrate communities (Sun et al., 2024). Similarly, the highest abundance of insects at KSF was seen during the summers, aligning with Müller et al. (2024).

The seasonal fluctuation of insects at RSF and KSF has been demonstrated in Figure 1. The fluctuation of insects was the highest for May (rainy season), followed by April. On the other hand, the slightest fluctuation of insects can be seen in October or the winter season. At KSF, the abundance of insects was the highest in July, followed by June. The slightest fluctuation of insects can be seen in October or winter. The high abundance of insects before and during the rainy season may be due to favorable temperature and humidity, as reported in previous studies (Zhao et al., 2023).

Relationship of insect community dynamics with temperature: Principal components for KS explain a maximum variance of 94.1% by temperature in PC1 and PC2, and 93.3% variance for RSF. The biplots demonstrated high collinearity in principal components 1 and 2 (Fig. 2).

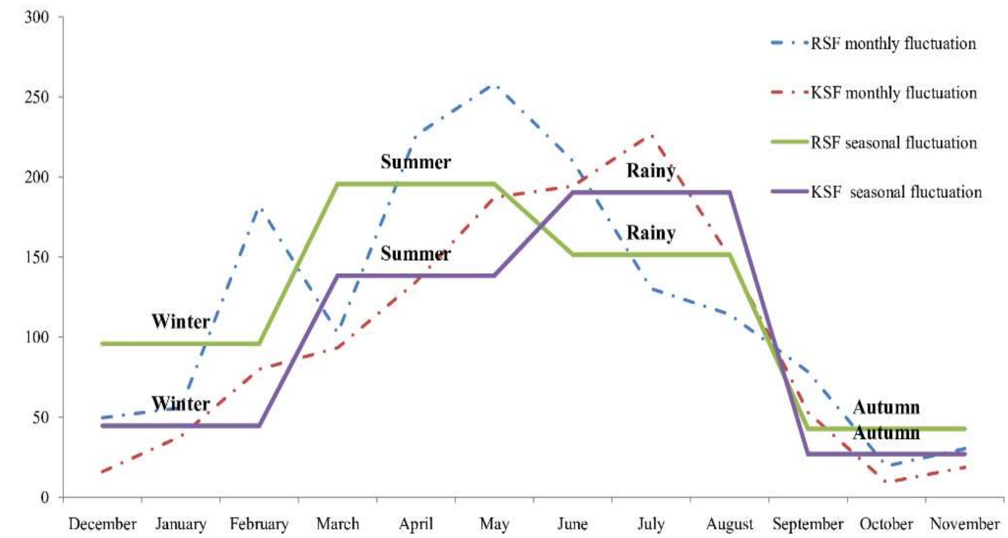

Fig. 1. Seasonal and monthly fluctuations derived from the seasonal index of insects in both forests

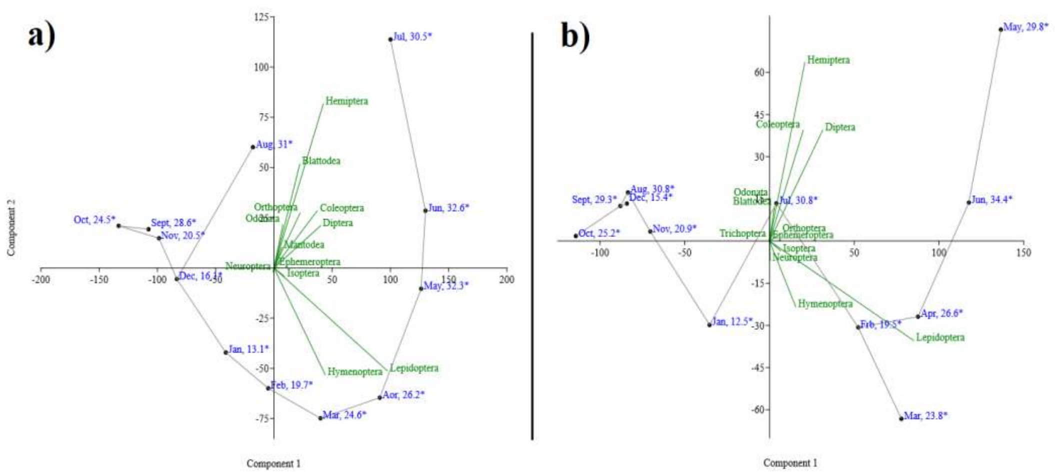

Fig. 2. PCA analysis of annual insect fluctuation showing the relationship with temperature. a) Scatter plot of PC-1 & PC-2 for KSF b) Scatter plot of PC-1 &PC-2 for RSF

Table 2. Descriptive seasonal insights of insect communities at RSF and KSF

Index	Site	Winter	Summer	Rainy	Autumn
Taxa S	RSF	46	71	67	60
	KSF	37	70	67	32
Simpson (1–D)	RSF	0.96	0.975	0.976	0.948
	KSF	0.952	0.971	0.965	0.928
Shannon (H')	RSF	3.467	3.959	3.917	3.513
	KSF	3.267	3.905	3.774	3.054
Evenness (e^H/S)	RSF	0.696	0.738	0.750	0.559
	KSF	0.709	0.709	0.650	0.662
Margalef	RSF	6.909	9.618	9.580	10.470
	KSF	5.574	9.334	8.784	5.407

Table 3. Turnover in the regional biogeography of the two sites

Diversity Index	Value	Interpretation
Jackard's Similarity Index	0.68	68% similarity
Jackard Distance of Dissimilarity	31.18%	31% dissimilarity
Wilson and Shmida, β	0.184	Low turnover
Whittaker, β	0.184	Low turnover
Bray-Curtis dissimilarity	0.294	29.4% dissimilarity

The most communities of insects at KSF thrive at temperatures between 24 to 30°C, and 23.8 to 34.4°C at RSF. Most insect communities fall within the first and the fourth quadrants in both wet and moist forests. The PCA highlights that most insect communities of insects show less diversity at temperatures corresponding to the months from September to January, and thrive at temperatures between 24 and 34°C. Such findings on insect thermal niche have also been reported in previous studies (Dingha, 2009; Wu et al., 2017; Brewer et al., 2021; Qiu et al., 2012). Various other biotic and abiotic factors, such as temperature, altitude, humidity, understory vegetation, and solar intensity, contribute to the potential growth of insects within these two distinct forests, which requires further investigation.

Species turnover: Statistically significant ($p<0.05$) Pearson's correlation coefficient of 0.82 exists between the species diversities of both sites (Table 3). The two sites present 68% similarity in species but also show 31% dissimilarity in the diversity of communities, suggesting relatively low species turnover between wet and moist forests.

This study limits the environmental parameters to temperature only. Further research is required on these al ecosystems, considering other parameters along with temporal dynamics. The study will serve as a foundation and baseline for future research on insect ecology and conservation in forest ecosystems with similar rainfall regimes.

CONCLUSION

This study shows that the wet and moist Sal forests of the western Himalaya support a high and largely overlapping insect fauna (7,787 individuals, 92 species; 64 species shared between sites) with relatively low species turnover (29-31% dissimilarity). Lepidoptera were dominant in both forest types, and insect diversity and abundance peaked in the warmer months. Multivariate analysis reveals that most insect communities are concentrated between 24-34°C, indicating a strong temperature dependence of community dynamics. These results provide a practical baseline for detecting climate-driven changes in insect assemblages in Sal forests. The standardized, long-term insect monitoring program in the region with continuous temperature loggers and repeat surveys (pre-monsoon/monsoon focus) should be initiated and need to protect habitat heterogeneity.

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