J. Env. Bio-Sci., 2019: Vol. 33 (1): 19-29 ISSN 0973-6913 (Print), ISSN 0976-3384 (On Line)

ALTITUDE AND SEASONALITY OF THE HYMENOPTERAN INSECTS ASSOCIATED WITH HIGH ALTITUDE FOREST OF NANDA DEVI BIOSPHERE RESERVE, WESTERN HIMALAYA, INDIA

Kishor Kumar[1], P.C. Joshi[2], M.K. Arya,[3] and P. Nath[2]
G.B. Pant National Institute of Himalayan Environment & Sustainable Development,
Himachal Regional Center, Mohal-Kullu, 175 126, Kullu, Himachal Pradesh
Department of Zoology and Environmental Sciences, Gurukul Kangri University, Haridwar, Uttarakhand
Department of Zoology, DSB, Campus College, Kuamun University, Nainital (Present address)
Corresponding Author Email[1]: kishorkkothari5@gamil.com

Received: 10-10-2018 **Accepted:** 12-11-2018

Assessment of altitude, habitat, and seasonality of the Hymenoptera associated with a forest of the Nanda Devi Biosphere Reserve (NDBR) was carried out during 1998-2000. The Reserve area spreads across the three districts of Uttarakhand State i.e. Chamoli, Bageshwar, and Pithoragarh. The area selected for the study sites falls within the buffer zone of NDBR representing to Chamoli district of Uttarakhand State. The study reveals a total of 20 species of Hymenoptera belonging to 17 genera of 07 families were recorded during the study period. Among the recorded Hymenoptera, Apidae was the most dominant family with 7 species and 5 genera followed by Scolidae with 5 species and 5 genera each, Pomplidae, Ichneumonidae, and Vespidae (2 species each) and Sphecidae and Eumenidae 01 species each respectively. The species richness of observed insects generally decreased with the increase of altitude of the study area and higher density and diversity was concentrated between the middle altitudinal zone. Across the years, it's observed that the population density, abundance, and diversity of the Hymenopterans are highly influenced with the availability of the floral resources, floral habitat, seasonal pattern, weather, and climate cycles of the study sites. Environmental variable i.e., relative humidity and temperature also play an important role in the fluctuation of density and diversity of the Hymenoptera. Generally, higher density diversity was recorded during the rainy season while the lowest range of density and diversity are recorded during the winter season.

Key words: .Hymenoptera, Altitude, Seasonal variations, Diversity, Density

Hymenoptera comprises of Honey bees, solitary bee, bumble bees, carpenter bees, wasps, ants, predators, and parasitoids. The global diversity of hymenopteran fauna is about 1,53,088 species (Zhang 2013), of which approximately 10,605 species are known from India. Indian Himalayan biogeographic region has the representation of 3,054 species under 816 genera of 52 families and 16 superfamilies (Rajamohana *et al*., 2018). The Hymenoptera are well recognized for providing valuable ecosystem services in the form of pollination for successful fertilization, the formation of fruit, seed, and sustainable production in the natural and agroecosystems. The bees and other associated pollinators responsible for the successful fertilization and production of approximately 87 species of the world leading food crops i.e., fruits, vegetables or seeds, comprising of 35% of global food production (Losey & Vaughan 2006, Klein *et al*., 2007 and Gallai *et al*., 2009). Besides the conservation and management of biodiversity, pollinators are also known one of best biodiversity indicators and are most sensitive to environmental variation and habitat quality (Tscharntke *et al*., 1998; Klein *et al*., 2002; Tylianakis *et al*., 2004 and 2005). Several factors such as habitat, abiotic and biotic factors, flowering resources and microclimatic conditions also influence the density and diversity of Hymenopteran insects (Wardell *et al*., 1998; Klein *et al*., 2002; Tylianakis *et al*., 2006. Temporal variation in abiotic factors such as air humidity and temperature as well as seasonal availability of resources may influence the populations of many arthropods (Kearns 1998; Tylianakis *et al*., 2005 and Stangler *et al*., 2015).

First-time detailed investigation on diversity and distribution of the Indian Hymenoptera (Bees and Wasp) carried out by Pioneer workers i.e., Bingham (1897) and Cameron (1897). Subsequently detailed work on other Hymenoptera insects (Honey Bees, Bumble, Carpenter and Solitary bees, Wasps, Ants, etc.) fauna of Indian Sub-continent has been undertaken by several other earlier workers Morley 1913; Allen 1975; Kaur & Jonathan 1979; Husain & Agarwal 1981a b, 1982a,b; Das & Gupta 1983; Mondal and Nandi 1989; Das & Gupta 1989 and Engel 2002). The impact of altitude, latitude, season, habitat heterogeneity, biotic and abiotic factors (floral resources, temperature, relative humidity) on population density, body size, body weight and Biomass of Hymenoptera and various other insect groups have been undertaken by several others earlier workers (Evans 1964; Davis & Gray1966; Evans &

Murdoch 1968; Janzen & Schoener 1968; Janzen 1973; Vats & Singh 1978; Wolda 1978; Kaushal 1979; Vats & Mittal 1983; Kaushal and Vats 1984; Powell & Powell 1987; Kaushal & Joshi 1988; Kaushal & Joshi 1991; Andow 1991; Rathcke & Jules 1993; Kruess & Tscharntke 1994; Stone 1994; Roland & Taylor1997; Joshi & Sharma 1997; Raw 1998; Wolda 1988; Chilima & Leather 2001; Williams *et al*., 2001; Klein *et al*., 2002; Hunter 2002; Tylianakis *et al*., 2004; Tylianakis *et al.,* 2005; Ulrich 2006 and Ulrich 2008).Significant account of work regarding the inventory and species composition of Hymenoptera fauna from Western and North Western Himalaya (Uttarakhand and Himachal Pradesh) been carried out by several other earlier workers (Paiva 1907; Singh 1963; Gupta & Das 1977; Mani & Sharma 1982; Williams 1988; Das & Gupta 1989; Singh & Singh 1993; Gupta 1995; Jonathan 1995; Uniyal & Singh 1996; Gupta 1997; Jonathan 2005). Based on the synthesis of available information on the altitudinal and seasonal variation of density and diversity of Hymenoptera particularly in Nanda Devi Biosphere Reserve not has been carried out so far. Realizing the various direct and indirect importance of Hymenoptera in biodiversity conservation and sustainable ecosystem management the present study have been proposed with following objectives a. to assess the species composition and population density of Hymenoptera); ii. to assess the effect of seasonal and temperature variation on the population density of Hymenopteran community.

MATERIALS AND METHODS

The Study Area: The study was conducted in the Nanda Devi Biosphere Reserve (NDBR), a world Heritage Site located in the Northern part of West Himalaya, India. It has a large altitudinal range (1,800-7,817m asl) and covers an area of 6,407.03 km$^{2.}$ The unique topography, climate and soil support diverse habitats, species, communities and ecosystems. The reserve harbors high diversity of both flora and fauna. A total of 45 villages fall within the buffer zone of the reserve, which are populated by 653 permanent and 4808 seasonal residents (Samant *et al*. 2004). The endangered mammals are snow leopard (*Uncia uncia),* Himalayan black bear (*Selenarctos thibetanus),* brown bear (*Hemitragus jemlahicus*) and serow (*Capricornis sumatraensis*) and Musk deer (*Moschus chrysogaster*). Among the birds Himalayan Monal phesant (*Lophophorus impejanus*), Koklas phesant (*Pucrasia macrolopha*), Himalayan snow cock (*Tetraogallus himalayensis*), Himalayan golden eagle (*Aquila chrysosaetos*), Eastern steppe eagle (*Aquila rapax)*, Black eagle (*Ictinaetus malayensis*), and Himalayan bearded vulture (*Gypaetus babatus*) are endangered species (Kala *et al*. 1998; Kumar *et al*., 2001). The plant diversity includes ecologically and economically important species such as *Aconitum heterophyllum, Podophyllum hexandrum, Nardostachys grandiflora, Picrorhiza kurrooa and Saussurea ovallata* etc. Four study sites (with an area of 3 ha each) i.e., Reni, Lata, Tolma and Dronagiri were selected in the NDBR, in a manner that they represent different altitudes, habitat types and level of disturbances due to settlements of migratory grazers (Table 1). Four study sites (i.e. Reni, Lata, Tolma and Dronagiri) were selected in the buffer zone of NDBR to cover the different altitudes, habitat types and level of disturbances due to physical and anthropogenic pressure by the various migratory shepherd communities and their cattle. Each study site is having an area of 3 ha. An extensive and regular monthly collection of insects was made during the course of study (1998-2000). A detailed description of selected sites has been given in Table 1.

Assessment of Density and Diversity of Hymenoptran Insect: The population density of Hymenoptera was assessed by Sweep sampling method (Gadagkar *et al*. 1990). The collected Hymenopterans were transferred into bottles containing ethyl acetate soaked cotton. All the specimens were brought to the laboratory; these were preserved and subsequently got identified with reference to collections in the Entomology divisions of the Zoological Survey of India (ZSI), Kolkatta and Indian Agricultural Research Institute (IARI), New Delhi as well as with the help of (Beeson 1941, ZSI 1995; ZSI 1997). The study was conducted on monthly interval during 1998-2000. The density of insects was expressed as a number of individuals/hectare. For the estimation of biomass collected individuals of the insect was stretched, pinned and oven dried at 60^{0}C for 72 hours. Each sampling year was divided into 3 seasons i.e., winter (November, December, January, and February), summer (March, April, May and June) and Rainy(July, August, September and October) respectively.

Temperature and Humidity: To determine the effect of abiotic parameters on density, body weight/ biomass of Hymenopteran insects, the temperature and humidity of selected study site were also recorded during the sampling of insects by using thermo hygrometer.

Vegetational Composition: To determine the potential role of flowering resources for conservation and sustenance of majority of the Hymenopteran fauna a detailed survey of vegetational composition was also carried out from all the selected study sites. Collected vegetation samples/ herbarium got indentified from the help of plants taxonomist from GBPNIHESD, Kosi- Katarmal, Almora and standard keys (Samant et al.1996, Samant 1999).

RESULTS AND DISCUSSION

1. (Abiotic Factors): Variation in Temperature and Humidity: Abiotic factors i.e., temperature, relative humidity, and rainfall influence the density and diversity of majority of insects in various ways including the Hymenoptera. Keeping in view of the high importance of climatic variables for successful completion of life cycles of the insects, the data on temperature and relative humidity were also recorded during sampling of the insects from each of selected study sites. The annual variation pattern of temperature and humidity during the study period (1998-2000) are given a Fig.1 and 2.

Biotic Factors

2 (i). Vegetational Composition: Hymenoptera (Bees and other associated Insect/ pollinators) are known as bio-indicators. The density and diversity of the majority of the Hymenoptera rely on various flowering resources providing pollen, nectar and nesting material for food and survival Hymenoptera. Some of Pollinating (Hymenoptera) equally important for the successful pollination of the majority of wild and domesticated flowering plants for their successful fertilization and maintenance of crop productivity in general and conservation and management of biodiversity in particular. Considering the importance of Hymenopteran fauna for the conservation of the plant diversity as well as potential food resources, the information of available Plants (Herbs, Shrubs, and Trees) were also carried out during the assessment of density and diversity of insects from each of the study sites. A total of 150 plant species, including 20 trees, 34 shrubs, and 96 herbs were recorded from across the study sites and some of the key species are given in Table 1.

2 (ii). Species composition of Hymenoptera: Across the selected study sites in NDBR, a total of 20 species of Hymenoptera belonging to 17 genera of 07 families were recorded during the study period. Among the recorded Hymenoptera, Apidae was the most dominant family with 7 species and 5 genera followed by Scolidae with 5 species and 5 genera, Pomplidae, Ichneumonidae, and Vespidae (2 genera and 2 species each), and Sphecidae and Eumenidae 01 species each respectively. Maximum numbers of Hymenopteran species were recorded from the study sites located in the low altitudinal area while lowest numbers of hymenopteran species were reported from the study sites located in a high altitudinal area (Table 1and 2).

3. Assessment of Population Density of the Hymenoptera: Biannual observations on the population density of the Hymenoptera indicated a strong monthly variation among the study sites in a high altitude biosphere reserve. Population density and diversity of Hymenoptera are highly influenced with altitude, habitat, climate and seasonal patterns of the sampling year (Fig.3 & 4). During both, the year's generally population density and diversity of Hymenopteran insects decreases with increasing of altitude. Higher density and diversity of insect observed in middle altitudes (Lata, Tolma) while lowest density and diversity were recorded in (Dunagiri) higher altitudinal sites (Table 1, Fig. 3 & 4).

4. Seasonal Variation in the Population Density of Hymenoptera: Across the study sites, generally increasing trend of the density values was started from the summer season and reached a maximum during the rainy season. Across the sites, the lowest values of the densities were recorded during the months of the winter season. This may be attributed to the maximum availability of food resources during the summer and rainy season (Fig.5). Across the years among each of study site monthly variation on temperature highly influence the population density and diversity of the Hymenopteran insects. During both, the years' population density of Hymenoptera were significantly increased with the increase in the temperature and relatively decreases with decrease in the temperature during the winter (December-March) winter months (Fig.6 and 7).

The population density, abundance, diversity, body weight and biomass of Hymenoptera are closely associated with the diversity of the seasonal flowering resources, habitat quality, and altitude, seasonal and climatic variation in a particular area. In the present study density and species diversity of

Table 1: General features of the selected study sites in the Nanda Devi Biosphere Reserve as recorded during study period

Parameters(	Altitude (m)	Annual Temperature range (⁰C)	Annual Humidity range (%)	Major vegetation types
Reni	2000	3-26	20-88	*Cupressus torulosa, Lyonia ovalifolia, Rumux hastaus, Hippophae salicifolia, Demodium elegans, Apluda mutic a, Cynodon dactylon and Cannabis sativa*
Lata	2300	3-26	18-70	*Cedrus deodara, Aesculus indica, Juglens regia, Pyrus pashia, Colquhonia coccinea, Berberis aristata, Caragana versicolor, Cotoneaster microphyllus*
Tolma	2550	3-24	23-67	*Cedrus deodara, Cupress us torulosa, Berberis aristata, B. kumonensis, Arundinaria, Artemisia nilagarica, Thalictrum pauciflorum, Sporobolus sp. and Apluda mutica.*
Dronagiri	3200	0.5-18	22-75	*Artemisia nilagarica, Pinus wallichiana, Betula utilis, Taxus baccata, Cirsium wallich i, Anaphilis contrata*

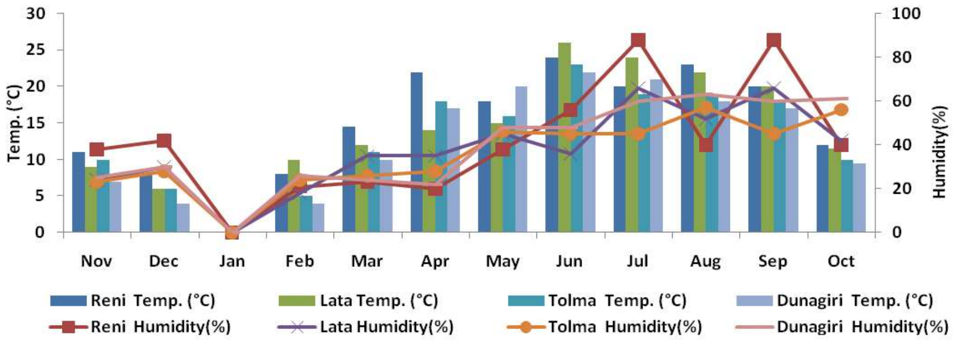

Fig.1: Variation in the temperature (⁰C) and humidity (%) among the study sites in the NDBR (1998-1999).

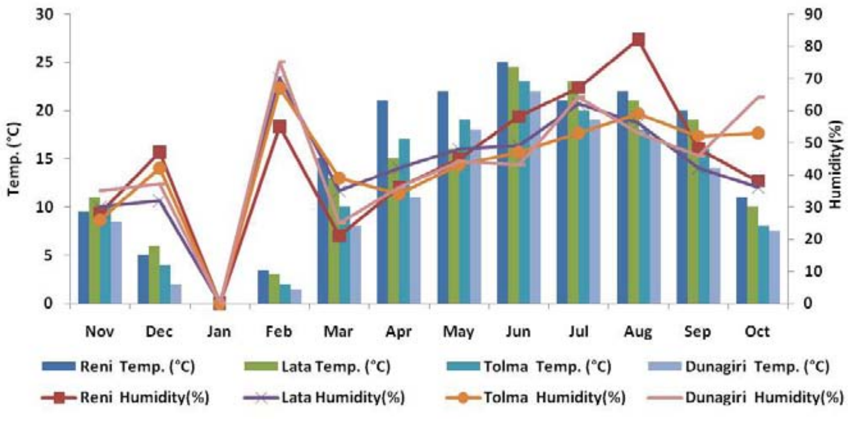

Fig.2: Variation in the temperature (⁰C) and humidity (%) among the study sites in the NDBR (1999-2000).

Table 2: Species composition of Hymenoptera among the selected sites in NDBR

S.N.	Taxonomic Groups	1998-1999				1999-2000			
Family : Apidae		S1	S2	S3	S4	S1	S2	S3	S4
1.	*Apis cerana*	+	+	+	-	+	+	+	-
2.	*Apis laboriosa* Smith.	+	+	+	+	+	+	+	+
3.	*Coelioxy sp.*	+	+	-	-	+	+	-	-
4.	*Crocisa ramosa* Lepel.	+	+	-	-	+	+	-	-
5.	*Anthophora sp.*	+	+	+	+	+	+	+	+
6.	*Bombus tunicatus* Smith	+	+	+	+	+	+	+	+
7	*Bombus flavescens* Smith	-	-	+	+	-	-	+	+
Scolidae									
8.	*Campsomeris asiatica himalaya* Bar	-	+	+	+	-	+	+	+
9.	*Megacampsomeris prismatica* Smith	+	-	-	-	+	-	-	-
10.	*Scolia venusta* Smith.	-	-	+	-	-	+	+	-
11.	*Scolia (Discolia) dehraensis* Betrem	-	-	-	+	-	-	-	+
12.	*Elias* sp	+		+	+	+		+	+
Pomplidae, Ichemonidae and Vespidae									
13.	*Salius flavns* Fabr	+	+	-	-	+	+	-	-
14.	*Aporus cotesi* Cameron				+				+
Ichemonidae									
15.	*Ichneumon* sp.	+	+	+	+	+	+	+	+
16.	*Ophion* sp.	+	+	+	-	+	+	+	-
Vespidae									
17..	*Vespa velutina auraria* Smith	+	+	+	+	+	+	+	+
18..	*Polistes maculipennis* Saum	-	+	+	+	+	+	+	+
Sphecidae									
19.	*Amnophila punctata* Smith	+	+	+	+	+	+	+	+
Eumenidae									
20.	*Eumenes punctata* Saussure.	-	-	+	-	-	-	+	-
	Total (Across th e selected sites)								
		13	13	15	13	14	14	14	12

Abbreviations used: S1: Reni, S2: Lata, S3: Tolma, S4: Dunagiri, +: species present, -: species absent

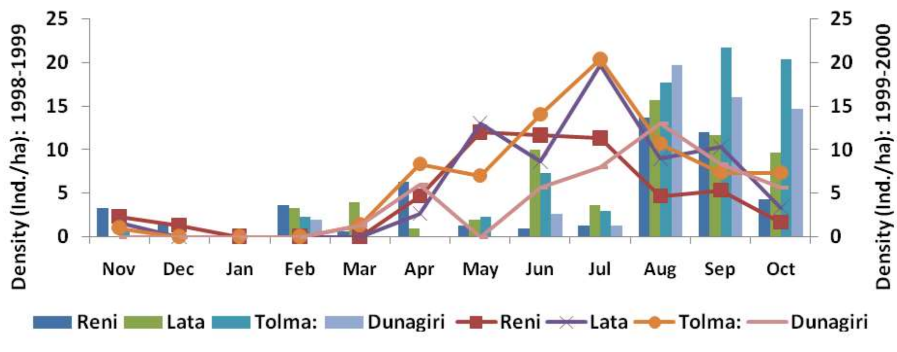

Fig.3: Monthly Variation in Density (Ind./ha) of the Hymenoptera (1998-2000).

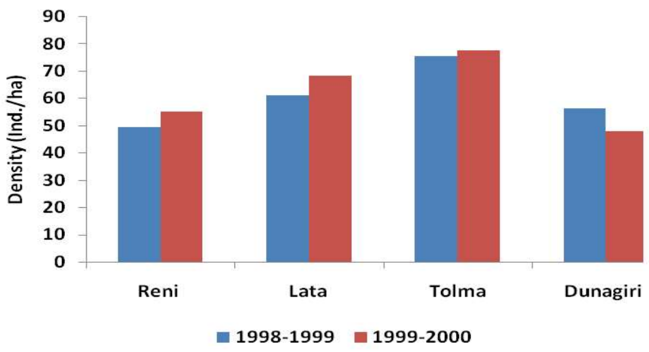

Fig. 4: Variation in the total Density (Ind. /ha) of the Hymenoptera (1999-2000).

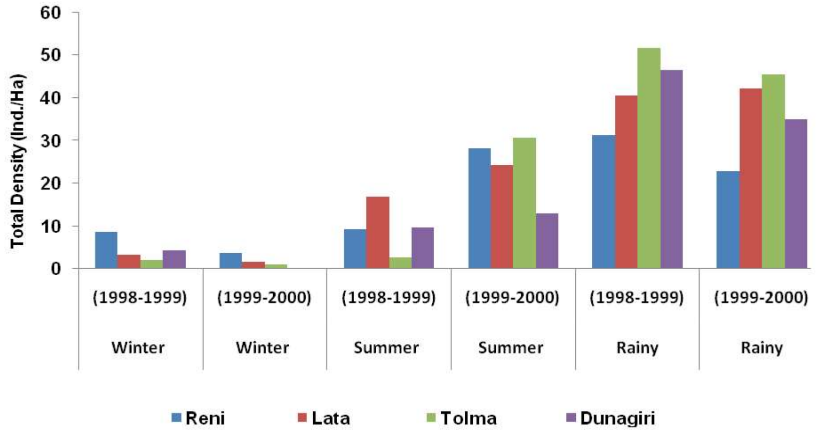

Fig. 5: Variation in Total Seasonal Density (Ind/ha) of the Hymenoptera (1998-2000).

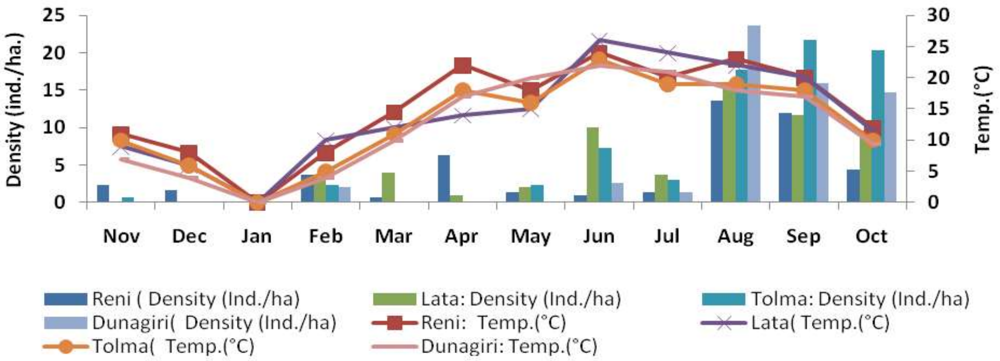

Fig. 6: Variation on Population Density of Hymentoptera with annual monthly temprature among the slected study sites (1998-1999).

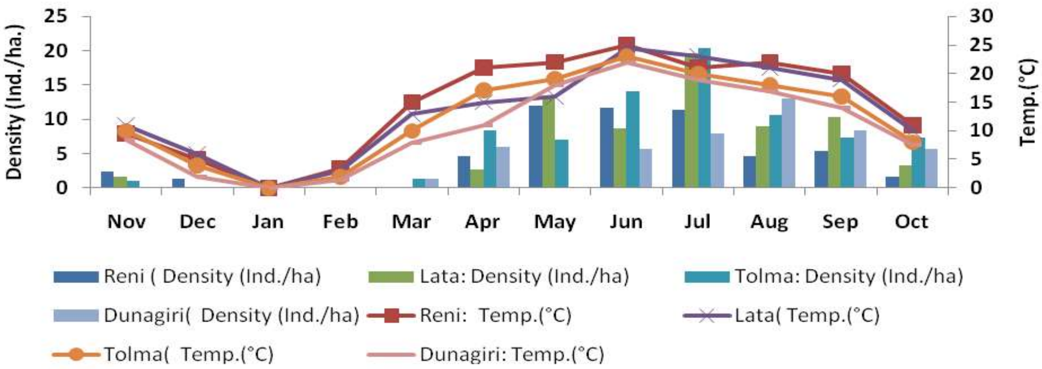

Fig. 7: Variation on Population Density of Hymentoptera with annual monthly temprature among the slected study sites (1999-2000).

majority of Hymenoptera (honey bees, bumble, carpenter & wild bees, wasps, hornets, etc.) exhibits a high variation with the altitude of the study. Generally increasing patterns of density and diversity was observed with decreasing altitude. Maximum diversity of Hymenoptera have reported from the sites located between the lower to middle altitude and comparatively decreased density and diversity are observed from the sites located in the highest altitudinal range. Janzen 1973 and Lawton et al. 1987 reported the highest density and diversity of insect from middle/intermediate elevations from Costa-Rica and Britain respectively. Wolda (1987) worked on the effect of altitude and habitat quality on tropical forest insect community of Republic of Panama and revealed the insect's species richness as well as sample size decreased gradually with an increasing altitude over a 2200 m from and reached maximum in intermediate altitude. McCoy (1990) studied distribution patterns of insects along an elevation gradient(100 m and 1700 m) among the twelve open fields in the southern Appalachian Mountains of North Carolina, Virginia, and Maryland and also observed the highest richness and abundance between the mid-elevation sites. Samson et al., 1997 surveyed the patterns of Ant along an elevational gradient in the Philippines extending from lowland dipterocarp forest (250 m elevation) to mossy forest (1750 m) and found higher species richness and relative abundance at mid-elevations and declined in diversity were reported sharply with increased elevation. More recently, Escobar *et al*. 2005 conducted studies on the altitudinal variation of dung beetle (Scarabaeidae: Scarabaeinae) assemblages in the Colombian Andes and found the highest richness of Scrab beetles between the middle elevation. The finding of present investigation also supported by the finding of various pioneer and recent workers on altitudinal range wise variation in diversity, abundance, body size and body mass of hymenopterans under various ecosystems (Kusnezov, 1957; Janzen *et al*. 1976; Wolda 1987; Fowler and Claver1991; Faiji- Brener and Ruggiero, 1994; Samson *et al.,*1997; Brehm & 2003; Joshi *et al*., 2008).

In the present finding, it was seen that during both the sampling years the seasonal pattern of the study area highly influences the population densities and diversity of the hymenopterans insect because the presence and absence of the Hymenoptera in a particular location entirely depend on the available flowering plant diversity and there blooming time. In the result of the present study also revealed the increased trend of density and diversity of Hymenoptera between the months of summer and rainy (July-Oct.) and lowest values of density and biomass are recorded during the months of (Nov.-Feb.) winter season (Figs.3 and 5). Our investigations also indicate a positive influence of annual climatic trend i.e. (season) on density and diversity of the hymenopterans population in a temperate region. The climatic conditions in the rainy season provided the most suitable environment for the growth and development of Hymenoptera populations. The rainy season also supports the highest diversity of floral food resources (pollen, nectar, nesting, and prey) which provides the best possible opportunity for the survival and mating success of the majority of the Hymenopteran insects. Similarly, the winter season of the high land area provided an abruptly adverse condition for the growth and survival of Hymenoptera population. Wolda (1980) reported the highest peaks of Leafhoppers (Homoptera) density and abundance during the rainy season from Panama. Kaushal and Vats 1983 obtained minimum values of density and biomass of insects either in summer (April-June) or in winter (October-February) and the maximum values during the rainy season (late June-September) from a tropical grassland. Wolda and Broadhead (1985) also reported a strong seasonal variation in the abundance of Psocoptera community in the tropical forest of Panama. Kaushal (1979) and Kaushal & Vats 1988 obtained maximum insect density in the middle of summer season while minimum density in the dry winter season from temperate grassland. Several other studied undertaken by various workers under different parts of the world also reported the increasing trend of abundance, density and biomass of the diverse insect groups including Hymenoptera between summer and rainy seasons and declined value of density and biomass during the winter season by several other earlier workers (Evans 1964, Evans and Murdoch 1968; Janazen & Schoener 1968, Wolda 1978, , Kaushal 1979; Janzen et al. 1982, Kaushal & Vats 1983, Wolda et al., 1985, Wolda 1988, Wolda et al., 1998; Chilima & Leather 2001; Richards & Coley(2007) and Richards & Windsor 2007).Insect abundance and distribution are regulated by several biotic and abiotic factors and their interactions. Among abiotic factors, temperature and humidity stand out as the most important ones constraining abundance and distribution of insect. Our result (Figs. 6 and 7) also indicates a significant regulating factor of temperature on density, diversity and distributional patterns of Hymenoptera.

Our findings also supported with similar findings by other workers regarding the effect of several other factors, such as prey abundance, floral resources diversity, and availability of places for nesting and microclimatic conditions on population density, body size weight and biomass of Hymenoptera (Klein *et al*., 2002; Tylianakis *et al*., 2006). Land-use patterns, biotic and abiotic factor including microclimatic conditions affect the diversity and distribution of the hymenopterans (Klein *et al*., 2002; Tylianakis *et al*., 2006; Batista Matos *et al*., 2013; Stangler *et al*., 2015). On the basis of the present study, it can be suggested that the conservation and management of natural habitats of Hymenoptera support the better food resource arability (seasonal flowering plants), nesting sites and favorable environment for survival and high population density and diversity of Hymenopteran fauna. So, Hymenoptera fauna linked with wild and agro-ecosystem can provide better ecosystem services in the form of sustainable crop production as well as biodiversity conservation.

ACKNOWLEDGEMENTS

Authors are thankful to Director, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, Uttarakhand for logistic support. Prof. B.D. Joshi, former Head & Dean, Department of Zoology and Environmental Sciences, Gurukul Kangri University, Haridwar is highly acknowledged for his continuous help and support during the course of study. Residents of Reni, Lata, Tolma and Suraithota village are duly acknowledged for their support in various ways during the field survey.

REFERENCES

1. Allen, H.W. (1975). The genus Tiphia of the Indian subcontinent. Technical Bulletin of United State Department of Agriculture 1509 : 1-96.
2. Andow, D.A. (1991). Vegetational diversity and arthropod population response. Annual Review of Entomology 36:561-586.
3. Beeson,C.F.C. (1941). The Ecology and control of the forest insets of India and the neighbouring countries. Vasant Press, Dehradun, 1007 pp.
4. Bingham, C.T. (1897). The Fauna of British India including Ceylon and Burma: Hymenoptera, 1(Wasps and Bees). pp597.
5. Brehm, G., and Fiedler, K., (2003). Faunal composition changes with altitude in an Andean montane rain forest. Journal of Biogeography 30(3):431-440.
6. Bruhl, CA,,Mohamed, M., and Linsenmair, K.E. (1999). Altitudinal distribution of leaf litter ants a transaction primary forests on Mount Kinabalu, Sabah, Malaysia. Journal of Tropical Ecology 15:265-277.
7. Cameron, P. (1897). Hymenoptera orientalia, or contributions to a knowledge of the Hymenoptera of the Oriental Zoological Region, part 5. Memoirs and proceedings of the Manchester Literary and Philosophical Society 41: 44-51.
8. Chilima, C. Z., and Leather, S.R. (2001). Within-tree and seasonal distribution of the pine woolly aphid *Pineus boerneri on Pinus kesiya* trees. Agricultural and Forest Entomology 3(2): 139-145.
9. Das, B.P. and Gupta, V.K. (1983). A catalogue of the families Stenogastridae and Vespidae frofll the Indian Subregion

(Hymenoptera: Vespoidea). Oriental Insect 17: 395-464.

10. Das, B.P. and Gupta, V.K. (1989). The social wasps of India and the Adjacent countries (Hymenoptera : Vespidae). Oriental Insect Monograph 11:1- 292.
11. Davis, L.V. & Gray, I.E. (1966). Zonal and seasonal distribution of North Carolina salt marshes insects. Ecological Monograph 36: 275-296.
12. Engel, M.S. (2002). The honey bees of India, Hymenoptera: Apidae. Journal of Bombay Natural History Society 99(1) : 3-7.
13. Escobar, F., Lobo, J.M. and Halffter, G. (2005). Altitudinal variation of dung beetle (Scarabaeidae: Scarabaeinae) assemblages in the Colombian Andes. Global Ecology and Biogeography 14: 327-337.
14. Evans, F. C., and Murdoch, W.W. (1968). Taxonomic composition, trophic structure and seasonal occurrence in a grassland insect community. Journal of Ecology 37: 259-273.
15. Evans, H. E. (1964) A synopsis of the American Bethylidae (Hymenoptera, Aculeata). Bulletin of the Museum of Comparative Zoology 132, 1-222.
16. Farji-Brener, A. G. and Ruggiero, A. (1994). Leaf cutting ants (Atta and Acromyrmex) inhabiting Argentina: pattems in species richness and geographical range sizes. Journal of Biogeography 21: 391-399.
17. Fowler, H.G. & Claver, S. (1991). Leaf cutter ant assemblages: effect of latitude, vegetation, and behavior. In ant plant interactions (eds. C.R. Huxley and D.F.Cutler). Oxford: Oxford University Press.pp.51-59.
18. Gadagakar, R., Chandrashaekara, K. and Nair,P.(1990). Insect species diversity in the tropics: sampling method and case study. Journal of Bombay Natural History Society 87 (3): 328-353.
19. Gallai, N., Salles, J.M., Settele, J., and Vaissiere, B.E. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics 68(3): 810-821.
20. Gupta, S. K. (1995). Hymenoptera : In Fauna of Western Himalaya (U.P.). Himalayan Ecosystem Series: Part 1. Ed. Director Zoological Survey of India, Kolkata, India. Pp. 81-89.
21. Gupta, S. K. (1997). Hymenoptera: In Fauna of Nanda Devi Biosphere Reserve. Ed. Director Zoological Survey of India, Kolkata, India. Pp. 97-104.
22. Gupta, V.K., and Das, B.P. (1977). Distributional patterns of Indian Vespidae (Hymenoptera) with reference to altitude. Entomon 2(2): 209-213.
23. Hunter, D.M. (2002). Landscape structure, habitat fragmentation and the ecology of insects. Agricultural and Forest Entomology 4: 159 -166.
24. Hussain, T. and Agarwal, M.M. (1981a). Systematic studies on Indian Dirhininae (Hymenoptera Hymenoptera:Chalcididae). Oriental Insect 15: 179-193.
25. Husain, T. & Agarwal, M. M. (1981b). Taxonomic studies on Indian Epitraninae (Hymenoptera: Chalcididae). Oriental Insect. 15 : 413-432.
26. Husain, T. & Agarwal, M. M. (1982a.) Taxonomic studies on Haltichellinae of India (Hymenoptera: Chalcididae) P. T. I. Haltichellini Oriental Insect 16: 313-336.
27. Husain, T. & Agarwal, M. M. (1982b). Indian species of Brachymeria Westwood (Hymenoptera : Chalcididae). Oriental Insect: 491-509.
28. Janazen, D. H. and Schoener, T. W. (1968). Difference in insect abundance and diversity between wetter drier sites during a tropical dry seasons. Ecology 49 : 46-110.
29. Janzen, D.H. (1973). Sweep Samples of Tropical Foliage Insects: Effects of Seasons, Vegetation Types,Elevation, Time of Day, and Insularity. Ecology 54(3): 687-708.
30. Janzen, D.H., Ataroff, M., Farinas, M.., Farinas, M., Reyes, S., Rincon, N., Soler, A., Soriano, P and Vera, M. (1976). Changes in the arthropod community along an elevational transect in the Venezuelan Andes. Biotropica, 8: 193-203.
31. Janzen, D.H., De Vries, P.J., Higgins, M.L., and Kimsey, L.S. (1982). Seasonal and site variation in Costa Rican euglossine bees at chemical baits in lowland deciduous and evergreen forests. Ecology 63:6-74.
32. Jonathan, J.K. (2005). Hymenoptera: Ichneumonidae in Fauna of Western Himalaya (Part -2). Ed. Director Zoological Survey of India, Kolkata, India. Pp. 191-220.
33. Jonathan, J.K. (1995). Hymenoptera : Ichneumonidae. Himalayan Ecosystem Series: Fauna of Western Himalaya Part I (Uttar Pradesh) : 91-110.
34. Joshi, P. C. (1997). Population dynamics and biomass of Hymenoptera in a temperate grassland. The Indian Forester 123 (3): 245-248.
35. Joshi, P.C. and Sharma, R. (1998). Population density and secondary net production of above ground entomofauna of a cropland field. Uttar Pradesh Journal of Zoology 18 (1): 1-4.
36. Joshi, P.C., Kumar, K. and Arya, M. (2008). Assessment of insect diversity along an altitudinal gradient in Pinderi forests of Western Himalaya, India. Asia Pacific Journal of Entomology. 11(1):5-11.
37. Kaur, R. and Jonathan, J.K. (1979). Ichneumonologia Orientalis, Part VIII. The tribe Phytodietini from India (Hymenpotera : Ichneumonidae). Oriental Insect Monograph 9 : 1-276.
38. Kaushal, B. R. (1979). Studies on seasonal variations in population density and biomass of aboveground insects in a tropical grassland and energetics of two insects. Ph.D. Thesis. Kurukshetra University, India p.242.
39. Kaushal, B.R.and Joshi, P.C. (1991). Energy dynamics of grasshopper population in a temperate grassland community. Australian Journal of Ecology 16: 295- 300.

40. Kaushal, B.R. and Joshi, P.C. (1988). Population, biomass and secondary net production of aboveground insects in a temperate grassland. Proceedings of Indian National Science Academy of Science 97(4): 319-327.

41. Kaushal, B.R. and Vats, L.K. (1983). Population dynamics and biomass production of above ground insects In a tropical grassland. Proceedings of Indian Academy of Science (Anim. Sci.). 92(6): 447-452.

42. Kaushal, B.R. and Vats, L.K. (1984). Fluctuations of Hymenopteran Populations and Biomass in a Tropical Grassland. Proceedings of Indian National Science Academy of Science 50(6):565-570.

43. Kearns, C.A., Inouye, D.W. amd Waser, N.M. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics 29: 83-112.

44. Klein, A.M., Steffan-Dewenter, I., Buchori, D., and Tscharntke, T., (2002). Effects of land-use intensity in tropical agroforestry systems on flower-visiting and trap-nesting bees and wasps. Conservation Biology 16: 1003-1014.

45. Klein, A.M., Vaissiere, B.E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of Royal Society of London (Biology) 274: 303-313.

46. Kruess, A., and Tscharntke, T. (1994) Habitat fragmentation, species loss, and biological-control. Science 264: 1581-1584.

47. Kumar, K., Joshi, P.C. and Badoni, V.P.(2018). Variation in population density and biomass of grasshoppers (Insecta: Orthroptera) in Nanda Devi Biosphere Reserve (NDBR), West Himalaya, India. Journal of Environment and Bioscences 32(1):125-135.

48. Kumar, K., Joshi, P.C., Joshi, R. and Arya, M. (2015). Variation in population density and biomass of grasshoppers (Insecta: Orthroptera) in Nanda Devi Biosphere Reserve (NDBR), West Himalaya, India. Journal of Environment and Bioscences 32(1):125-135.

49. Kusnezov, N. (1957). Numbers of species of ants in faunae of different latitudes. Evolution 11:298-299.

50. Lawton, J. H., Macgravin, M. and Heads, P.A. (1987). Effect s of altitude on the abundance and species richness of insect herbivores on Bracken. Journal of Animal Ecology 56: 147-160.

51. Losey JE, Vaughan M (2006) The economic value of ecological services provided by insects. Bioscience 56: 311-323.

52. Mandal, A.K. and Nandi, N.C. (1989). Fauna of Sundarban Mangrove Ecosystem, West Bengal, India. Fauna of Conservation Areas, 3, Zoological Survey of India, Calcutta. pp 116.

53. Mani, M.S. and Sharma, S.K. (1982). Proctotrupoidea (Hymenoptera) from India. Oriental insects 16(2):135-258.

54. McCoy, E. D. 1990. The distribution of insects along elevational gradients. Oikos 58: 313-322.

55. Mondal, A. K. and Nandi, N. C. (1989). Fauna of Sundarban Mangrove Ecosystem, West Bengal. Fauna of Conservation Area(ZSI) 3: 1-110.

56. Morley, C. (1913). Fauna of British India, including Ceylon and Burma. Hymenoptera Vol. III. Ichneumonidae. Taylor & Francis. London. Pp.531.

57. Paviva, C.A. (1907). Records of Hellliptera and Hynlenoptera from tbe Himalayas. Records Indian MilS. 1: 13-20.

58. Powell, A.H., and Powell, G.V.N. (1987). Population dynamics of male Euglossine bees in Amazonian forest fragments. Biotropica 19(2):176-189.

59. Rajmohana, K., Saini, J., Girish Kumar, P. and Patra, S. (2018). Insecta: Hymenoptera. In, Faunal Diversity of Indian Himalaya: 353-398 (Published by the Director, Zool. Surv. India, Kolkata).

60. Rathcke, B.J., and Jules, E.S. (1993). Habitat fragmentation and plant pollinator interactions. Current Science. 65: 273-277.

61. Raw, A. (1998). Population densities and biomass of Neotropical social wasps (Hymenoptera, Vespidae) related to colony size, hunting range and wasp size. Revista Brasileira de Zoologia 15 (3): 815 - 822.

62. Richards, L.A. and Coley, P.D. (2007). Seasonal and habitat differences affect the impact of food and predation on herbivores: a comparison between gaps and understory of a tropical forest. Oikos 116: 31-40.

63. Richards, L.A., Windsor, D.M. (2007).Seasonal variation of arthropod abundance in gaps and the understorey of a lowland moist forest in Panama. Journal of Tropical Ecology 23:169-176.

64. Roland J, Taylor PD (1997) Insect parasitoid species respond to forest structure at different spatial scales. Nature 386: 710-713.

65. Samant, S.S. (1999). Diversity, nativity and endemism of vascular plants in a part of Nanda Devi Biosphere Reserve, West Himalaya I. Himalayan Biosphere Reserve 1 (1 & 2) : 1-28.

66. Samant, S.S., Dhar, U. and Rawal, R.S. (1996). Natural resources use by natives within Nanda Devi Biosphere Reserve in Western Himalalya. Ethanobotony 8 : 40-50.

67. Samson, D.A., Ricart, E.A, and Gonzales, P.C. (1997). Ant Diversity and Abundance along an Elevational Gradient in the Philippines. Botropica 29(3): 349-363.

68. Sharma, S.K.(1979). Studies on the Indian Diapriidac (Proctotrupoidea: Hymenoptera) Mem. School. Ent., No.7: 1-87.

69. Singh, S. (1963). Entomological Survey of Himalaya. Part XXIV and Final Annotated check list of the insects from the North-East (Punjab) Himalaya. Agra University Research Journal 12 : 363-393.

70. Singh, S.and Singh, S.P. (1993). Altitudinal distribution of Apoidea (Hymenoptera) and their association with high altitude Angiosperms in the Kulu and Lahaul Spiti region of N. W. Himalaya. Annals of Entomology 11(2) : 33-47.

71. Stangler, E.S., Hanson, P.E., and Dewenter, I.S. (2015). Interactive effects of habitat fragmentation and microclimate on trap-nesting Hymenoptera and their trophic interactions in small secondary rainforest remnants. Biodiversity and Conservation 3:263-277.
72. Stone, G.N. (1994). Activity patterns of females of the solitary bee Anthophora plumipes in relation to temperature, nectar supplies and body-size. Ecological Entomology 19: 177-189.
73. Tscharntke, T., Gathmann, A., and Steffan-Dewenter, I. (1998). Bioindication using trap-nesting bees and wasps and their natural enemies: community structure and interactions. Journal of Applied Ecology 35: 708-719.
74. Tylianakis, J., Veddeler, D., Lozada, T., López, R.M., Benítez, P., Klein, A.M., De Koning, G.H.J., Olschewski, R., Veldkamp, E., Navarrete, H., Onore, G., Tscharntke, T. (2004). Biodiversity of land-use systems in coastal Ecuador and bioindication using trap-nesting bees, wasps, and their natural enemies. Lyonia 6, 7-15.
75. Tylianakis, J.M., Klein, A.M., and Tscharntke, T. (2005). Spatiotemporal variation in the diversity of hymenoptera across a tropical habitat gradient. Ecology 86,3296-3302.
76. Tylianakis, J.M., Klein, A.M., Lozada, T., Tscharntke, T., (2006). Spatial scale of observation affects alpha, beta and gamma diversity of cavity-nesting bees and wasps across a tropical land-use gradient. Journal of Biogeography. 33: 1295-1304.
77. Ulrich, W (2005). Regional species richness of families and the distribution of abundance and rarity in a local community of forest Hymenoptera. Acta Oecologica 28(2):71-76.
78. Ulrich, W. (1999a). Abundances, biomass and density boundaries in the Hymenoptera: Analysis of the abundance-weight relationship and difference between forest and open landscape habitat. Polish Journal of Ecology 47(1): 73-86.
79. Ulrich, W. (1999b).The density - weight and the biomass - weight distribution can be generated by the species weight distribution together with density fluctuations: Evidence from model species distributions in the Hymenoptera. Polish Journal of Ecology 47(1): 87-101.
80. Ulrich, W. (2006). Body weight distribution of European Hymenoptera. Oikos 114(3):518-528.
81. Ulrich, W. (2008). Body size and the relative abundance of species. Ecological Questions 10: 19-29.
82. Uniyal, V. P. and Singh, S. K. (1997). A preliminary study of the ecological relationship between high altitude flowering plants and insects in the Tirthen Valley in the Great Himalayan National Park, Himanchal Pradesh, India. Indian Bee Journal 58 (3): 137-139.
83. Vats, L. K. and Mittal, K. (1983). Taxonomic composition, trophic structure and seasonal fluctuations of insects in a tropical deciduous forest stand. Indian Journal of Forestry 6 (1): 24-27.
84. Vats, L. K. and Singh, J.S. (1978). Population, biomass and Secondary net production of aboveground insects in a tropical grassland. Tropical Ecology 9: 51-64.
85. Wardell, G.A., Berhardt, P., Binter, R., Burquez, A., Burchmann, S., Cane, J., Cox, P.A., Dalton, V., Feinsinger, P., Ingram, M., Inouye, D., Jones, C.E., Kennedey, K., Kevan, P., Koopowitz, Medellin, R. and Morakesm S,M. (1998). The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yield. Conservation biology 12(1):8-17.
86. Williams, M.S, 1988. Social wasps (Hym., Vespidae) from the Kashmir Himalaya. Entomological Monthly Magazine 124:149-152.
87. Williams, N.M., Minckley, R.L., and Silveira, F.A. (2001). Variation in native bee faunas and its implications for detecting community changes. Conservation Ecology 5(1):1-7.
88. Wolda H (1980). Seasonality of tropical insects. Journal of Animal Ecology 49:277-290.
89. Wolda H. (1978). Seasonal fluctuations in rainfall, food and abundance of tropical insects. Journal of Animal Ecology 47: 369-381.
90. Wolda, H. (1988). Insect seasonality: why? Annual Review Ecology and Systems 19: 1-18.
92. Wolda, H. (1987). Altitude, habitat and tropical insect diversity. Biological Journal of the Linnean Society 30: 313-323.
92. Wolda, H. and Broadhead, E. (1985). Seasonality of Pscoptera in two tropica forests in Panama. Journal of Animal Ecology 54: 519-530.
93. Wolda, H. O'Barien, C.W., and Stockwell, H.P. (1998). Weevil Diversity and Seasonality in Tropical Panamaas Deduced from Light-Trap Catches (Coleoptera: Curculionoidea). Smithsonian Contributions to Zoology 590: 1-76.pp.
94. Wolda, H., Flower, O.H., and Flowers, R. (1985). Seasonality and diversity of mayfly dults (Ephemeroptera) in a "non-scasonal" tropical environment. Biotropica 17: 330-335.
95. Zhang, Z. Q. (2013). Phylum Arthropoda. Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness (Addenda 2013). Zootaxa 3703: 17-26.
96. Zoological Survey of India (1995). Fauna of Conservation Areas 2: Fauna of Western Himalaya (UP). Eds. Director Zoological Survey of India, Kolkata, India. Pp.288.
97. Zoological Survey of India (1997). Fauna of Conservation Areas 9: Fauna of Nanda Devi Biosphere Reserve (A World Heritage Site). Ed.. Director Zoological Survey of India, Kolkata, India. Pp.166.