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Species diversity and seasonal dynamics of insects in the high altitude tea estate in Uttarkhand, India

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ABSTRACT: The study explored the insect communities and their seasonality within tea plantations micro-climate and finds the relatedness of these insects with the environment variables of the terroir. The study carried out at the Ghorakhal Tea Estates of Uttarakhand, collected a total of 2195 insect individuals, belonging to seven orders and 15 families and their population dynamics were measured along with the environmental variables in the estate. The Shannon-Weiver Index (H) indicated moderate species richness (2.94). The most abundant Order was Hymenoptera (30%), followed by Lepidoptera (27%). Family of pollinator bees (24%) and Pierid butterflies (19%) were dominant in the tea plantation area. The highest diversity and evenness of insect communities was observed during the summer season. The study highlights the influence of temperature, air quality, and humidity on the insect population. Canonical Correspondence Analysis suggests a significant relationship between abiotic environmental factors and insect species' abundance. Distribution of 69.4 per cent was explained by the temperature and humidity, and 30.5 per cent by the air quality. Insect diversity was positively correlated to temperature (0.85) and humidity (0.93) and negatively correlated with air quality (-0.89).

KEY WORDS: Biodiversity, climate dependence, Shannon-Weiver Index, Canonical Correspondence Analysis

INTRODUCTION

Insects play a crucial role in the functioning of ecosystems and provide a wide range of benefits to humans (Scudder, 2017). They have played unique role in the Tea culture, which is an integral part of many societies. Xu (2013) explored the history of insect tea (made from the faeces of insects) and its cultural significance made from insects that feed on tea leaves. *Camellia sinensis* is a species of evergreen shrub or small tree in the flowering plant family Theaceae, whose leaves and leaf buds are used to produce the popular beverage tea (Graham, 1992). It requires proper rainfall, drainage, and slightly acidic soil (Graham, 1992, 1999). Green Tea phenolic compounds are predominately composed of catechin derivatives, although other compounds, such as flavonols and phenolic acids, are also in lower proportion (Chan *et al*., 2007). It is grown in India and Sri Lanka at altitudes up to 2000m above sea level (Graham, 1999). In India, Tea cultivation began in the Darjeeling district in the early 1850s, with thousands of acres of land being cleared and numerous nurseries being established with China Jat (Atkinson, 1980). In 2018-19, the plantation sector

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in India had a gross output value of $31475.14 billion, which accounted for approximately two per cent of the country's total agricultural output value (Viswanathan, 2021). This highlights the crucial contribution of Tea plantation sector to the country's inclusive development due to its significant role (Joseph and Viswanathan, 2016). A major land area contributes to tea plantation in Uttarakhand. The state is divided into two regions, Garhwal and Kumaon, with 13 districts. The climate ranges from subtropical in the southern foothills to warm temperate in the middle Himalayan valleys. In Uttarakhand, 572.19 ha of inorganic farming is done under the Uttarakhand Tea Development Board, while 593.81 ha of Organic farming is done (UTDB, 2023). The Ghorakhal Tea Estate (GTE) is the second-largest Organic farm in the state that covers 112.26 ha. The Tea is being cultivated over 105 ha for 30 years (UTDB, 2023). The region remains isolated from the urban town and has a unique ecosystem that provides optimum conditions for excellent growth of flora and fauna (Arti, 2018). The Tea estates are essential sources of national income and require much care; thus, identifying factors that have beneficial or detrimental effects on its growth becomes necessary. Many pests are responsible for damaging the tea plant. Rai (2004) reported that various pests cause heavy damage to the plant. Previous records of insect fauna in or around GTE are scarce (Smetacek, 2010, 2011) which highlights the entomofaunal research gap in the region, thus making a survey primarily important.

Tea terroirs offer a unique micro-environment that affects its associated biodiversity unlike any other landscape, which consequently affects its own growth (Mattson and Addy, 1975; Suba and Bhattacharya, 2024). Also, Insects are sensitive to climate and act as nature's indicator organisms. In light to this knowledge, we hypothesised that these environment variables would have a positive correlation with the insect population dynamics. We also assumed a strong effect of the seasons on the alpha diversity variables of the insects exclusive to the Tea ecosystem. Accordingly, the objectives of this study were designed to (i) Measure the three environment variables (temperature, air quality and humidity) inside the tea estate throughout the study period; (ii) Monitor the insect communities and their status in the estate; (iii) Calculate the seasonality of insects using standardized methods; and (iv) Statistically elucidate the relationship between the environment variables with the distribution of these insect communities.

MATERIALS AND METHODS

This study was conducted for one year, from May 2022 to June 2023, in GTE. It is situated in the Nainital district of Uttrakhand The geographic latitude and longitude are 29º38 N to 79º28' E at an altitude of 1740m, and the closest town (Bhowali) is about three kilometres away from the terroirs. The site has even distribution of tea cultivars with fragmented distribution of Pine cover. The overall climate in the plantation area is warmer than the downtown area. Three environmental parameters were recorded using standardised digital instruments, i.e., mean temperature of the month, mean humidity and air quality index (AQI). All the meteorological parameters were compared daily from the Accuweather Weather Database for standard error following Sadeghian *et al*. (2022). AQI was obtained from the UPCB database (UPCB, 2023). Ten transects of 20x20 metre were observed for one hour each, inside the plantation area. Two transects were monitored on each visit and their mean values were used to summarise the results for the Tea estate. Butterflies, bees and some flying insects were observed using the traditional Pollard walk method (Pollard 1977). Bug and beetles were observed by sweep net sampling method and beating plant foliage. Flies were sampled using a Malaise trap, following Nejati *et al*. (2020).

Insects were preserved using cotton-soaked fumigants in the Jar (Chloroform and 10% Ethyl Acetate) and then preserved in 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 using a Stereomicroscope, after bringing the collected insects to the laboratory, and compared to the reference collections in the Insect

Biodiversity Laboratory at the Department of Zoology, D.S.B. Campus, Kumaun University, Nainital. Identification was based on key descriptions. Those that could not be identified at the species level were identified at the genus level. Those not readily identified were sent to the Northern Regional Station Zoological Survey of India, Dehradun. Seasons were distributed according to the method used by Farooq *et al.* (2021), i.e., Summer = S (March, April, and May), Rainy = R (June, July, and August), Autumn = A (September, October, and November), Winter = W (December, January and February). Insects were classified on the basis of the number of sightings according to Farooq *et al.* as Very Common (VC) >=70 sightings, Common (C) =30-69, Occasional = (O) = 10-29, Rare = (R) =<=9. All the statistical analysis was performed using Microsoft Excel and PAST 4.13 software, including significance tests, correlation, and multivariate test. The CCA correlation score was further used to construct correlation matrix.

RESULTS AND DISCUSSION

A total of 2195 insect individuals of 26 species were observed during the study, belonging to seven insect orders and 15 families. Among the abundance of various orders, Hymenoptera recorded maximum (30%), followed by Lepidoptera (27%) and Diptera (23%). Orthoptera (3%) and Dermaptera (2%) were in lower abundance. With respect to abundance of families, the most abundant family was Apidae (24%), followed by Pieridae (18%), Culicidae (13%), Nymphalidae (7.5%), Coccinellid*ae* and Vespidae (each 6%), Lebelullidae (5.4%), Sarcophagidae (5.1%), Calopterigidae (3.2%), Calliphoridae (2.8%), Acrididae (2.7%), Asilidae (2.1%), Forficulidae (1.9%), Lycaenidae (0.8%) and Erebidae (0.4%) . Overall, the Shannon Weiver Index (H) was 2.94, whereas Simpson's Dominance (D) was 0.06, and the Gini-Simpson Index (or 1-D) was 0.93, concluding a moderate richness of species during the study. The Pielou's evenness (e^H/S) was high (0.7), signifying the even distribution of most species at the study site. Menhinick Index was 0.53, whereas the Margalef Index was 3.12 (Table 1).

Table 1. Distribution, relative abundance and status of insects observed at the GTE

Order/ family/ Species	Distribution during seasons				RA	Status
	Winter	Summer	Rainy	Autumn		
Dermaptera						
Forficulidae						
Forficula spp. (Linnaeus)	-	+	+	-	0.02	C
Hymenoptera						
Apidae						
Apis dorsata (Fabricius)	-	+	+	-	0.06	VC
Apis cerana (Fabricius)	+	+	+	+	0.16	VC
Bombus haemorrhoidalis (Smith)	+	+	-	+	0.02	C
Vespidae						
Vespa tropica (Linnaeus)	-	-	+	+	0.03	VC
Polistes olivaceus (DeGeer)	+	+	+	-	0.03	VC
Odonata						
Calopterigidae						
Neurobasis chinensis (Linnaeus)	+	+	+	-	0.03	VC

Lebelullidae						
Crocothermis servilla (Drury)	+	+	+	+	0.05	VC
Diptera						
Calliphoridae						
Calliphora vomitoria (Linnaeus)	+	+	+	-	0.03	VC
Asilidae						
Neoitamus spp. (Osten-Sacken)	-	+	+	-	0.02	C
Culicidae						
Culex pipiens (Linnaeus)	-	+	+	+	0.04	VC
Uranotaenia sp. (Lynch Arribjlzga)	-	+	+	+	0.09	VC
Sarcophagidaea						
Sarcophaga argyrostoma (Robineau-Desvoidy)	+	+	+	-	0.05	VC
Orthoptera						
Acrididae						
Acrida exaltata (Walker)	-	+	+	-	0.03	VC
Coleoptera						
Coccinellidae						
Coccinella sempunctata (Linnaeus)	-	+	+	-	0.06	VC
Lepidoptera						
Nymphalidae						
Vanesssa indica (Herbst)	-	+	+	-	0.01	R
Danaus chrysippus (Linnaeus)	+	+	+	-	0.01	O
Ypthilma baldus (Fabricius)	+	+	+	+	0.06	VC
Pieridae						
Colias fieldii (Ménétriés)	+	+	+	-	0.01	R
Belenois aurota (Fabricius)	+	+	+	+	0.02	V.C.
Eurema hecabe (Linnaeus)	-	+	+	+	0.03	V.C.
Pieris brassicae (Linnaeus)	+	+	+	-	0.08	VC
Leptosia nina (Fabricius)	+	+	+	-	0.03	VC
Catopsila pyranthe (Linnaeus)	-	+	+	-	0.01	R
Lycaenidae						
Lampides boeticus (Linnaeus)	-	+	+	-	0.01	R
Erebidae						
Amata bicincta (Kollar)	-	+	+	-	0.02	R

(+)= present, (-)= absent, VC= Very Common, C= Common, O= Occasional, R= Rare); RA- Relative abundance

Of the 26 insect species, 17 were very common, three were commonly seen, one was an occasional visitor and five were rarely observed. *Colias fieldii* (Ménétriés), *Catopsila pyranthe* (Linnaeus), *Lampides boeticus* (Linnaeus) and *Vanesssa indica* (Herbst) were the rare species at the site. *Danaus chrysippus* (Linnaeus) was an occasional visitor. *Neoitamus* spp. (Osten-Sacken), *Bombus haemorrhoidalis* (Smith) and *Forficula* spp. (L.) were common, while the remaining 17 species were very common (Table 1).

The highest Shannon diversity index was observed in Summer (2.9), followed by the Rainy season (2.8). A similar trend for evenness can be seen during the two seasons as 0.8 and 0.7 Pielou's evenness, respectively. The least Shannon diversity and evenness can be seen in the Autumn season. Insects were most evenly distributed during the Summer (Fig. 1). The rainy season shows the highest Margalef Index value (3.41). The alpha diversity variables, tallied seasonally, confirm a significant effect of seasonal variations on insect assemblage (Dominance, Shannon, Simpson, Evenness, Margalef, and Fisher alpha) (2 way ANOVA, $p<0.01$, Sum of squares=27.91, f=10.76) which supports our second hypothesis.

The Individual Rarefaction Curve for various seasons (Fig. 2) estimates the collection effort efficiency. The plot shows the formation of an early asymptote for the winter and autumn seasons, whereas both summer and rainy seasons form a late asymptote curve due to the relatively high number of species found in the rainy and summer seasons.

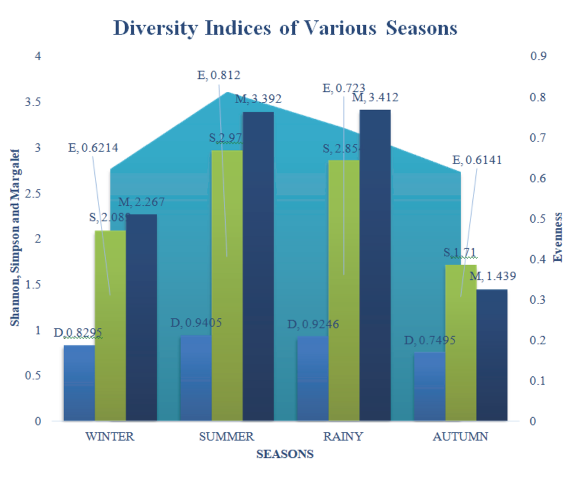

Fig. 1 Seasonal diversity of Insects

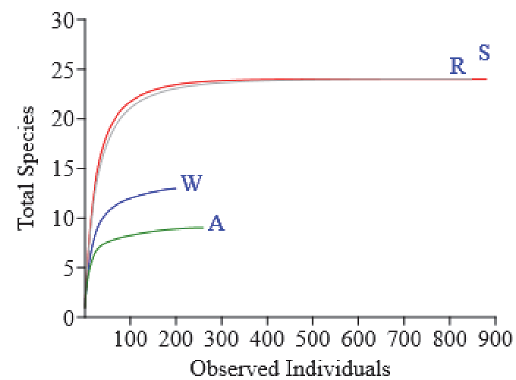

Fig. 2 Seasonal Individual Rarefaction Curve

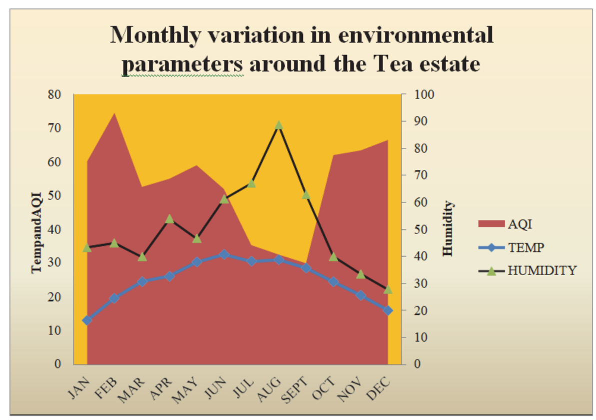

Fig. 3 Monthly variations in the environmental parameters

Among the monthly variation of environmental parameters (Air Quality Index, Temperature and Humidity), the highest humidity in the Tea estate was recorded in August. The average Air Quality Index (AQI) was much lower and fair (53.6). The highest AQI was recorded from November to February, rising above 63. The month of February saw the highest AQI at 74.5 (Fig. 3).

The C.C.A. analysis determined the relationship between insect abundance and environmental variables. The *p*-value of 0.017, suggests a statistically significant relationship between the environmental variables and species abundance data. Axis 1 and 2 demonstrates the statistically

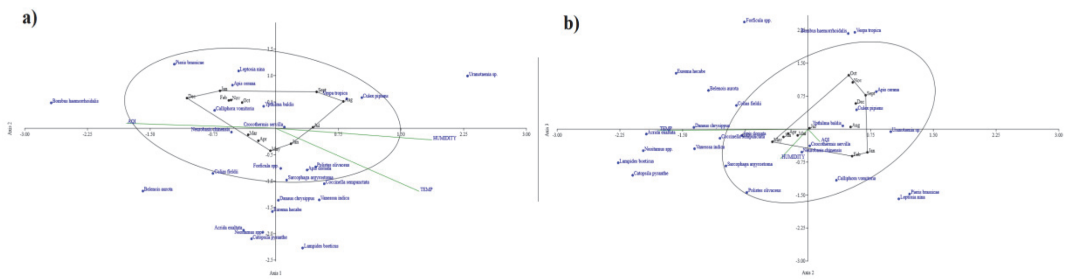

Fig. 4 (a, b): Relationship of insects with the environment variables. a) CCA between Axis 1 vs. 2 b) CCA between Axis 2 vs. 3.

significant relatedness of species on independent variables (Fig. 4a). Axis 3, on the other hand, has a non-significant *p*-value (0.733), explains no significant variations. The insect communities had a positive correlation with Temperature (0.85) and Humidity (0.93), and a negative correlation with the air quality (-0.89) (Fig. 5). Overall correlation of the insect assemblage was noted with these variables.

Distribution of *Bombus haemorrhoidalis* was negatively correlated with temperature (-2.04), which is in correlation with several previous findings (Peat and Goulson, 2005; Ghimire and Bhusal, 2021). The insect community was negatively correlated with air quality, i.e. poor air quality reduced the overall alpha diversity which is in alliance with the disturbance hypothesis and other recent studies (Dial and Roughgarden, 1998; Meléndez-Jaramillo *et al*, 2021). *V. tropica*, *C. pipiens*. and *Uranotaenia sp.* were positively correlated to Air quality, which may be due to their lower sample size, infact their distribution was greatly explained by temperature and humidity collectively (correlation>78%). Axis 1 and 2 explain 69.41 and 30.58 per cent of the variations in the species distribution respectively, which can be attributed to the environmental variables (Fig. 4b). These findings also correlate with previous reporting (Buchori *et al*., 2018; Hamid *et al*., 2014) and further support our first hypothesis that the environmental conditions of the tea estate do affect the population dynamics of its associated insect communities. While most of the species at Ghorakhal Tea Estate show high association with temperature and humidity, butterflies, bees and dragonflies show moderate association with air quality, suggesting their behaviour as indicator species. *Uranotaenia sp.* and other flies show a high association with temperature. This is also certain because temperature highly affects the population dynamics of blood-feeding flies (Yamana and Eltahir, 2013).

In the present study most of the recorded species of insects were locally abundant (Sondhi and Kunte, 2018). *Ceryx wallengren* which was previously identified in this region by Smetacek (2010) was not recorded in our study, instead another member of subfamily Arctiinae, *Amata bicincta* was identified which is not a local endemic species (Majumdar, 2010). The present study does not monitor the insect communities outside the perimeters of the tea estate, and therefore we could not obtain a comparative data with the surrounding biodiversity, which is a major limitation in this study. Neither does the study present temporal data beyond a year, which underscores our understanding of the long-term effect of climate change in this micro-environment. Most studies associated with tea also highlight the associated pest activity, which is an understudied aspect of this work

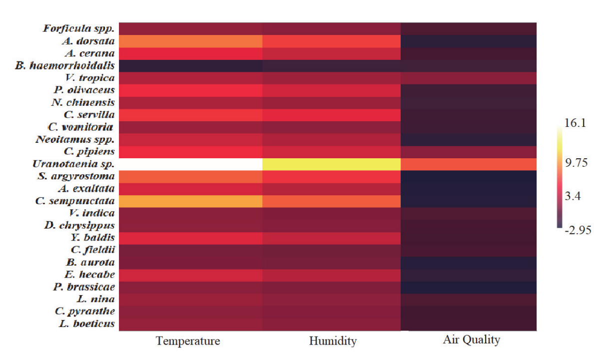

Fig. 5 Correlation of Insect assemblage in Tea estate with environment variables

(Chhetri 2007; 2010). Higher abundance of Hymenoptera (30%) and diversity in the order Lepidoptera was noted from the GTE, which corresponds to the reporting of various studies from the western Himalaya (Goswami *et al*., 2013; Arya *et al*., 2020; Chandra *et al*., 2023). Among the pollinators, Apidae was the most abundant (24%), followed by Pieridae (18%). Diversity and evenness for both autumn and monsoon seasons were found to be highest. Chhetri (2007; 2010) measured the insect diversity for two seasons, autumn and monsoon, in the Teesta valley tea garden, with Shannon diversity indices of 1.62 and 1.73, respectively, and evenness indices of 0.90 and 0.88, respectively. Several studies have reported high seasonal diversity of insects during the spring with low abundance in autumn which correlates with our findings (Bhusal *et al*., 2019). Das (2021) reported 39 species of Orthoptera in the tea agroecosystem of West Bengal. The study found orthopteran insects as significant species in the tea agroecosystem.

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